VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

# Virginia Stormwater Management Handbook

*Version 1.0*

**DISCLAIMER**

This document is provided as guidance and, as such, sets forth standard operating procedures for the agency. However, it does not mandate or prohibit any particular action not otherwise required or prohibited by law or regulation. If alternative proposals are made, such proposals will be reviewed and accepted or denied based on their technical adequacy and compliance with appropriate laws and regulations.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **%** | Percent |
| **°F** | Degrees Fahrenheit |
| **ACEC** | American Council of Engineering Companies |
| **AFM** | Acid-forming material |
| **ANSI** | American National Standards Institute |
| **APWA** | American Public Works Association |
| **ASCE** | American Society of Civil Engineers |
| **B&B** | Balled-and-Burlapped |
| **Bay Act** | Chesapeake Bay Preservation Act |
| **BMP** | Best Management Practice |
| **BOD** | Biological Oxygen Demand |
| **CBPA** | Chesapeake Bay Preservation Area |
| **CDA** | Contributing Drainage Area |
| **CEC** | Cation Exchange Capacity |
| **CERCLA** | Comprehensive Environmental Response, Compensation, and Liability Act |
| **CFR** | Code of Federal Regulations |
| **CGP** | General VPDES Permit for Discharges of Stormwater from Construction Activities |
| **COD** | Chemical Oxygen Demand |
| **CSS** | Combined Sewer System |
| **CWA** | Clean Water Act |
| **CWP** | Center for Watershed Protection |
| **DBH** | Diameter Breast Height |
| **DCP** | Dynamic Cone Penetrometer |
| **DCR** | Virginia Department of Conservation and Recreation |
| **DCR** | Department of Conservation and Recreation |
| **DGIF** | Virginia Department of Game and Inland Fisheries |
| **DOF** | Virginia Department of Forestry |
| **DPOR** | Department of Professional and Occupational Regulation |
| **DV** | Design Volume |
| **E&S** | Erosion and Sediment |
| **EMC** | Event Mean Concentration |
| **ESC** | Erosion and Sediment Control |
| **ESCL** | Erosion and Sediment Control Law |

| | |
|---|---|
| **ESM** | Soil Erosion Control and Stormwater Management |
| **ESW** | Exceptional State Waters |
| **ETA** | Effective Treatment Area |
| **FEMA** | Federal Emergency Management Agency |
| **FHWA** | Federal Highway Authority |
| **$ft^2$** | Square feet |
| **$g/cm^3$** | Grams per cubic centimeter |
| **GCM** | Global Climate Model |
| **GI** | Green Infrastructure |
| **GIS** | Geographic Information System |
| **gpm** | Gallon per minute |
| **HBAV** | Home Builders Association of Virginia |
| **HDS** | Hydrodynamic Separator |
| **HEC-RAS** | Hydrologic Engineering Center River Analysis System |
| **HLR** | Hydraulic Loading Rate |
| **HPA** | Horizontal Projected Area |
| **HRPDC** | Hampton Roads Planning District Commission |
| **HSG** | Hydrologic Soil Group |
| **HUC** | Hydrologic Unit Code |
| **IDF** | Intensity/Duration/Frequency |
| **ISA** | International Society of Arboriculture |
| **IWS** | Internal Water Storage |
| **Ksat** | Hydraulic Conductivity |
| **LDA** | Land-Disturbing Activity |
| **LID** | Low-Impact Development |
| **LiDAR** | Light Detection and Ranging |
| **LOI** | Loss on Ignition |
| **MARISA** | Mid-Atlantic Regional Integrated Sciences and Assessments |
| **MS** | Minimum Standard |
| **MS4** | Municipal Separate Storm Sewer System |
| **MTD** | Manufactured Treatment Device |
| **MTFR** | Maximum Treatment Flowrate |
| **NCDEQ** | North Carolina Department of Environmental Quality |
| **NCRS** | Natural Resources Conservation Service |
| **NFIP** | National Flood Insurance Program |
| **NOAA** | National Oceanic and Atmospheric Administration |

| | |
|---|---|
| **NOT** | Notice of Termination |
| **NPDES** | National Pollutant Discharge Elimination System |
| **NPL** | National Priority List |
| **NPS** | Nonpoint Source |
| **NRCS** | Natural Resources Conservation Service |
| **NVRC** | Northern Virginia Regional Commission |
| **NVSWCD** | Northern Virginia Soil and Water Conservation District |
| **NWI** | National Wetlands Inventory |
| **NWS** | National Weather Service |
| **O&M** | Operation and Maintenance |
| **P2** | Pollution Prevention |
| **PAH** | Polynuclear or Polycyclic Aromatic Hydrocarbon |
| **PCB** | Polychlorinated Biphenyl |
| **PDF** | Portable Document Format |
| **PDSI** | Palmer Drought Severity Index |
| **PFAS** | Per- and Polyfluoroalkyl Substances |
| **pHfox** | Field Oxidized pH |
| **PLS** | Pure Live Seed |
| **POD** | Point of Discharge |
| **PPE** | Personal Protective Equipment |
| **PPP** | Pollution Prevention Plan |
| **PR** | Pollutant Removal |
| **PSH** | Potential Stormwater Hotspot |
| **PV** | Ponding Volume |
| **qpTv** | Obtained Peak Discharge of the Treatment Volume |
| **QV** | Water Quantity Volume |
| **Regulation** | Stormwater Regulation |
| **RCRA** | Resource Conservation and Recovery Act |
| **RR** | Runoff Reduction |
| **RSC** | Regenerative Stormwater Conveyance |
| **Rv** | Volumetric Runoff Coefficient |
| **S&S** | Standards and Specifications |
| **SA** | Surface Area |
| **SAG** | Stakeholder Advisory Group |
| **SAV** | Submerged Aquatic Vegetation |

| | |
|---|---|
| **SCM** | Stormwater Control Measure |
| **SHWT** | Seasonally High Water Table |
| **SPCC** | Spill Prevention Control and Countermeasure |
| **SPT** | Standard Penetration Testing |
| **SVOC** | Semi-Volatile Organic Compound |
| **SWEMA** | Stormwater Equipment Manufacturers Association |
| **SWM** | Stormwater Management |
| **SWMF** | stormwater management facility |
| **SWPPP** | Stormwater Pollution Prevention Plan |
| $t_{d\text{-}TV}$ | Drain Time |
| **TMDL** | Total Maximum Daily Load |
| **TN** | Total Nitrogen |
| **TP** | Total Phosphorus |
| **TR** | Total Pollutant Reduction |
| **TSS** | Total Suspended Solids |
| $Tv_{BMP}$ | Treatment Volume of the Best Management Practice |
| **UL** | Urban Land |
| **URSA** | Urban Reforestation Site Assessment |
| **USACE** | U.S. Army Corps of Engineers |
| **USCS** | Unified Soil Classification System |
| **USDA** | U.S. Department of Agriculture |
| **USEPA** | United States Environmental Protection Agency |
| **USGS** | U.S. Geological Survey |
| **VAC** | Virginia Administrative Code |
| **VACRE** | Virginia Association of Commercial Real Estate |
| **VDACS** | Virginia Department of Agriculture and Consumer Services |
| **VDCR** | Virginia Department of Conservation and Recreation |
| **VDEQ** | Virginia Department of Environmental Quality |
| **VDOT** | Virginia Department of Transportation |
| **VESCH** | Virginia Erosion and Sediment Control Handbook |
| **VESCP** | Virginia Erosion and Sediment Control Program |
| **VESMA** | Virginia Erosion and Stormwater Management Act |
| **VESMP** | Virginia Erosion and Stormwater Management Program |
| **VMRC** | Virginia Marine Resources Commission |
| **VNLA** | Virginia Nursery and Landscape Association |
| **VOC** | Volatile Organic Compound |

| | |
|---|---|
| **VPDES** | Virginia Pollutant Discharge Elimination System |
| **VRP** | Voluntary Remediation Program |
| **VRRM** | Virginia Runoff Reduction Method |
| **VSMP** | Virginia Stormwater Management Program |
| **VWEA** | Virginia Water Environmental Association |
| **VWP** | Virginia Water Protection |
| **WEF** | Water Environment Federation |
| **WLA** | Waste Load Allocation |
| **WQv** | Water Quality Volume |

# CHAPTER 1 INTRODUCTION

**Contents:**

Welcome to the Virginia Stormwater Management Handbook! This Handbook is a dynamic and evolving resource that provides information on stormwater management, including erosion and sediment control, in Virginia. As a national leader in surface water quality management and protection, the Virginia Department of Environmental Quality (VDEQ) aspires to provide the "best-in-class" Stormwater Handbook to improve the design, construction, and maintenance of stormwater infrastructure in the Commonwealth. The Handbook is designed to assist multiple audiences including the development and engineering/planning communities, utilities, environmental advocacy groups, Virginia localities, other state agencies, and the staff and faculty of Virginia colleges and universities, among others.

**Underlying this Handbook is a desire to assist everyone involved in land development in meeting this overarching VDEQ Goal:**

*"A healthy environment, and healthy state and local economies of Virginia are intrinsically related; balanced economic development and the protection of our environment are not mutually exclusive."*

This Handbook cannot replace or provide common sense, and it cannot anticipate every potential design, construction, and operational scenario. Perhaps most critically – it does not assume responsibility for design, construction, and operations for work that needs stormwater infrastructure.

As our society has evolved to develop laws, regulations, guidance, and handbooks of increasing specificity seeking to provide answers to all conceivable eventualities, some people have tended to use these documents as a substitute for their lack of experience and tried to substitute reliance on handbooks, guidance, regulations, and laws in lieu of knowledge, experience, and comprehension of the activities in which they are engaged. Design professionals, Project Owners, and Contractors are always responsible for their work and should always employ common sense in how they implement it.

VDEQ will continue to improve this Handbook with ongoing input from all stakeholders as described later in this chapter. If you see something in this Handbook that does not pass the "common sense" test or realize something is missing – say so and let's improve this Handbook by working together to make it even better as we all strive for continual improvement. In the end, DEQ is deploying this Handbook to help everyone involved in land development provide places for people in the Commonwealth to live, work, and recreate in a manner that minimizes impacts from stormwater runoff and sediment while building sustainable, resilient communities.

## 1.1 Purpose of the Handbook

This section provides brief background information on the need to manage stormwater and a history of Virginia's efforts to guide the management of erosion and stormwater. In addition, it presents the Virginia Stormwater Management Handbook objective and purpose. Perhaps most importantly, this section describes the importance of taking a "common sense" approach to designing projects that comply with stormwater management requirements in the applicable laws and regulations.

### 1.1.1 Background

Unmanaged and improperly managed stormwater runoff has the potential to convey significant amounts of pollutants to and impact quality standards in waterways across the United States. As a result, the USEPA has stated that stormwater management remains one of the greatest challenges to meeting water quality standards (USEPA 2023). Pollutants found in stormwater may include nutrients, sediments, metals, motor oil, lawn and garden care products, trash, and anything else that washes from streets and developed parcels into local streams and lakes, and eventually into the Chesapeake Bay and the Atlantic Ocean. In addition, unmanaged stormwater also causes significant flooding and erosion. This Handbook, **from a stormwater management perspective**, focuses on providing guidance for siting and designing post-construction best management practices (BMPs), as well as providing construction and maintenance guidelines that facilitate long-term performance of BMPs.

While all lands erode, not all lands can be considered a source of sediment pollution. There has always been a certain amount of erosion that occurs naturally. However, major problems occur when large amounts of sediment enter Virginia's waterways. The accelerated erosion that causes sedimentation is most often caused by construction sites, urban/suburban stream banks, surface mining, poorly managed croplands, and logging roads (VDEQ 1992). Typical sediment loading rates from construction sites vary from 100 to 200 tons per acre per year, but in some areas can be considerably higher if no erosion control practices are implemented (University of Missouri 2023). The successful mitigation of soil losses on urban construction sites results in reduction of environmental damage and savings to developers (VDEQ 1992). This Handbook, **from an erosion and sediment control perspective**, focuses on one specific sediment pollution source — construction sites — and provides guidance for the design and maintenance of construction BMPs.

**Virginia is an Erosion Control and Stormwater Management Pioneer**

Virginia has been a pioneer on the establishment of erosion and sediment control programs and the implementation of stormwater BMPs (sometimes known as stormwater control measures [SCMs], low-impact development [LID] techniques, or green infrastructure [GI]) to help address the stormwater quality and quantity challenges. The first *Erosion and Sediment Control Handbook* in Virginia was developed in 1974 and focused on local program establishment.

In 1979, the Virginia State Water Control Board (the Board) published the first *Urban BMP Handbook* to address urban pollution and included the first standards and specifications for pollution source controls, runoff controls, and water collection and treatment. The Board also published in 1979 a *BMP Handbook for Hydrologic Modifications* to address nonpoint source pollutions that included channel modifications, dredging, and impoundments. In 1989, the Chesapeake Bay Local Assistance Manual was published and provided guidance on water quality protection practices and policy including the establishment of total phosphorous (TP) as the "keystone pollutant."

**Regional and Local Stormwater Leadership**

Other Virginia stormwater pioneering efforts at the regional level include the development of the *BMP Handbook for the Occoquan Watershed* in 1987, prepared by the Northern Virginia Regional Commission (NVRC, formerly Northern Virginia Planning District Commission), which included design guidance for ponds, infiltration trenches, and non-structural BMPs. NVRC, in association with the Engineers & Surveyors Institute, also developed the *Northern Virginia BMP Handbook* in 1992, which included procedures for calculating phosphorus removal as well as guidance for the planning and design of ponds, infiltration trenches, and several "nonconventional and experimental" BMPs at that time such as street sweeping, grass swales, buffers, and marsh vegetation. NVRC also prepared a *Low Impact Development Supplement* in 2007 to the BMP Handbook that included design guidance for green infrastructure practices.

The Hampton Roads Planning District Commission (HRPDC) developed the *Best Management Practices Design Guidance Manual for Hampton Roads Virginia* in 1991, which included design guidance for BMPs appropriate for use in southeastern Virginia to facilitate compliance with the stormwater management and Chesapeake Bay Preservation Act (CBPA) requirements. HRPDC and NVRC have also developed guides for maintaining and operating BMPs to address the critical need to maintain all stormwater infrastructure.

Virginia municipalities have also been leaders (from the 1980s to the present) in the development of BMP design guidance in their Public Facility Manuals or Design and Construction Standards Manuals. In addition, Virginia municipalities have prepared Stormwater Management and Watershed Management Master Plans (e.g., Virginia Beach, Newport News, Chesterfield County, Henrico County, Roanoke County and City, Prince William County, and Fairfax County among others). These plans identified the need to use stream restoration as a BMP and included regional stormwater ponds and other innovative BMPs that are now included in this Handbook. Some Virginia municipalities (e.g., Virginia Beach, Norfolk, Portsmouth, Alexandria, Arlington County, Lynchburg) are also implementing resilience projects, updating design standards to account for climate change, and taking an asset management approach to BMP and stormwater/drainage system maintenance.

VDEQ has included selected guidance and specifications developed by regional and local agencies in previous handbooks. This collaboration has enhanced and helped standardize the stormwater design methodologies used in Virginia.

**Virginia Handbook Updates**

In 1992, VDEQ published the *Virginia Erosion and Sediment Control Handbook* (Third Edition), and in 1999, the Virginia Department of Conservation and Recreation (DCR) published the *Virginia Stormwater Management Handbook* (First Edition). VDEQ updated that *Stormwater Handbook* in draft form in 2011 and 2013 (Draft, Second Edition) and established, in cooperation with the Virginia Water Resources Research Center, the *BMP Clearinghouse*, which provides detailed BMP specifications, manufactured treatment devices evaluation information, and other references and tools. The Virginia Department of Transportation (VDOT) also has a *BMP Design Manual of Practice and a BMP Maintenance Manual* that focus on BMPs for linear projects.

**BMP Benefits**

Virginia has recognized since the 1970s the importance of construction and post-construction BMPs as tools to manage stormwater. BMPs continue to evolve and provide the following benefits:

- BMPs play a critical role in reducing pollution and protecting Virginia's waterways as well as protecting downstream areas from flooding, erosion, and water quality degradation.
- BMPs are used to manage combined sewer systems (CSSs), and the information in this Handbook will help to address the requirements of the first of the nine minimum controls — Proper Operation and Regular Maintenance Programs — to reduce the effects of combined sewer overflows (CSOs) on receiving waters and prevent flooding and sewer backups.
- BMPs are also key components of resilience and flood risk management strategies and can be a catalyst for adapting to precipitation changes related to climate change and spurring economic development in urban areas (WEF et al. 2022).

## 1.1.2 Objective

Figure 1-1 Handbooks and Guidance that VDEQ Consolidated in this Virginia Stormwater Handbook


Despite the Commonwealth's historical attention to stormwater management, factors such as the involvement of multiple agencies and evolving state and federal requirements led to production of a growing number of guidance documents. As a result, VDEQ relied on outdated and uncoordinated materials to communicate good engineering practices for stormwater management at land-disturbing sites. The *Erosion and Sediment Control Handbook, Stormwater Handbook*, and *Chesapeake Bay Local Assistance Manual*, for example, are each older than or approaching 30 years of continued use. Further, VDEQ last approved its BMP Design Specifications in 2011. Over the years, the field of stormwater management has progressed greatly, and designers and manufacturers have developed new and improved old BMPs and products to reduce erosion, control sediment, and reduce pollutant runoff that impacts water quality. New BMPs are also increasingly designed to adapt landscapes for the impacts of a changing climate. Likewise, the Code of Virginia and the Virginia Administrative Code have changed significantly since these documents were originally published.

To keep pace with the evolving statutes, regulations, and stormwater management principles and technology, state agencies have adopted manuals, technical bulletins, information bulletins, and guidance documents (Figure 1-1). Consequently, dozens of current materials confuse permit applicants and design professionals. The amount and conditions of these materials introduce inefficiency in the permitting process, both affecting design professionals' ability to develop permit applications and prepare plans, and state and local agency staff's efficiency during plan review and approval. Their status also affects the climate resilience of Virginia because newly installed BMPs are not designed to effectively manage the volume and quality of more intense rainfall events.

In developing this Handbook, **VDEQ's objective** was to consolidate, update, and replace existing materials. Key needs addressed in the development of the Handbook included the identification of modern BMPs and design specifications. A BMP nomenclature has also been prepared that will integrate construction BMPs to address erosion and sediment control requirements and post-construction BMPs to address stormwater management and Chesapeake Bay protection requirements, all within the framework of state's regulatory requirements. Finally, this Handbook is a living document, with an online presence that facilitates regular feedback from users that will inform updates.

### 1.1.3 Purpose and Scope

The purpose of this Handbook is to provide guidance on erosion and stormwater control measures necessary to comply with the following laws and regulations:

- Virginia Erosion and Stormwater Management **Act**, §§ 62.1-44.15:24 through 62.1-44.15:50 of the Code of Virginia;
- Erosion and Sediment Control **Law** for Localities Not Administering a Virginia Erosion and Stormwater Management Program, §§ 62.1-44.15:51 through 62.1-44.15:66 of the Code of Virginia;
- Virginia Erosion and Stormwater Management **Regulation**, 9VAC25-875-10 et seq; and

- Other associated state or federal regulations impacting erosion and sediment control and stormwater management.

The guidance in this Handbook will also assist in the protection of the waters of the Commonwealth of Virginia from the adverse impacts of construction and post-construction stormwater runoff. The guidance provided applies to new development, redevelopment, and upgrades (retrofits) to existing development. The Handbook focuses on erosion and sediment control, stormwater site planning and design, pollution source control and prevention, runoff volume reduction, stormwater treatment, stream channel protection, and flood protection.

Related topics (such as development and implementation of Virginia Erosion and Stormwater Management Programs, Virginia Erosion and Sediment Control Programs, or watershed management and stormwater master planning) are **not** addressed in the Handbook. In addition, the Handbook does **not** address agricultural runoff.

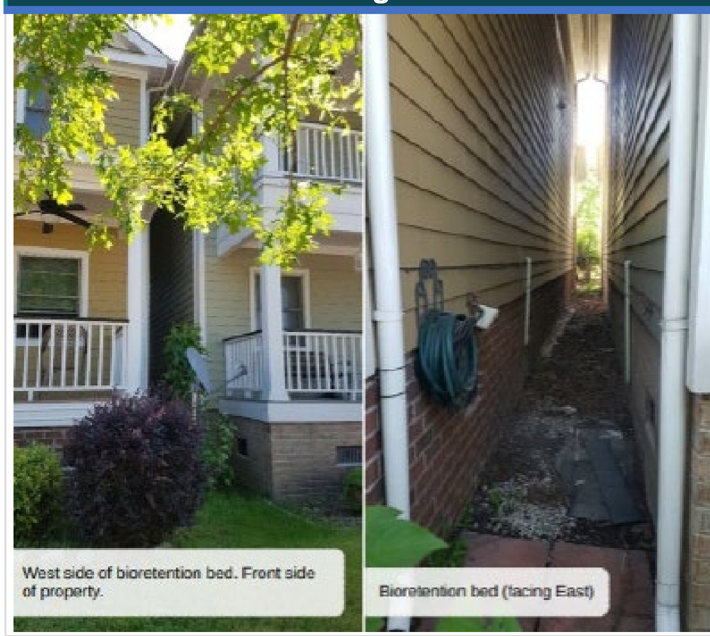
### 1.1.4 The Need for "Common Sense" in the Implementation of BMPs

The effectiveness of stormwater management programs depends largely on how well and how safely BMPs perform over time (WEF et al. 2022). As these programs evolve throughout Virginia, the number of established BMPs is increasing rapidly. In fact, some communities have hundreds or even thousands of BMPs that have been constructed as part of land development projects or by local governments and state agencies to address stormwater quantity and quality requirements. Many BMPs are also designed and constructed to address stormwater and CSS regulatory compliance requirements. Therefore, given the importance of BMPs and number of BMPs being constructed, it is good practice to not only follow the guidance in this Handbook and apply good engineering principles, but also to use common sense in BMP planning, design, construction, and maintenance.

The following examples illustrate where good common sense is needed in the implementation of BMPs:

**Consider Space Limitations in the Selection of BMPs.** In sites with limited space, BMPs that require larger footprints (e.g., basin or ponds) may not be the best option. In those cases, filtration and infiltration BMPs may not apply. However, common sense will limit the use of even these practices in space-constrained sites. In a recent example in a townhouse subdivision, bioretention practices that were only 2 feet wide were proposed in between townhouse blocks that were very close together. The gutters/eaves extended about 15 inches from the building on either side, creating significant shade and limiting the success of plant establishment and maintenance access (see Figure 1-2).

***Figure 1-2 Common Sense - Provide Space for Maintenance and Light for Plant Survival.***




In some cases, designers have used square ponds with very high walls, and even retaining walls, around them. This type of design makes maintenance extremely difficult and creates hazards for residents. Appropriate planning and BMP selection will minimize life-cycle cost and will make BMPs safe. The Handbook includes many BMP options that can fit in tight spaces. Chapter 6 in the Handbook, Site Design and BMP Selection, provides ideas on how to select appropriate BMPs for your site.

**Provide Inspection and Maintenance Access.** As described in Chapter 10, BMP Inspections and Maintenance, designers need to design with maintenance in mind. For example, when designing porous pavement BMPs, the designer needs to ensure that space and clearances are provided for maintenance trucks and that adequate access to the inlet is provided for vacuum trucks. In pond design, the designer needs to provide stabilized access for heavy equipment in forebay areas. All BMPs need to be maintained, and access (inspection, vehicle, equipment) is a critical activity during the BMP life cycle.

**Provide Setbacks from Ponds in Residential Development.** One of the key challenges to the use of ponds in infill development is the local government's requirement to maintain a setback (e.g., a 50-foot-wide vegetated perimeter area) from retention or detention ponds to residential structures (both existing and proposed). This requirement is a good common-sense practice used by local governments to ensure proper BMP performance and facilitate future maintenance, but perhaps more importantly, it provides safety features to protect residents.

The development community has at times requested a waiver from this setback requirement to maximize the available space on the site. If the location of the BMP requires a waiver of this requirement, other BMP options should be evaluated.

Additional screening, such as privacy fencing for the residences, in combination with other vegetative screening options should be considered when the reduced setbacks are allowed. Any vegetative screening approach should comply with the requirements to avoid woody vegetation on embankments. Native plants should be prioritized, and use of invasive species (such as bamboo) should be avoided.

**Wet Ponds in Infill Development.** Wet ponds are generally not the ideal, common-sense BMP option for infill development sites. These sites typically have limited drainage areas, which will not support adequate runoff to maintain a permanent pool volume or aquatic benches. Safety benches are recommended for wet ponds, especially where these facilities are located close to residences. To locate this type of ponds in these constrained sites, extremely steep side slopes and deep forebays are sometimes proposed with development plans, creating unsafe conditions for the community and future maintenance problems for the local government. In addition, these sites may not have adequate grade for ponds to include a low-level outlet and/or valve to drain the pond by gravity for maintenance purposes.

The use of wet ponds in small infill lots should be avoided if the local government requirements and the Handbook design criteria cannot be met. Chapter 8, BMP Design Specifications for Stormwater Management, provides additional information.

**Consider Topography in the Selection and Design of BMPs.** A recent (2023) complaint that reached the Director of VDEQ was over a multiyear battle involving a plan that showed a level spreader along the edge of a parking lot. The developer argued that the approved plan could not be built as designed and permitted as "anyone with common sense could see." VDEQ Inspectors concurred with the conclusion but stated that they must enforce the approved plan. The design had two errors: (i) reliance on 2 ft contour interval (CI) topographic data with an allowed accuracy of approximately half a CI (or 1 ft) for a level spreader designed to be less than 0.10 ft above the grade receiving the flow (good practice in this instance would be to use field-run topographics for this area); and (ii) not carefully labeling the topographic lines so a "hump" was erroneously interpreted as a low spot. The result was a parking lot edge approximately 18 inches below the ground into which stormwater was supposed to flow via gravity. The design engineer was at fault; the plans should not have been approved, the contractor should have stopped construction as soon as these issues were discovered, the developer managing the project should have intervened, the inspector should not have said just "build the approved plan," and a re-design should have been immediately undertaken. No one involved demonstrated common sense or took responsibility to solve the problem. Instead, there were years of finger-pointing, which is unproductive.

**Consider Soils, Underlying Geology, and Groundwater:** The most common source of poor BMP performance is the lack of attention to design factors such as soils handling practices (e.g., plants prefer to grow in topsoil, not compacted subsoil; graded and compacted soils produce more runoff than natural in-situ soils; infiltration-based designs in soils that do not infiltrate near the design's assumed rate), underlying geologic constraints (e.g., karst and acid-forming materials [AFMs]),and groundwater conditions (e.g., too many bioretention failures and wet basements arise due to inaccurate assessments of the expected seasonal high groundwater level).

## 1.2 Handbook Overview

This section presents an overview of what is new in this Handbook and the terminology used. In addition, this section provides a brief description of the content of each chapter.

### 1.2.1 What is New in this Handbook?

The first edition of the *Erosion and Sediment Control Handbook* was released in 1974, while the first edition of this *Stormwater Handbook* was released in 1999, as mentioned above. The former was referred to as the "Green Book," and the later was referred to as the "Blue Book" because of the green and blue plastic binders, respectively, that contain those documents. The second edition of the Stormwater Handbook was released in draft form in 2013 and included updated design specifications published in the BMP Clearinghouse in 2011 and 2013. This edition of the Handbook will be the first entirely digital online edition to be published.

This edition of the Handbook not only reflects the recently **consolidated erosion and stormwater management law and regulations**, but it also builds on the previous handbooks, as well as recent VDEQ guidance memos, to present **construction BMPs** (erosion and sediment controls) and **post-construction BMPs** (stormwater management BMPs) more comprehensively. All BMP specifications have been updated and have a **consistent specification format** (see Table 1-1) to facilitate the use of the Handbook.

**Table 1-1 Consistent Specification Format Elements**

| Spec Sections | Description |
|---|---|
| **Definition** | Each BMP is defined in a straightforward manner and clearly describes how they work. |
| **Purpose and Applicability of Best Management Practice** | A short description of the use of the BMP and where it is applicable. |
| **Planning and Considerations** | A description or table showing the feasibility criteria of each BMP. |
| **Stormwater Performance Summary** | Information on the functions provided by each BMP including the pollutant reduction characteristics. |
| **Design Criteria** | Information on key design guidance, sizing, and material specifications. |
| **Construction Specifications** | Information on construction sequence, installation guidance, material specification, and typical schematics, as applicable. |
| **Operations and Maintenance Considerations** | Guidance on maintenance operations during and after construction. |

The handbook is available in digital form through a web site that facilitates future updates. All specifications and BMP details are also available in digital form. VDEQ has also made AutoCAD files available for download.

The Handbook incorporates the best information available on **site design and BMP selection** as well as updated information on **construction and inspection and maintenance of BMPs** from recent leading state and local stormwater management manuals and other resources from around the country and overseas. The Handbook also incorporates the work of leading researchers, Virginia agency staff, stormwater engineering professionals and other journalistic contributors. The Handbook includes updated appendices and information on the Virginia Runoff Reduction Method (VRRM), bioretention design information, soil characterization and infiltration testing, and site assessment and design guidelines for stormwater management in karst topography. As a result, VDEQ considers this Handbook to be on the cutting edge of guidance and a best-in-class stormwater management resource.

The Handbook provides a new construction and post-construction **BMP categorization** based on the function provided by each BMP that will facilitate future BMP tracking, monitoring, and maintenance. Each chapter has a list of acronyms and abbreviations to facilitate its use. Also, the user will see more photographs and graphics to illustrate points being made in the text. These graphics and figures will continue to be updated each year. Most chapters include helpful information or "tools," such as checklists, reference tables, and other quick-reference components. Furthermore, each chapter includes a list of helpful reference documents. To maintain the Handbook, VDEQ plans to conduct yearly updates as described in Section 1.4.2.

## 1.2.2 Terminology and Best Management Practice Categories

There are many names and terms used in the stormwater sector to describe erosion controls and stormwater treatment practices. This causes confusion in the way elected officials and the public perceive and understand stormwater management.

This Handbook uses the term BMPs to describe erosion and sediment controls; stormwater control measures (SCMs); stormwater facilities; low-impact development practices; green infrastructure; nature-based solutions; and manufactured treatment devices (MTDs) such as hydrodynamic devices, filtering devices, and biofiltering devices. The use of the term "BMPs" is consistent with the Virginia statutes and regulations.

To minimize confusion and standardize the stormwater terminology, the National Research Council report *Urban Stormwater Management in the United States* (NRC 2008) recommended the use of SCMs to describe BMPs and other terms. The American Society of Civil Engineers (ASCE) and the Water Environment Federation (WEF) are using SCMs as the preferred term in recent Manuals of Practice. Virginia will continue to adjust stormwater terminology as laws and regulations are enacted and during future updates of the Handbook to facilitate communications and standardization of stormwater terminology.

The BMPs in this Handbook are separated into two broad high-level categories based on the stage of the project in which they are used (i.e. construction and post-construction). The BMPs are further divided into categories based on the type or function of the practice.. This categorization is consistent with recent national Manuals of Practice developed by ASCE and WEF. The BMP categories are presented in Table 1-2.

| Table 1-2 BMP Categories | | |
|---|---|---|
| **Construction BMP Categories** | **Post-Construction BMP Categories** | **Post-Construction MTD / Proprietary BMP Categories** |
| Erosion Control Measures | Basins | Hydrodynamic Devices |
| Sediment Control Measures | Conveyance | Filtering Devices |
| Surface Stabilization Measures | Filtration and Infiltration | Biofiltering Devices |
| Perimeter Control Measures | Support Components | |
| Environmental Sensitive Area Protection | | |

### 1.2.3 Overview of Chapters

This Handbook is divided into ten chapters, each of which addresses important topics in the design of BMPs. The Handbook also includes 10 appendices that provide information to support the design of BMPs and additional details on evolving topics. The following is a brief description of each chapter:

- **Chapter 1, Introduction.** Describes Virginia's erosion and sediment control and stormwater management leadership, VDEQ's objective and purpose of the Handbook, as well as suggestions on how to use it. This chapter also presents the Handbook development process and the plan to keep it updated.
- **Chapter 2, Why Erosion and Sediment Control and Stormwater Management Matter.** Describes the importance of erosion and sediment controls and stormwater management. In addition, this section describes the role of climate in stormwater design.
- **Chapter 3, Laws and Regulations.** Provides an overview of the laws and regulations that impact erosion control and stormwater management design.
- **Chapter 4, Regulatory Compliance Process.** Provides a roadmap for regulatory compliance and outlines the process through which delegated authorities apply the Virginia Erosion and Stormwater Management Regulations to the multiple types of development and redevelopment projects.
- **Chapter 5, Erosion and Sediment Control and Stormwater Management Requirements.** Provides information on regulating land-disturbing activities and how to apply the technical criteria. It also presents the erosion and sediment control minimum standards and stormwater requirements.
- **Chapter 6, Stormwater Site Design and BMP Selection.** Provides guidance for stormwater site design and BMP selection while integrating environmental conservation and ecological restoration principles and concepts.
- **Chapter 7. Design Specifications for Construction BMPs.** Provides detailed planning, design, construction, and maintenance guidance and specifications for construction BMPs.
- **Chapter 8, Design Specifications for Post-Construction BMPs.** Provides detailed planning, design, construction, and maintenance guidance and specifications for post-construction BMPs.
- **Chapter 9, BMP Construction.** Describes construction activities, sequence, concepts, and inspection process that will result in successful BMP installation.
- **Chapter 10, BMP Inspection and Maintenance.** Provides an overview of inspections and maintenance requirements including responsibilities for monitoring, reporting, and enforcement, as well as common tasks associated with maintaining BMPs. This section also provides information on maintenance plans and agreements.

## 1.3 How to Use This Handbook

The Handbook is organized in a logical progression starting with the need for erosion control and stormwater management and followed by the laws, regulations, and compliance process and requirements. Subsequently, the Handbook presents guidelines on stormwater site design and BMP selection as well as design specifications. The Handbook ends with guidelines on BMP construction and BMP inspection and maintenance to emphasize the importance of these activities in the BMP life cycle.

The Handbook can be used in an academic sense to methodically build an understanding of the subject matter chapter by chapter. Each chapter is self-contained, so the reader can also turn to specific topics independently, depending on the type of information or guidance needed. There are comprehensive indexes at the beginning of each chapter showing the locations of specific topics, figures, tables, and appendices.

**Audience and Intent.** This Handbook is targeted to designers of BMPs, plan reviewers, and operations and maintenance staff. The Handbook's intent is to assist designers by providing information and support components that facilitate design and construction of BMPs while keeping maintenance in mind.

## 1.4 Handbook Development Process and Updates

This section presents a description of the process used by VDEQ to develop the Handbook and the process that will be used to update and revise the Handbook as new stormwater information becomes available and comments are provided to VDEQ by the users of the Handbook.

### 1.4.1 Handbook Development Process

VDEQ convened a Stakeholder Advisory Group (SAG) to assist in the development of the Handbook. The purpose of the SAG was to provide VDEQ and its contractor with direction, guidance, ideas, solutions, and feedback as the new Handbook was developed. The SAG was also requested to avoid identifying updates to the Handbook that will require additional statutes, rulemaking (regulations), or guidance as separate documents. SAG membership included representatives of the following groups:

- Building industry;
- Colleges and universities;
- Engineering community;
- Environmental community;
- Local government;
- Manufacturers of stormwater products;
- Regional agencies;
- Virginia agencies; and
- Virginia utilities.

The SAG members participated in the following four subcommittees that provided support in specific Handbook development areas:

1) **Handbook Outline and Chapters Subcommittee** that focused on developing the Handbook outline, the detailed chapter outlines, and the content for each chapter.
2) **Calculations Subcommittee** that focused on water quality and hydrologic and hydraulic calculations.
3) **Erosion & Sediment Control and Stormwater Management BMPs Subcommittee** that guided the development of BMP specifications.

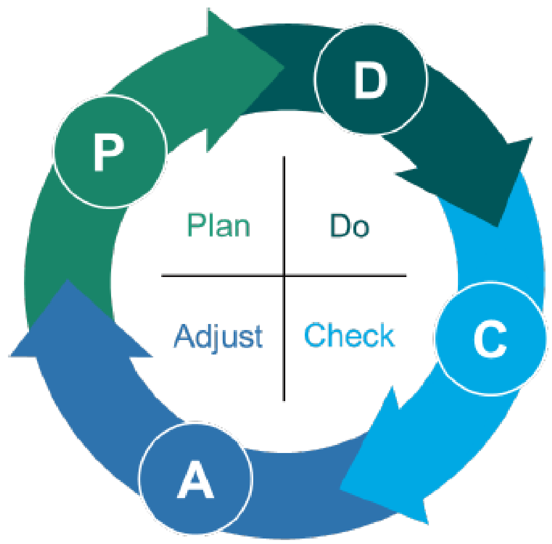
4) **Handbook Planning, Production, and Outreach** that guided the outreach efforts to present the Handbook to as many interested groups as possible. This subcommittee also assisted with the Handbook planning and productions tasks.

These subcommittees worked in combined groups at times to support specific Handbook development tasks. All SAG meetings were conducted in VDEQ's Richmond office.

**Process to Develop the Handbook.** VDEQ used the used the following "Plan, Do, Check, Adjust" project management cycle, illustrated on Figure 1-3, to develop the Handbook:

- Plan – The SAG directed, suggested Handbook content, and received input from the VDEQ contractor.
- Do – The contractor prepared content for the Handbook, and the SAG and subcommittees also contributed content. The goal was to consolidate, structure, and organize the content systematically.
- Check – The SAG, subcommittees, and VDEQ staff reviewed content and recommended revisions as needed.
- Adjust – The contractor revised the Handbook content as needed in coordination with VDEQ and finalized the Handbook.

***Figure 1-3 Process Used to Develop the Handbook***




SAG members provided input and feedback throughout the Handbook development process.

### 1.4.2 Handbook Updates and Revisions Process

Virginia had an array of outdated handbooks and reference materials that have been a source of confusion for the regulated community and inefficiency in VDEQ's permitting process. To minimize confusion, VDEQ plans to maintain this new Handbook as a "living document" and provide ongoing and current information to stormwater designers, permit applicants, and their consultants.

Building on the process used to develop the Handbook, VDEQ plans to use a similar process to update the Handbook yearly. The Handbook, as a guidance document, can be revised to remain consistent with statutory and regulatory changes.

**Technical Review Committee.** VDEQ will convene a Handbook Technical Review Committee that will assist in maintaining the Handbook updates. The principal purposes of the Committee are to study and review subjects that present technical problems, review comments from Handbook users, develop recommendations for action, and advise VDEQ relative to the following:

- VDEQ stormwater policy;
- VDEQ guidelines for the planning, design, construction, and maintenance of stormwater infrastructure; and
- VDEQ standards and specifications governing the design, construction, quality control, and maintenance of BMPs to meet requirements for compliance with regulations, usability, longevity, maintainability, and other specific standards and characteristics as may be identified.

**Technical Review Committee Composition.** VDEQ will invite the following groups/organizations to become members of this Committee by assigning a representative and an alternate member:

| Group | Organizations with Representative and Alternate Members |
|---|---|
| Building Industry | Home Builders Association of Virginia (HBAV)<br>Virginia Association of Commercial Real Estate (VACRE) |
| Virginia Colleges and Universities | Civil and Environmental Engineering Chairman or Designee |
| Engineering and Architecture Community | American Society of Civil Engineers (ASCE)<br>American Public Works Association (APWA)<br>American Council of Engineering Companies (ACEC)<br>Virginia Water Environment Association (VWEA)<br>Stormwater Committee<br>Virginia Society of Professional Engineers<br>Virginia Chapter of the American Society of Landscape Architects |
| Environmental Community | Chesapeake Bay Foundation<br>James River Association<br>Virginia Director, Chesapeake Bay Commission |
| Local Government and Regional Agencies (one or two from each) | MS4 Phase I communities<br>MS4 Phase 2 communities<br>Planning District Commissions<br>Virginia Soil and Water Conservation Districts<br>Virginia Municipal Stormwater Association |
| Manufacturers of Stormwater Products | Stormwater Equipment Manufacturers Association (SWEMA)<br>Individual Manufacturers |
| Virginia Agencies | VDEQ (Chair of the Technical Review Committee)<br>Department of Housing and Community Development<br>Department of Conservation and Recreation<br>Economic Development Partnership<br>Virginia Department of Transportation |
| Virginia Utilities | Dominion Energy<br>Appalachian Power<br>Virginia Electric Cooperatives (one). |

**Handbook Update Process.** To ensure that the Handbook remains technically current, accurate, and reflective of VDEQ policy, the Handbook will “reside” on the internet and will be available to users through the technology platform enCodePlus. The platform allows users to provide feedback and comments on every section of the Handbook. The following steps summarize the process that VDEQ will follow to update the Handbook:

- **Identify Problems and Track Comments.** When an apparent problem is identified by a user of the Handbook or VDEQ staff, it will be logged and tracked within the enCodePlus platform for VDEQ. Users can also provide comments on any section of the Handbook that requires attention.
- **Review and Prioritize Problems and Comments.** VDEQ staff will use the platform to prepare a report of the problems identified and comments provided by the users. VDEQ will use those reports to prioritize the problems and comments.
- **Convene Technical Review Committee Meetings.** VDEQ staff will convene two meetings per year to review apparent problems and comments with the Technical Review Committee. The Committee will discuss potential solutions to the problems and will address the comments. The Committee will also recommend changes to VDEQ that need to be made in the Handbook. If a problem, legal or regulatory change, or significant technical development is identified that requires immediate attention, VDEQ will convene special meetings of the Committee as needed.
- **Revise Handbook Sections and Inform Users.** VDEQ will review the Committee recommendations and will make the necessary revisions to the Handbook. Handbook updates will be performed annually or at the discretion of VDEQ. VDEQ will determine if a public comment period will be required depending on the significance of the revisions. VDEQ will also maintain a publicly available record of the Handbook revisions in an appendix to the Handbook. All registered Handbook users will be informed of the changes via subscriptions to the platform.

It is important that the Handbook reflects the needs and concerns of all Virginia jurisdictions and Handbook users. So that VDEQ may better serve local government and Handbook users alike, VDEQ requests to be informed through Handbook comments of any changes in local stormwater policy that could have an effect on the Handbook.

## 1.5 Acknowledgements

This Handbook is a product of the work of a Stakeholder Advisory Group (SAG) comprised of representatives of state, regional, and local agencies; Virginia Tech; and representatives of environmental and industry groups (e.g., building, engineering, manufacturers) and universities having special knowledge and interest in stormwater management.

The Virginia Department of Environmental Quality (VDEQ) managed the development process. The consulting team, led by Arcadis, prepared Handbook content, facilitated numerous SAG meetings (i.e., 12 over an 18-month period), and solicited comments and revised content based on feedback. enCodePlus digitized and built the online platform.

VDEQ greatly appreciates the many hours of time that SAG members contributed to development of this Handbook. The Handbook is a stronger product because of their participation in development meetings and feedback on early drafts. VDEQ recorded all received comments. Comments not addressed in this edition, as well as future comments, will be considered during future updates through the Handbook Updates and Revision Process described in Chapter 1.

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# CHAPTER 2 WHY EROSION AND SEDIMENT CONTROL AND STORMWATER MANAGEMENT MATTER

**Contents:**

## 2.1 Introduction

Development activity contributes to the health and growth of Virginia and its localities. The way in which sites are developed (be they roads, housing developments, warehouses, or solar farms) determines the impact these activities will have on the environment, and more specifically, downstream waterways. If not well managed, the impacts of development on downstream waterways can be diverse and significant, ranging from loss of aquatic habitats to increases in flooding to infrastructure damage from stream erosion. As development and associated land-disturbing activities (including emerging activities such as construction and operation of solar farms) take place across Virginia, erosion and sediment control and stormwater management will play an increasingly important role of limiting the cumulative impacts of human activity on the environment, economy, and communities.

In this chapter, we will briefly explore these impacts, review how erosion and sediment control and stormwater management can help to limit these impacts, and introduce the concept of managing that stormwater as a resource. Understanding these basics will help developers and engineers understand the motivation behind the regulations, policies, and procedures presented in this Handbook and comply with the regulations in ways that are both environmentally and economically efficient.

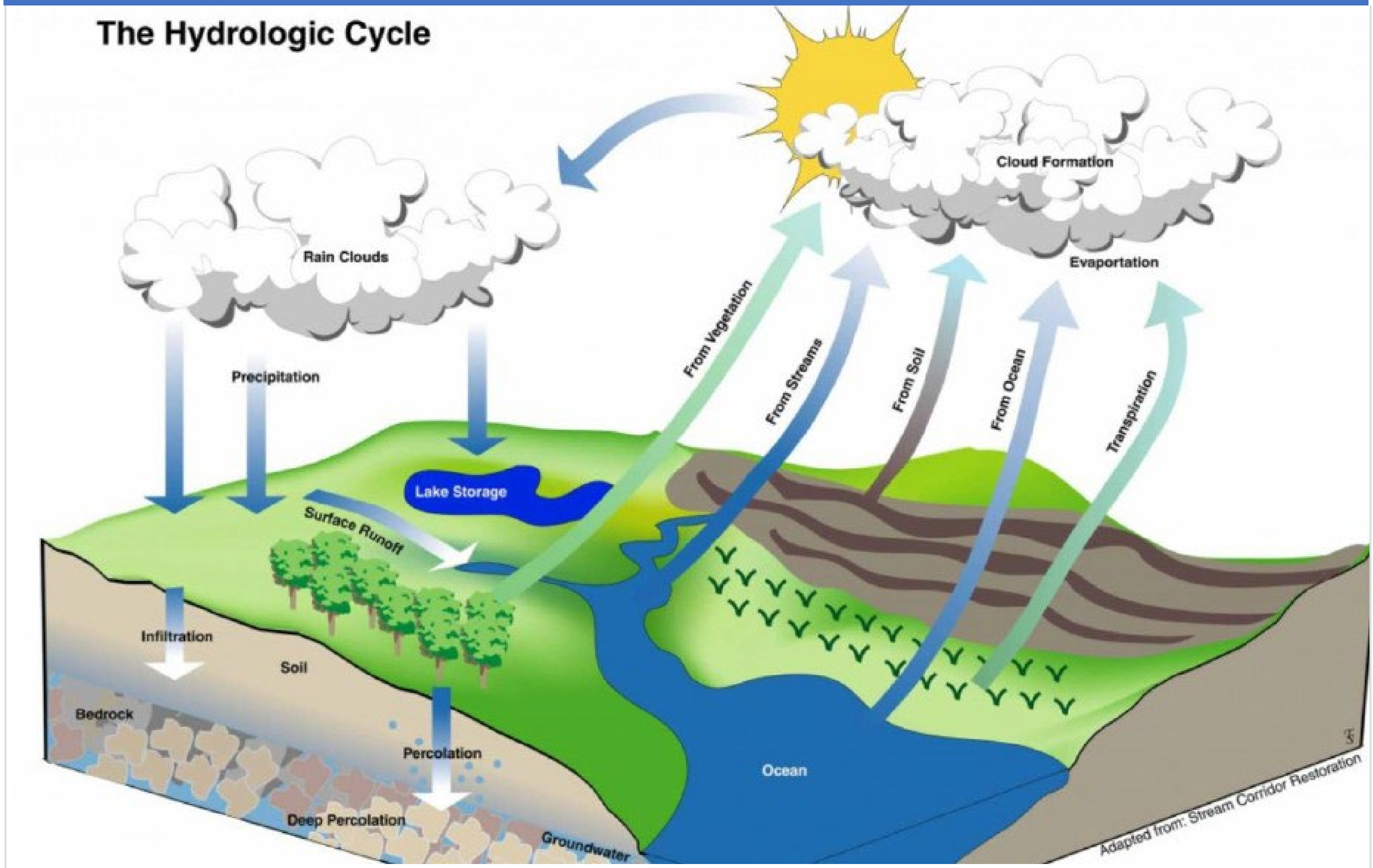
## 2.1.1 What Is Stormwater and How Is It Generated?

As a developer or designer, you are probably reading this Handbook because you are working on a development that subject to regulation under a state or locally administered program for erosion and sediment control or stormwater management. Getting a good feel for what stormwater is and how it's created is the first step toward developing effective strategies to manage it. So, what is stormwater?

### 2.1.1.1 The Hydrologic Cycle

In state law and regulation, "stormwater" means "precipitation that is discharged across the land surface or through conveyances to one or more waterways and that may include stormwater runoff, snow melt runoff, and surface runoff and drainage." § 62.1-44.15:24 of the Code of Virginia; 9VAC25-875-20. Expanding on this for purposes of this Chapter and the Handbook, stormwater refers to precipitation that is converted into runoff — water that "runs off the land." This is just one part of a larger process, called the hydrologic cycle, by which water moves through the landscape in a cycle that is powered by solar energy and gravity (Figure 2-1). As precipitation hits the ground, some soaks into the soil and becomes groundwater, is taken up by plants, or otherwise evaporates. The remaining water (stormwater) is transmitted to local streams or rivers. This can happen quickly, as stormwater flows over the land surface, or more slowly as stormwater flows just under the soil surface toward a downstream waterway.

**Figure 2-1 The Hydrologic Cycle**

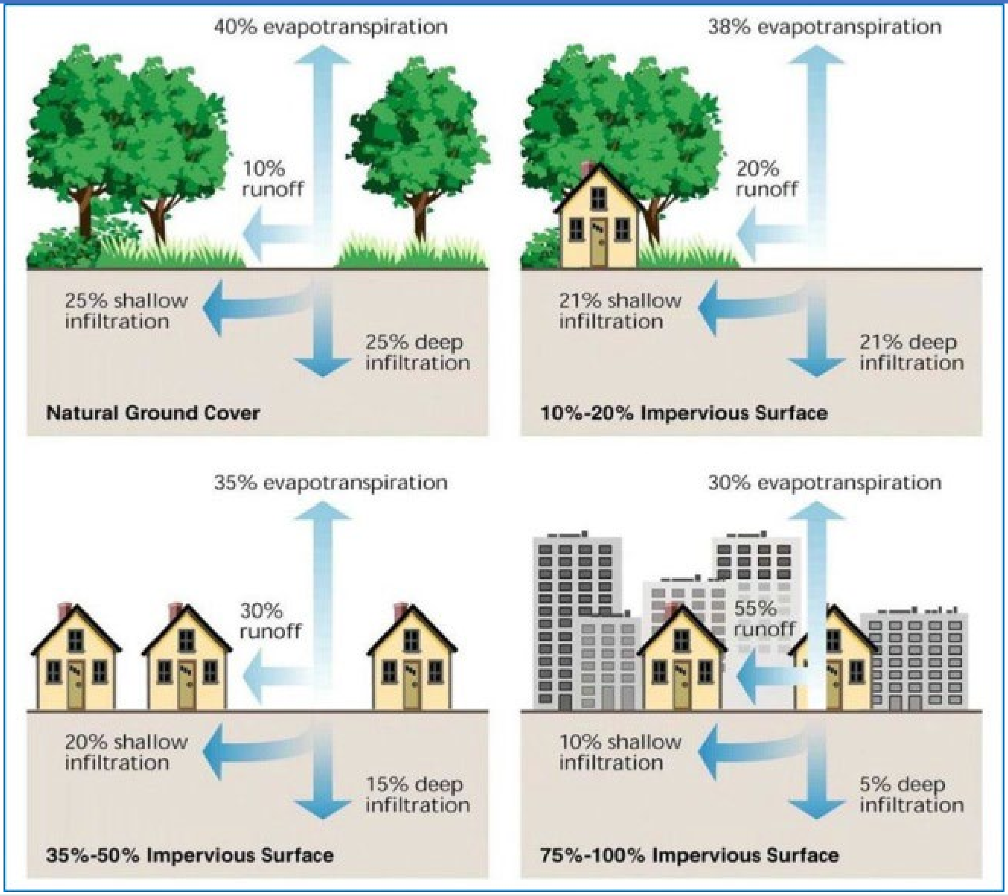



*Source: FISRWG 1998*

### 2.1.1.2 Development, Erosion, Sediment, and Stormwater

While stormwater runoff is a natural part of the hydrologic cycle, it can also have negative impacts on the environment, particularly when the natural land surface has been altered by land-disturbing activity, including development. The impact of development on the volume, rate, and timing of stormwater; rates of erosion; and sedimentation is well documented (e.g., Hollis, 1975, Schueler, 1987, Konrad and Booth, 2002) (Figure 2-2). During construction, the removal of vegetation from the land surface makes the landscape more susceptible to erosion and sediment production as rainfall encounters bare soil. In the finished developed landscape, impervious surfaces (e.g., roads, rooftops) limit the infiltration of precipitation into the soil, while the removal and alteration of native vegetation typically reduces evapotranspiration: the process through which soil moisture is taken up by plants and transmitted as water vapor. The net result of these two processes is an increase in the volume and flow rate of stormwater runoff. As stormwater runoff comes into contact with various parts of the developed environment, it commonly picks up a variety of pollutants including sediment, nutrients, pathogens, and metals. The impacts of erosion, sedimentation, and unmanaged stormwater on streams, waterways, and communities are discussed in more detail in Section 2.1.3.

***Figure 2-2 Impacts of Impervious Cover on Stormwater Runoff/Hydrology***




*Source: EPA 2003*

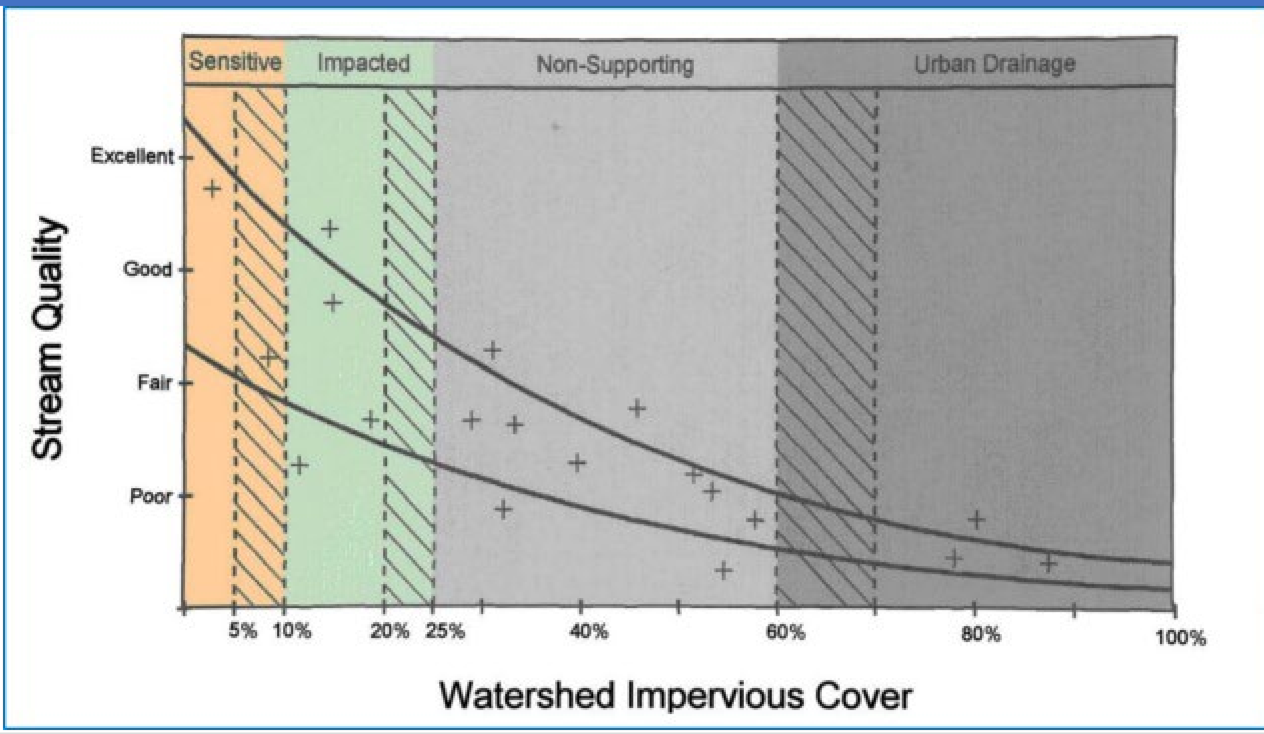
### 2.1.1.2.1 Controlling Erosion and Sediment and Managing Stormwater from the Start

This Handbook helps developers minimize impacts to waterways through erosion and sediment control (ESC) during construction and implementing post-construction stormwater management such that the rate, volume, and quality of stormwater are managed in accordance with Virginia's laws and regulations. The techniques used vary according to the type of development, the constraints of the physical environment, and other factors, but the goal is always the same – to restore, or at least mimic, the natural processes that are disrupted during and after development. In addition to compliance with the regulations, proper erosion and sediment control and stormwater management can mean a smoother, more efficient construction process with less erosion and dust. After construction, properly designed stormwater management can help reduce property management costs that may be caused by flooding, ponding, and drainage issues while enhancing the site's environmental quality.

### 2.1.1.2.2 The Impervious Cover Model

One of the primary motivations and justifications for ESC and stormwater management regulation comes from an understanding of how streams respond to urbanization; specifically, the level of impervious cover. The deleterious impacts of impervious cover on the health of stream systems have been well understood for at least two decades. The impervious cover model (Figure 2-3), first introduced by the Center for Watershed Protection (CWP 2003) posits that stream health (as measured by aquatic indicators such as fish and macroinvertebrates) predictably declines as the percentage of impervious cover in the landscape increases. This relationship has been substantiated by many studies over the years (Ourso and Frenzel, 2003, Roy A.H. et al., 2003, Walsh, C.J et al., 2007) and provides one of the important foundations for the need to regulate development processes that lead to erosion and sedimentation, and to manage stormwater.

***Figure 2-3 Reformulated Impervious Cover Model Reflecting Changes in Stream Quality in Response to Percent Impervious Cover in the Contributing Watershed***




*Source: Center for Watershed Protection and Chesapeake Stormwater Network 2008*

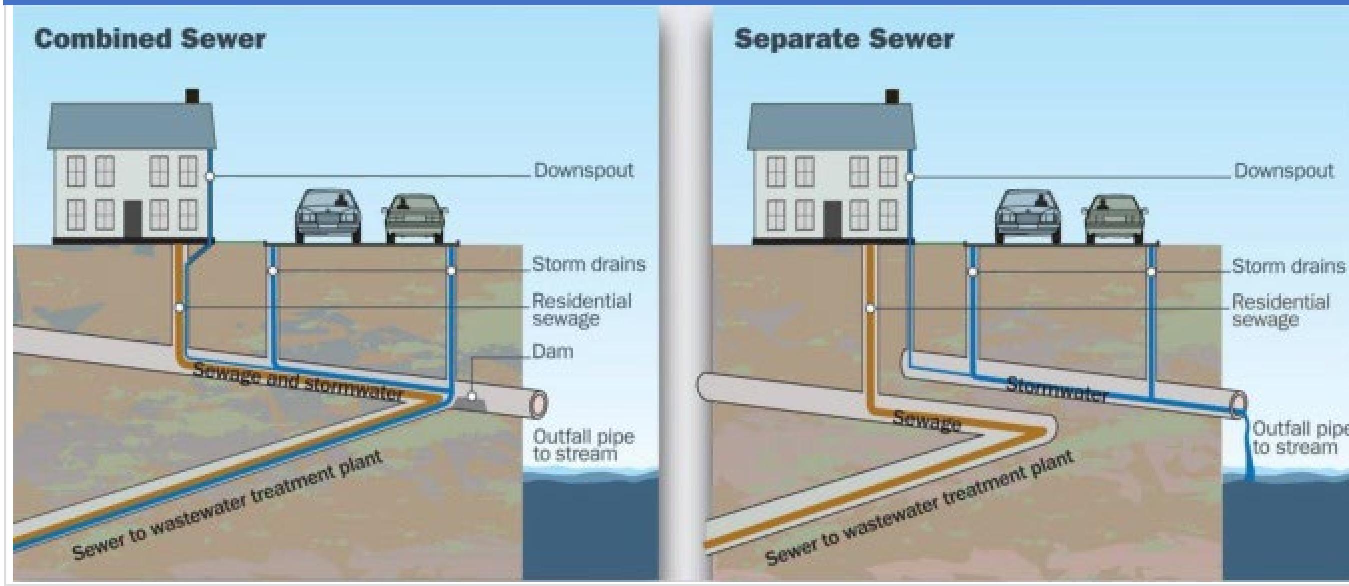
### 2.1.1.2.3 Types of Stormwater Collection and Conveyance Systems

Storm sewer systems are common features of the urban landscape that convey stormwater from impervious surfaces to waterbodies. In Virginia, most stormwater is collected and conveyed in storm sewer systems comprising pipe networks that carry only stormwater, with sanitary sewage (wastewater) carried by a separate sanitary sewer system. However, a small number of municipalities, including Lynchburg, Alexandria, and Richmond, convey stormwater using combined sewers.

Figure 2-4 illustrates the difference between these types of sewer systems. In a combined sewer system, sanitary sewage and stormwater are conveyed by a single pipe that leads to a wastewater treatment plant. During rain events, the flow may exceed the capacity of the storm pipe, resulting in the discharge of a mixture of stormwater and sewage directly into waterbodies.

In addition to conventional pipe networks, in many communities, stormwater is conveyed in part using open channels such as swales and ditches. These may be natural or man-made.

**Figure 2-4 Combined and Separate Sewer Systems**




*Source: Kessler 2011*

## 2.1.2 Changing Precipitation Patterns and the Role of Climate in Stormwater Design

Climate changes, including more frequent and intense storms and more extreme flooding events, can increase stormwater runoff. An increase in stormwater runoff can exacerbate existing, or introduce new, pollution problems (EPA 2023). In addition, a compelling and widening body of evidence suggests that rates and intensities of precipitation in the Mid-Atlantic states, including Virginia, are increasing and suggest that further increases are likely to occur over the coming decades as the effects of climate change continue to accrue (Figure 2-5).

Recent work completed by the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) and the Chesapeake Bay Program develop adjusted precipitation intensity/duration/frequency (IDF) curves to reflect the anticipated impacts of climate change for the Chesapeake Bay Watershed and Virginia (see Figure 2-6 for an example adjusted IDF curve). Median change factors (i.e., the percent increase in precipitation vs. current NOAA Atlas 14 (NOAA, 2006) estimates referenced in the Virginia Erosion and Stormwater Management Regulation) reported in the MARISA work range from 1.08 to 1.20 (i.e., 8% to 20% increase) depending on the event frequency and emissions assumptions (Miro et al. 2021).

**Adjusting for the Future: Virginia's Beach's Climate Ready Design Standards for Stormwater**

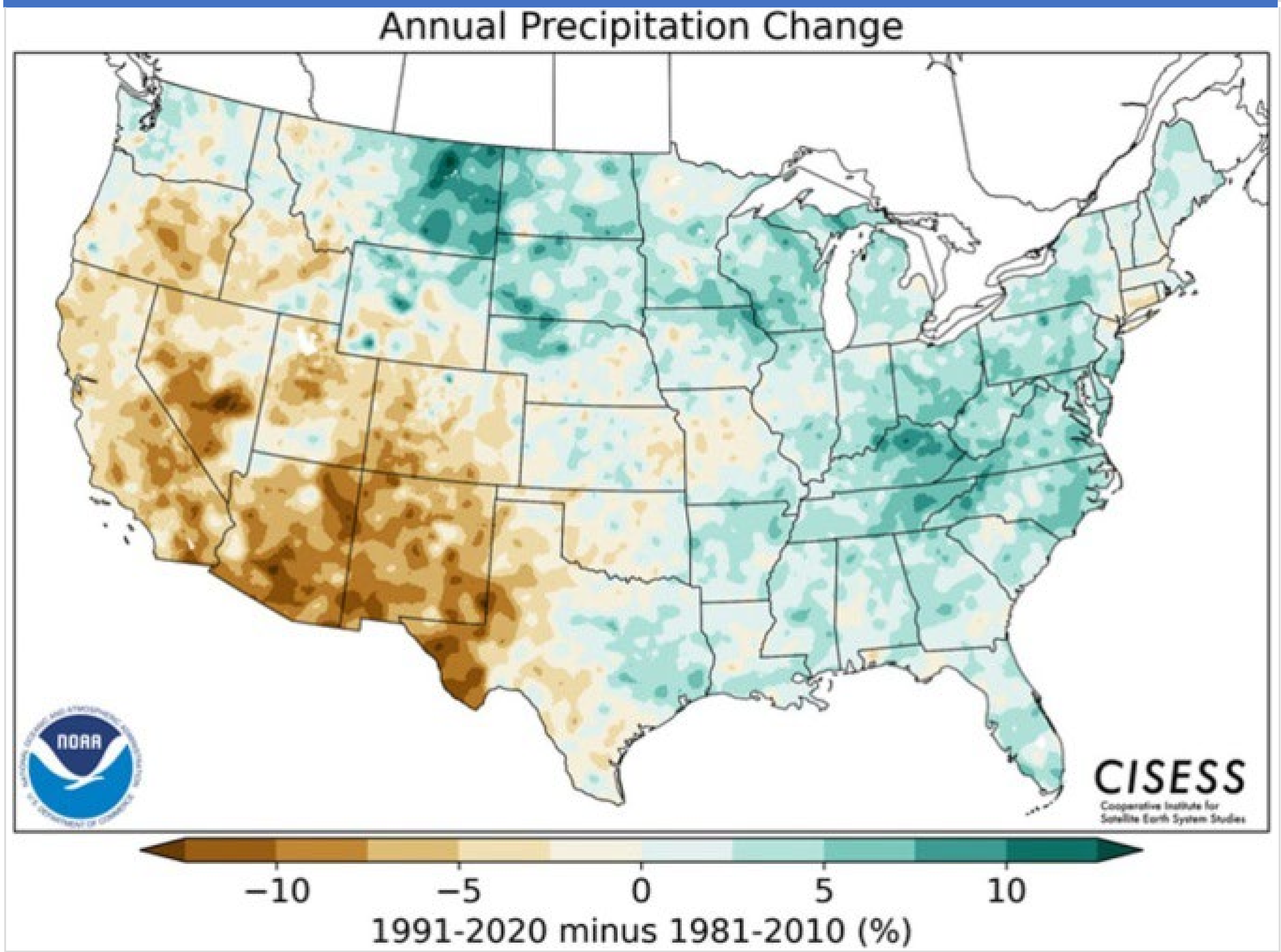
According to the U.S. Climate Resilience Toolkit, the Hampton Roads region is experiencing the fastest rate of sea level rise in the East Coast. What's more, rates of rainfall have increased by 10 percent over National Oceanic and Atmospheric (NOAA) Atlas 14 published values. Heavy rainfall has increased by about 7% per decade since 1950 (City of Virginia Beach, 2018)

In response to these changes, in 2019, the City of Virginia Beach updated its design standards, now requiring developers to design drainage infrastructure based on precipitation depths that are 20% higher than those reported in NOAA Atlas 14.

Increases in precipitation are likely to further compound the effects of urbanization on stormwater, erosion, and sedimentation. These trends, if continued, will present an added challenge, as enhanced measures may be needed to provide effective ESC and stormwater management.

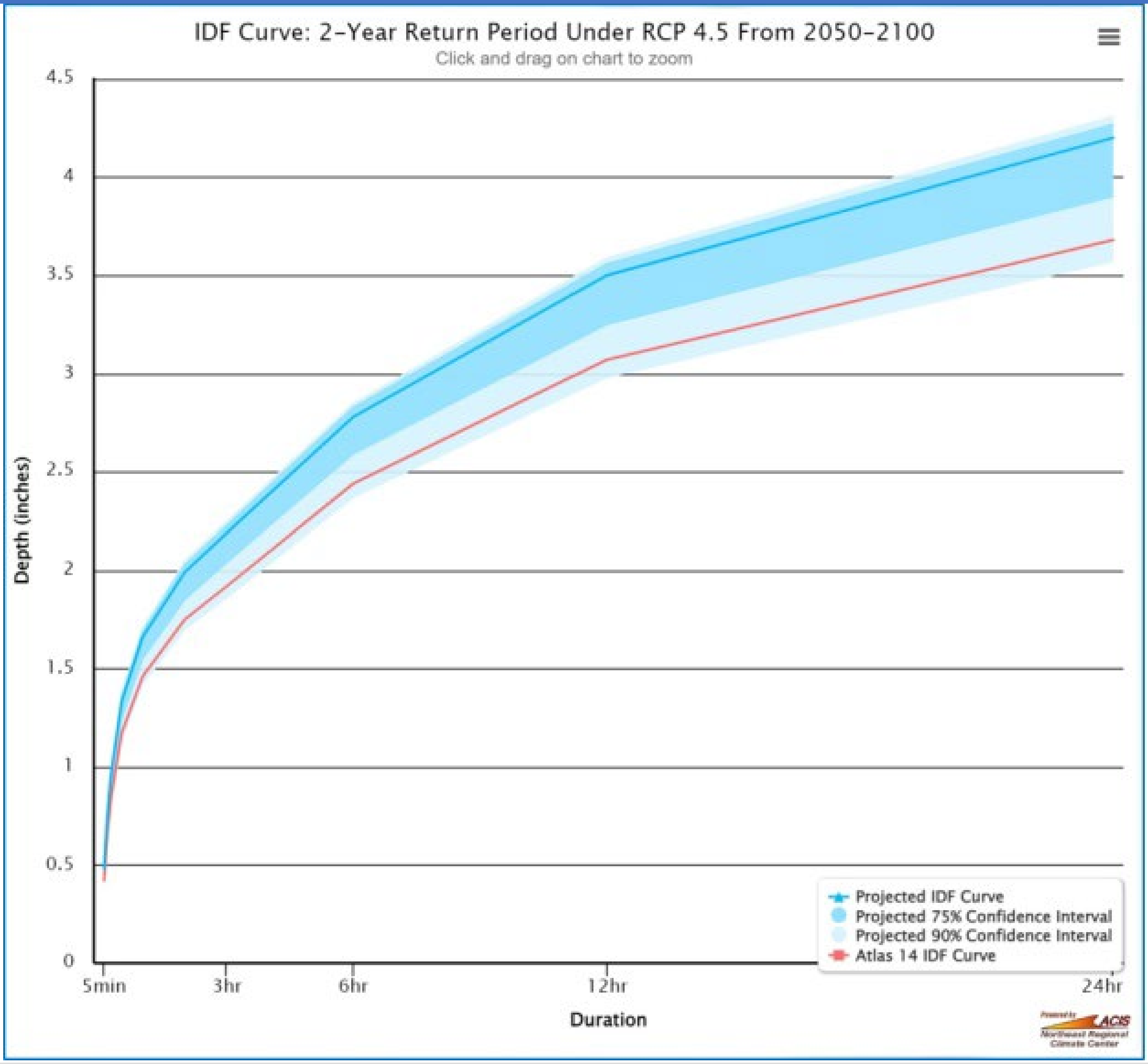
Hatching on Figure 2-5 represents areas where the majority of climate models indicate a statistically significant change. Virginia is part of a large area of projected increases that includes all of the Northeast.

***Figure 2-5 Projected Changes in Total Annual Precipitation (%) from the Period 1981-2010 to 1991-2020.***




*Source: NOAA 2022*

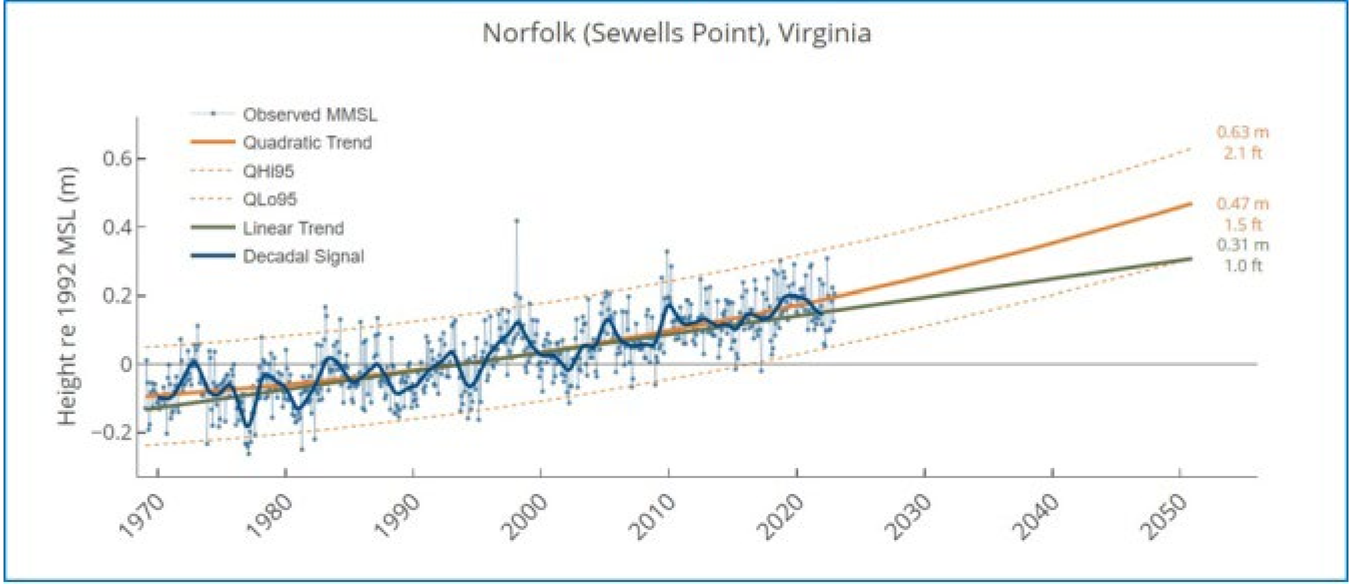
**Figure 2-6 IDF Curve for Charlottesville, VA Reflecting Adjusted Precipitation Estimates to Account for the Effects of Climate Change**




*Source: MARISA 2023*

Most scientists agree that the effects of climate change also include sea level rise. Along the Virginia Coast, sea levels have risen an estimated 17 inches between 1927 and 2020 (Sewells Point; NOAA 2022). Additionally, downscaled global climate models (GCMs) predict that significant sea level rise will occur through 2100. Although estimates vary widely, most moderate 2050 estimates of sea level rise along the Virginia coastline range from 1.5 to 2 ft (see example for Norfolk, VA on Figure 2-7). As sea level rise continues, a reduction in gradient (e.g., slope) will make stormwater more difficult to move, requiring larger conveyance systems (e.g., pipes) and even pumps. The construction of sea walls, bulkheads, and other measures to protect shoreline assets also create and exacerbate interior drainage issues (i.e., it becomes more difficult to move stormwater from land to sea), creating the need for more or bigger infrastructure, tide flaps and gates, or pumping systems.

**Figure 2-7 2050 Sea Level Rise Predictions for Norfolk (Sewells Point), Virginia.**




*Source: VIMS 2023*

Other impacts of climate change on stormwater are identified in Table 2-1.

**Table 2-1 Summary of Stormwater Impacts Caused or Worsened by Climate Change**

| Changing Feature | Primary Impact | Secondary Impact |
|---|---|---|
| Precipitation | More mixed water precipitation; more ice and/or rain-on-snow events | More runoff during winter; increased road salt usage because of more ice |
| Precipitation | Less rain during summer season | Surface water bodies going dry for longer periods; increased water level fluctuations; wetland and floodplain disconnection |
| Precipitation | Longer, more severe droughts over larger areas | Soil moisture depletion; more accumulated surface pollution; less available water supply |
| Precipitation | More extreme precipitation events | Flooding; erosion; rapid water level changes |
| Warmer winters | Less snow accumulation; more and earlier winter runoff; earlier snowmelt | Less water supply saved in snowpack (especially in the west); more winter road salt application; drier streams, wetlands, and floodplains earlier in the year; less groundwater recharge |
| Warmer winters | Shorter lake ice coverage | Earlier lake turnover in spring, later in fall; greater algal growth; more evaporation during winter; longer lake water stratification period |

| Table 2-1 Summary of Stormwater Impacts Caused or Worsened by Climate Change | | |
|---|---|---|
| **Changing Feature** | **Primary Impact** | **Secondary Impact** |
| Warmer summers | Increased temperature of runoff | Less cold-water fishery |
| Warmer summers | Increased humidity | Greater severity of storms and extreme events like tornadoes |
| Warmer summers | More suitable vector environment | Increases in the number and type of nuisance and health-related vectors (like mosquitoes in stormwater ponds) |
| Warmer summers | Less water available in wetlands, lakes, reservoirs, and streams | Evapotranspiration-transpiration increases result in volume loss; groundwater recharge decreases, affecting stream base flow |
| Warmer summers | Gradual warming of the oceans | Increased tropical storm frequency and severity; sea level rise |
| Warmer summers | Lower water levels | Some perennial streams become intermittent; hydrologic connections to riparian zones decrease |

Variations will occur in different parts of North America.

Source: IPCC 2007a, IPCC 2007b, and UCS-ESA 2005

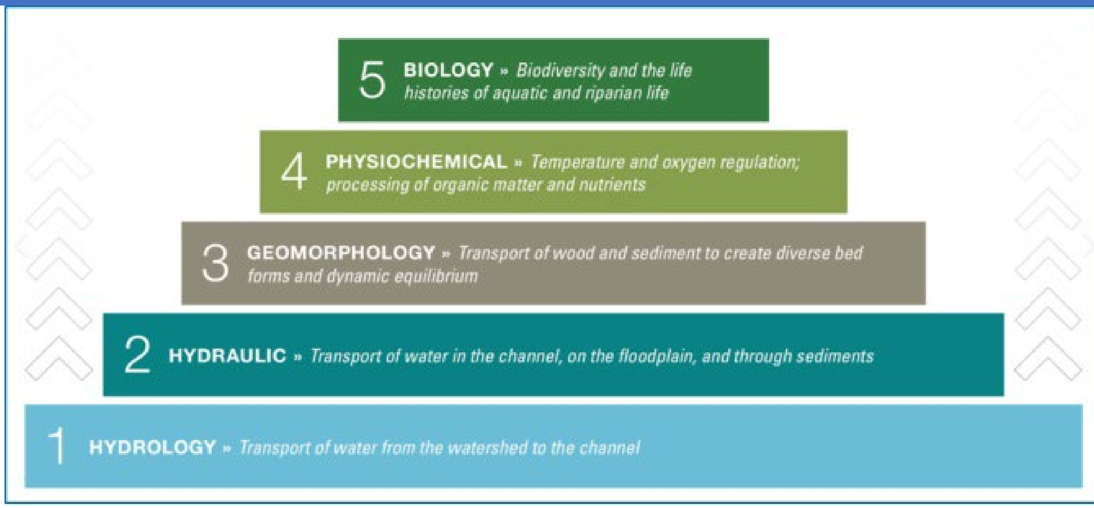
## 2.1.3 Impacts of Unmanaged Erosion, Sediment, and Stormwater

As mentioned above, scientists have developed a strong understanding of how development can disrupt natural processes in ways that have impacts for the environment, people, and communities. This section will briefly review the types of impacts that can occur. This is not intended to be a comprehensive review, but rather an introduction to key concepts and research findings.

### 2.1.3.1 How Streams Work: The Stream Functional Pyramid

Before considering how development impacts stream systems, it is important to provide a framework for describing how healthy streams function. The most widely used and arguably complete concept of stream function is the stream functional pyramid (Figure 2-8), which suggests that stream characteristics are arranged in a hierarchical order. Within this order, physical characteristics provide the foundation upon which chemical and finally biological characteristics develop. Specifically, geology and climate determine the hydrology of a watershed. The way hydrology interacts with stream channel characteristics determines hydraulics, which in turn gives rise to geomorphic processes, like sediment transport, that shape the channel and floodplain. Physicochemical characteristics include more transient characteristics such as stream chemistry and inputs of organic matter like leaves. These characteristics directly influence, and in turn are directly influenced by, biological communities.

**Figure 2-8 The Stream Functional Pyramid**




*Source: Harman et al. 2012*

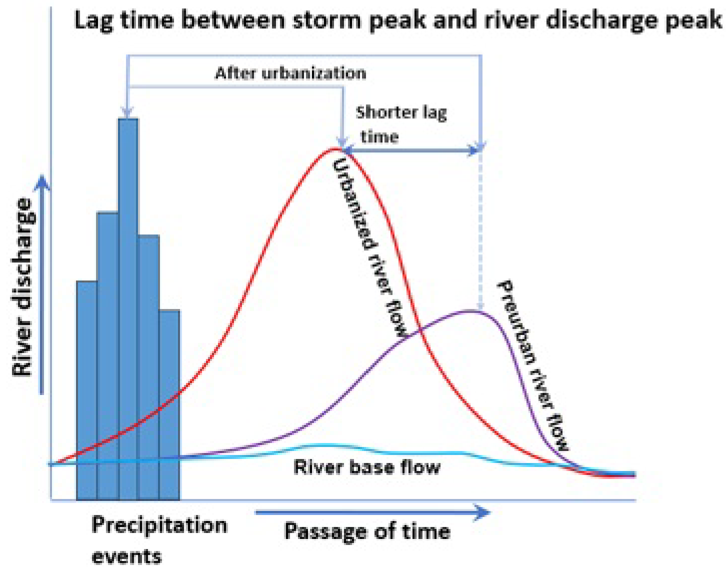
### 2.1.3.2 The Urban Stream Syndrome

As development occurs within a watershed, a series of predictable changes leads to physical, chemical, and biological impacts that can in turn undermine the uses and values of stream systems. Because of the wide range of impacts and causes, this condition has been termed the "Urban Stream Syndrome" (e.g., Walsh et al. 2005). Many of these changes can be thought of in terms of modifications to the stream functional pyramid discussed above, in which changes to the physical and chemical inputs lead to degradation of biological communities including population reductions, species richness, and diversity. However, the implications of impacts to streams extend far beyond the stream functional pyramid and include changes that have serious economic, public health and safety, and community impacts such as damage to near-stream infrastructure and structures; loss of life and property damage as the result of flooding; and diminishment of recreational, navigational, and consumptive uses. The following sections describe these changes in more detail.

#### 2.1.3.2.1 Flow Changes (Hydraulic and Hydraulic Impacts)

Flow within stream channels consists either of storm flow, which occurs in response to precipitation events, or baseflow, which is derived from groundwater inputs. Urbanization and development can often lead to predictable changes in the timing and quantity of both storm flow and baseflow (Figure 2-9). Streams draining watersheds that are heavily developed have higher, shorter duration peak flows during storm events and lower baseflows in between storms. The overall volume of water delivered to streams also increases as watersheds become developed.

**Figure 2-9 The Impact of Development of River Flows**




*Adapted from Duan et al. 2016*

### Baseflow

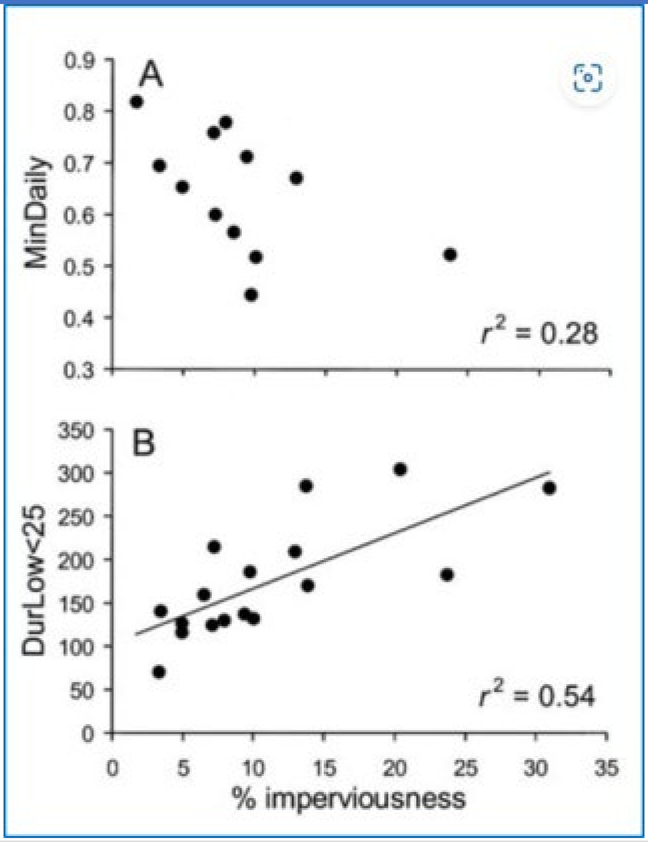
Baseflow refers to the flow in a stream channel that is not due to runoff from storm events. Baseflow quantity is critical for the sustenance of a variety of aquatic species including fish and macroinvertebrates. Baseflow is principally derived from inputs of groundwater.

Groundwater levels are in turn commonly affected by the rate and volume of infiltration of precipitation during and following precipitation events. Due to a reduction in infiltration capacity, streams in developed areas typically exhibit a reduction in baseflow relative to streams draining less developed watersheds (Figure 2-9).

### Channel-Forming Flows

Channel-forming flow, also commonly referred to as the effective, bankfull, or dominant discharge (these terms have important differences not discussed here) refer to medium- sized events (1- to 2-year recurrence interval) that are thought to be most responsible for moving sediment and hence determining the sizes, shapes, and forms of stream channels. Channel-forming flows may increase substantially because of unmanaged stormwater runoff, leading to an increase in erosive flows and adjustments to the channel size, slope, and other factors (see section on Geomorphic Impacts). These adjustments in turn may have consequences for habitat quality, flooding severity, and infrastructure.

**Figure 2-10 The Effect of Increasing Urbanization (Percent Imperviousness) on Baseflow Metrics Including A) Minimum Daily Stage/Mean Daily Stage in Late Spring B) Maximum Duration of Flow Stage during Autumn**




*Source: Roy AH et al. 2005*

### Flood Flows

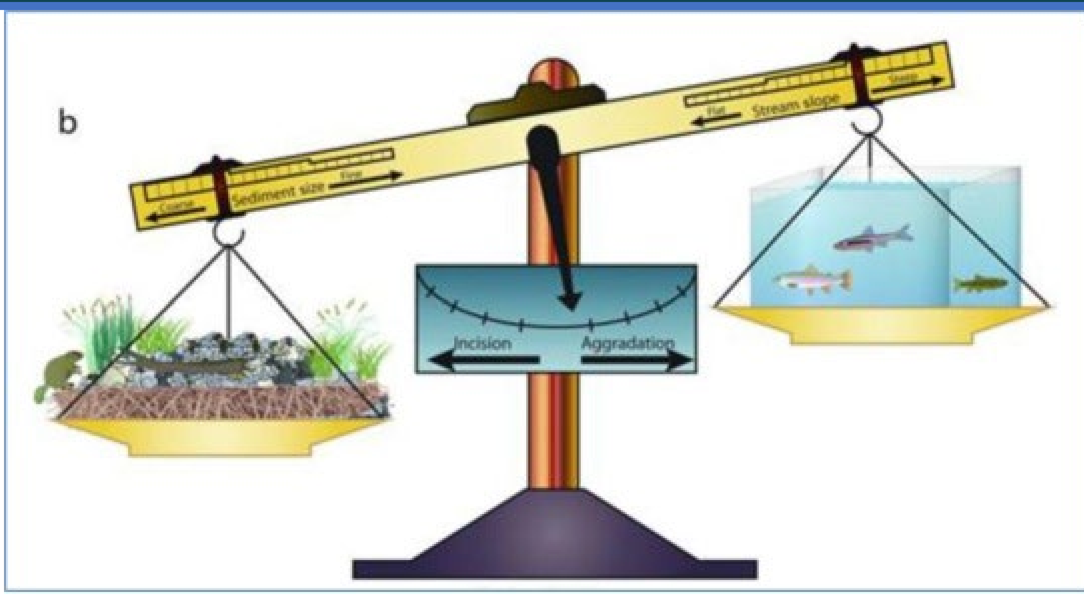
Flood flows refer to larger-sized events that occur more rarely (typically greater than a 2-year recurrence interval). In many cases, flood flows may completely fill and exceed the capacity of the stream channel, resulting in conveyance of flow within adjacent floodplains. Peak flow discharges for various flood events commonly increase in response to development due to an increase in surface runoff and a reduction in infiltration and evapotranspiration.

## 2.1.3.2.2 Geomorphic Impacts

Fluvial geomorphology refers to the study of the physical forms of stream systems, including the size, shape of channels and floodplains, and the processes that give rise to these forms. Although the level of sensitivity varies widely, the form of most stream channels develops in response to the amount of water and sediment coming from the contributing watershed. If the amount of water or sediment changes, the channel will respond. These adjustments are predictable, at least qualitatively, and generally occur such that streams trend toward an equilibrium state over time. This state, which is also called a quasi-equilibrium or dynamic equilibrium (as the equilibrium state can be associated with some movement of material, banks, and other environmental factors), is one in which the stream's ability to perform work (i.e., the available energy) equals the energy required to move the quantity of sediment delivered to the channel over time (Figure 2-11). Thus, if changes to the amount and timing of water and or sediment coming into the channel occur, the channel adjusts over time to a new equilibrium state. These adjustments, which can occur over both short and long time periods, can involve changes to many variables concurrently including channel width, depth, slope, sinuosity (which is a measure of channel length relative to valley length), and roughness.

The right side of the scale represents stream power, the product of discharge and slope, where the left side of the scale represents the size and amount of sediment.

***Figure 2-11 Streams Channels Can Rapidly Adjust to Changes in Sediment or Flow from Upstream***

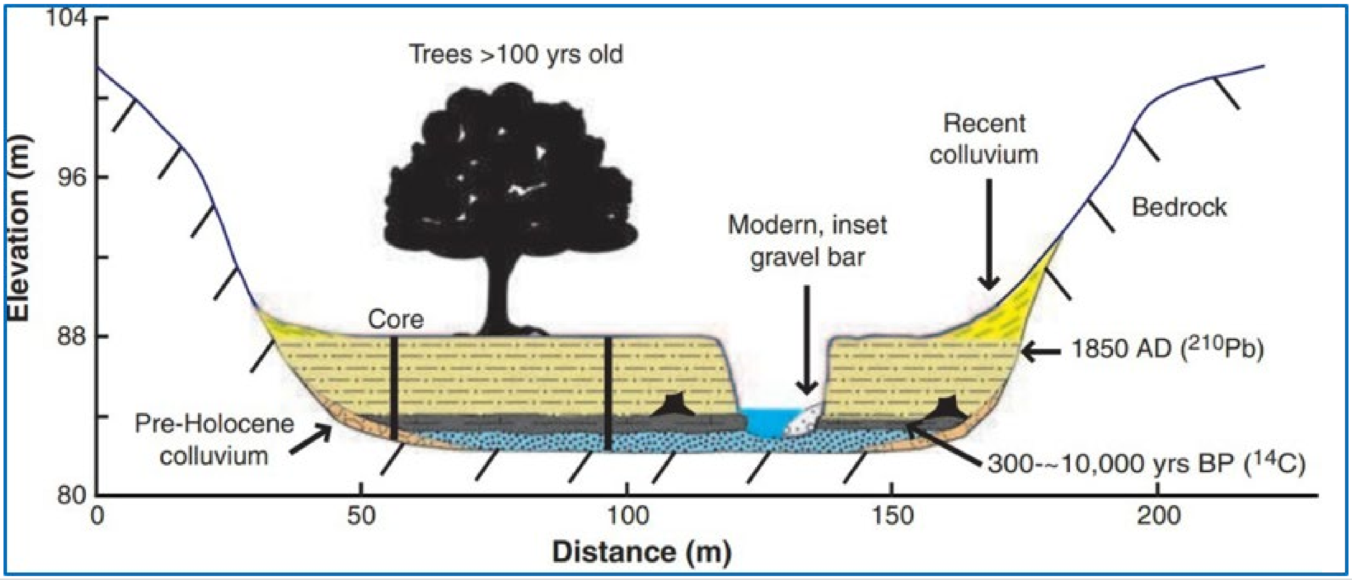



*Source: Pollock et al. 2014*

### Channel Evolution Models

Channel evolution models describe a predictable series of changes that stream channels undergo as upstream changes in flow and/or sediment loading occur. Channel evolution models developed for urban streams assume (as a starting condition) the presence of a "pre-modified" channel flowing through a non-urbanized, typically forested or agricultural landscape. In Virginia, as in many areas of the U.S., stream channels have been impacted by significant changes that occurred before urbanization but after European settlement. These changes are well documented in papers such as Walter and Merritts 2008 (see Figure 2-12) and consist of the buildup of sediment (called post-settlement alluviation or legacy sediment) within pre- settlement channels and floodplains in response to forest clearing, sediment production from agriculture, and the construction of mill dams. By the time urbanization began to accelerate in the 1950s, many channels and floodplains had been filled with sediment from eroding farm fields and trapped behind mill dams.

**Figure 2-12 Schematic Cross-Section Illustrating Typical Adjustments to Stream Channels in the Mid-Atlantic Since European Settlement**

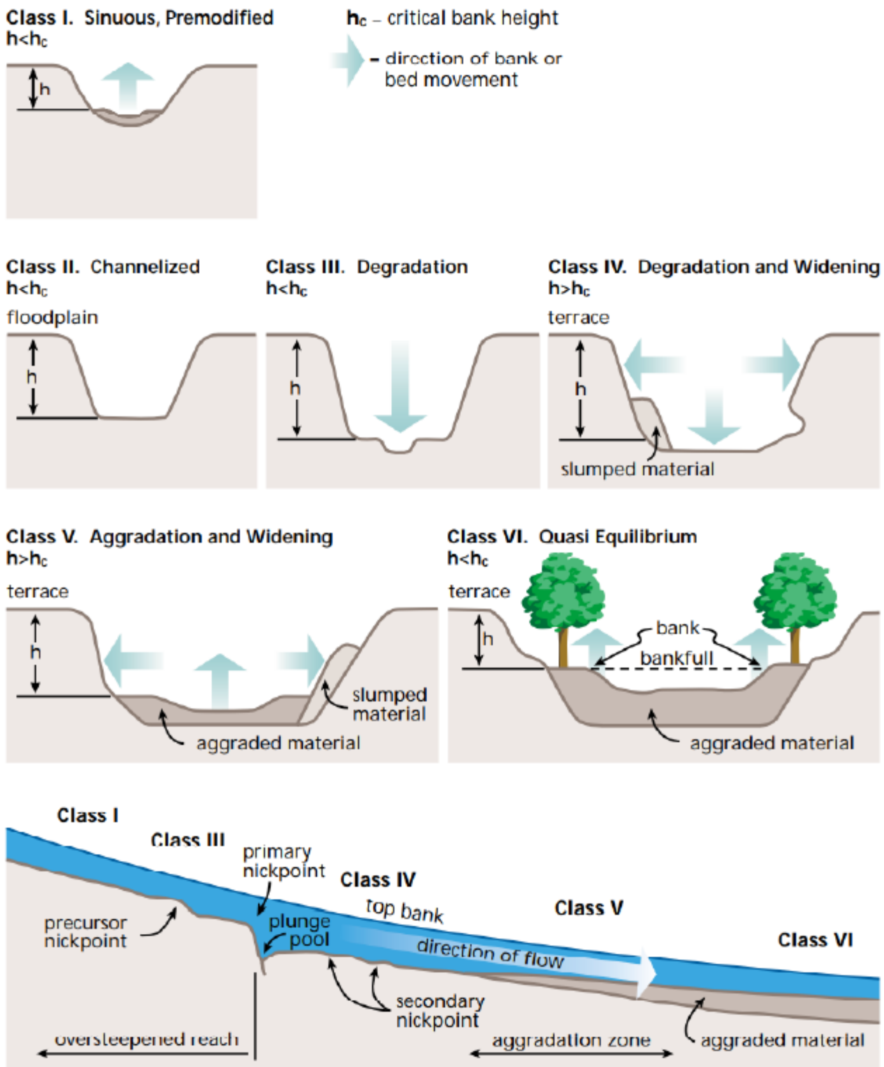



*Source: Walter and Merritts 2008*

### Channel Size Adjustments

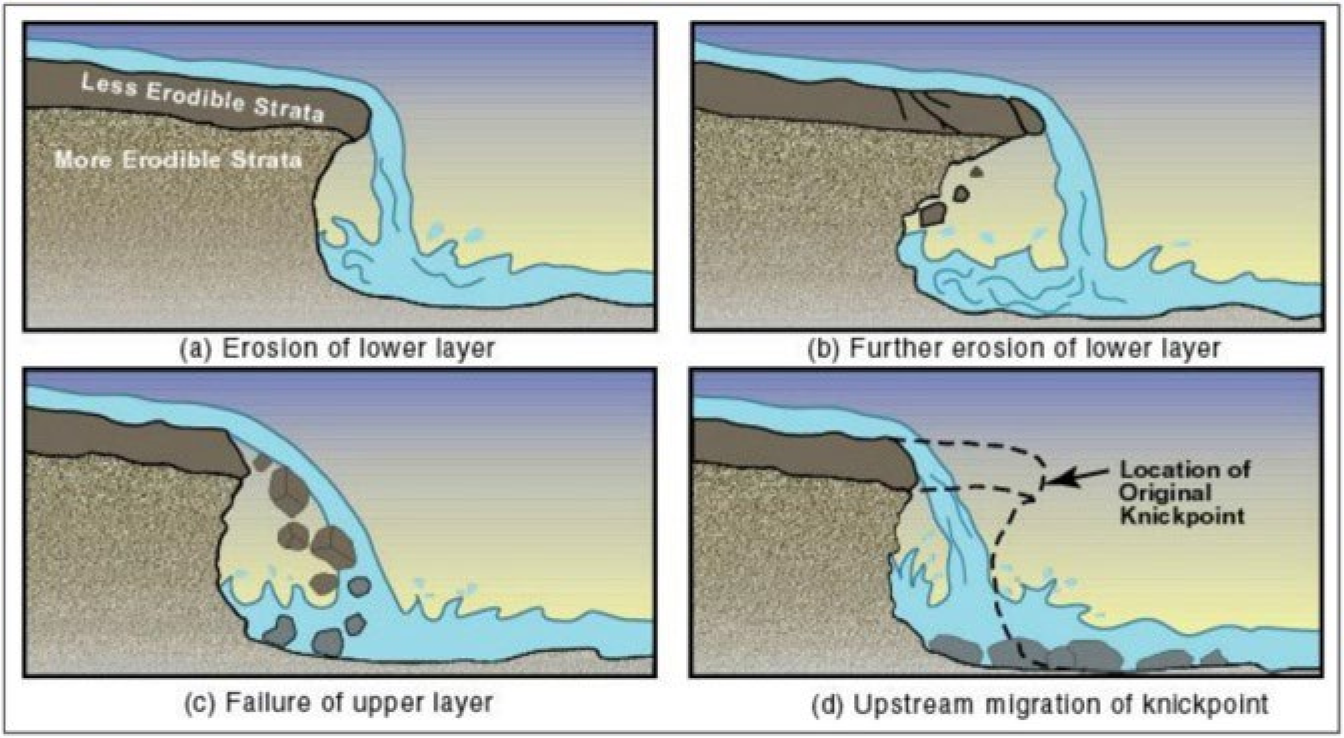
Channels draining urbanized watersheds may exhibit substantial deepening and widening, particularly in the middle of the channel evolution sequence discussed in the previous section. However, studies have shown that urban channels that are allowed to proceed to a new equilibrium form (e.g., Class VI from Figure 2-13) may become significantly narrower and shallower during the latter stages of adjustment.

**Figure 2-13 Channel Evolution Model Showing How Stream Channels Physically Transform in Response to Disturbances**




(Source: FISRWG 1998)

***Figure 2-14 Headcut Migration Process***




*Adapted from: Larson et al. 2014*

**Bank Erosion and Lateral Adjustments**

Channels downstream of urbanizing watersheds often exhibit significantly elevated rates of bank erosion and lateral movement in response to increases in channel-forming flows. Rates of lateral adjustment typically increase in the midpoint of the channel evolution process as banks fail following incision and decrease toward the later stages of adjustment.

The channel evolution model, which was initially developed to understand how streams react to channelization, is a convenient way to understand how channels change in response to urbanization (Figure 2-13). In Stage 1, channels are assumed at equilibrium just before the beginning of the urbanization process. As urbanization proceeds, flow energy increases while sediment loading delivered to channels decreases. These changes then produce a series of adjustments to channel width, depth, and slope. Typically, channels will initially down cut or incise as erosive energy increases and the amount of sediment transported to the channel decreases (Stage 2), followed by a channel widening as banks fail (Stage 3). Stage 4 channels aggrade as channel slopes are reduced and the channel width increases, eventually producing an equilibrium channel (Stage 5).

**Subsidence (Sinkhole Formation)**

Geomorphic impacts of stormwater are not limited to impacts to channels but can also include land subsidence and the formation of sinkholes in areas with karst features. When surface drainage patterns, soil moisture, and/or groundwater levels are altered, as frequently occurs during land disturbance associated with development, this equilibrium is disrupted. This often results in the development of cover collapse sinkholes when changes in waterflows and soil moisture weaken and transport soil and sedimentary deposits into and through the underlying cave networks. Once formed, sinkholes capture precipitation and funnel it directly into the ground. These impacts are discussed in detail in Appendix E.

### 2.1.3.2.3 Water Quality Impacts (Physiochemical Impacts)

Increased urbanization has reduced natural vegetation and soils that absorb and filter stormwater runoff. Point and nonpoint source water pollution from storm sewers, streets, rooftops, and parking lots swell downstream waterways every time it rains, causing higher-speed, higher-volume stormwater runoff to carry pollutants into streams, rivers, lakes, and coastal waters. With the population expected to increase in Virginia, and rainfall predicted to increase with higher peaks, urban stormwater will continue to be an issue that needs to be addressed.

Many older studies of pollutant transport in stormwater documented that pollutant concentrations showed a distinct increase at the beginning of a flow hydrograph referred to as the "first flush" (typically considered the first 0.5 inch of runoff from impervious surfaces during the first half hour of a storm). However, recent research has found that the actual transport process of stormwater pollutants is more complex, and that capturing the first flush does not necessarily ensure effective treatment of the majority of pollution in runoff.

Therefore, it is important to understand the nature and sources of urban stormwater pollution to effectively mitigate their impact. Table 2-2 lists the main pollutants found in urban stormwater runoff, typical pollutant sources, related impacts to receiving waters, and factors that promote pollutant removal. The table also identifies the pollutants that commonly occur in dissolved or soluble form, which has important implications for the selection and design of stormwater treatment practices. Concentrations of pollutants in stormwater runoff vary considerably among sites and storm events. Descriptions of those pollutant categories follow.

**Nutrients and Sediment**

*Bank Erosion within the Chesapeake Bay Watershed (Source: Gao 2015)*

Urban stormwater runoff typically contains elevated concentrations of nutrients and sediment, which is detrimental to the health and function of receiving streams, lakes, reservoirs, and estuaries. Nutrients such as nitrogen and phosphorus are most commonly derived from lawn fertilizer, detergents, and wastewater discharges. Elevated nutrient concentrations in stormwater runoff can result in excessive growth of vegetation or algae in water bodies; a process known as eutrophication. As this algae and plant growth decomposes, oxygen is consumed by decomposer microbes. This process can lead to hypoxia, or low dissolved oxygen, within receiving waters. Hypoxia has occurred in the Chesapeake Bay and the lower reaches of some of Virginia's major rivers. Sediment loading to waterbodies occurs from wash-off of particles that are deposited on impervious surfaces such as roads and parking lots, soil erosion associated with land disturbance, and streambank erosion. Excessive sediment loads can make water cloudy or turbid, detract from the aesthetic and recreational value of a waterbody, impair drinking water sources, harm aquatic life including fish and shellfish, and adversely impact wildlife habitats.

**Pathogens**

Pathogens are bacteria, viruses, and other microbes that can cause disease in humans. The presence of bacteria, such as fecal coliform or enterococci, is an indicator of pathogens and of potential risk to human health. Sources of pathogens in stormwater runoff include animal waste from pets, wildlife, and waterfowl; sanitary sewer overflows; combined sewer overflows; failing septic systems; and illegal sanitary sewer cross-connections. High levels of indicator bacteria in surface water have led to the closure of beaches and shellfish beds along coastal areas of Virginia.

**Organic Materials**

Oxygen-demanding organic substances, such as grass clippings, leaves, animal waste, and street litter, are commonly found in stormwater. As with excess nutrients, the decomposition of such substances in waterbodies can deplete levels of dissolved oxygen. This is a particular concern in the Chesapeake Bay because the Bay's average depth is unusually shallow for an estuarian system of this size and drainage area. As a result of the shallow depth, total volume of water (and oxygen) in the Bay is quite small and thus more susceptible to depletion than similarly sized yet deeper estuaries.

**Trace Metals**

Metals such as copper, lead, zinc, mercury, aluminum, chromium, nickel, and cadmium are commonly found in urban stormwater runoff. Primary sources include industrial and commercial sites; marinas; rooftops and painted areas; residue from vehicle anti-freeze, exhaust systems, brakes, and tires; corrosion of galvanized and chrome-plated products; improperly disposed of household chemicals; landfills and hazardous waste sites; and atmospheric deposition. Although metals generally attach to the solids in stormwater runoff or receiving waters, dissolved metals concentrations can be significant in stormwater runoff from industrial facilities, potentially requiring more complex and expensive treatment. Additionally, stormwater runoff can contribute to elevated metals concentrations in aquatic sediments, resulting in more difficult maintenance dredging in estuaries, where the contaminated sediments require special handling.

**Pesticides, Organic Pollutants, and Hydrocarbons**

Synthetic organic chemicals can be present at low concentrations in urban stormwater. Pesticides, phenols, polychlorinated biphenyls (PCBs), and polynuclear or polycyclic aromatic hydrocarbons (PAHs) are the organic compounds most frequently found in stormwater runoff, with per- and polyfluoroalkyl substances (PFAS), also known as forever chemicals, recently joining the list. Such chemicals can exert varying degrees of toxicity to aquatic organisms and can bioaccumulate in fish and shellfish. Toxic organic pollutants are most commonly found in stormwater runoff from industrial areas, while pesticides are found in most populated areas of the state.

Oils, greases, gasoline, and parking lot sealants, among other products, contain a wide array of organic and inorganic hydrocarbon compounds, including PAHs, and have proven to cause tumors, cancer, and mutations in certain species of fish, even at low concentrations. These substances can also cause surface films and shoreline deposits that are environmentally harmful. In large quantities, oil can impact drinking water supplies and affect recreational use of waters. Hydrocarbon sources include runoff from roads and parking lots, primarily due to engine leakage from vehicles, improper disposal of motor oil in storm drains and streams, spills at fueling stations, and restaurant grease traps.

**Chlorides and Deicing Compounds**

Salting of roads, parking lots, driveways, and sidewalks during winter months and snowmelt during the early spring result in the discharge of sodium, chloride, and other deicing compounds to surface waters via stormwater runoff. Excessive amounts of sodium and chloride may have harmful effects on water, soil, and vegetation and can also accelerate corrosion of metal surfaces, which results in even more pollution. Sufficient concentrations of chlorides may prove toxic to certain aquatic species, and excess sodium in drinking water can lead to health problems. Deicing compounds may contain nitrogen, phosphorus, and oxygen-demanding substances. They generally remain in the snowpack until the end of the snowmelt season, resulting in highly concentrated loadings during the spring snowmelt season and during winter rain-on-snow events.

**Trash and Debris**

Trash and debris are washed off of the land surface by stormwater runoff and can accumulate in storm drainage systems and receiving waters. Litter detracts from the aesthetic value of waterbodies and can harm aquatic life and wildlife either directly (by being mistaken for food) or indirectly (by habitat modification). In smaller streams, debris can cause blockage of the channel, which can result in localized flooding and erosion. Sources of trash and debris in urban stormwater runoff include residential yard waste, commercial parking lots, street refuse, combined sewers, illegal dumping, and industrial refuse.

**Table 2-2 Summary of Urban Stormwater Pollutants**

| Stormwater Pollutant | Potential Sources | Receiving Water Impacts | Removal Promoted by[1] |
|---|---|---|---|
| ***Excess Nutrients***: Nitrate, Nitrite, Ammonia, Organic Nitrogen, Phosphate, Total Phosphorus | Animal waste, fertilizers, failing septic systems, landfills, atmospheric deposition, erosion and sedimentation, illicit sanitary connections | Algal growth, nuisance plants, ammonia and nitrate toxicity, reduced clarity, oxygen deficit (hypoxia), pollutant recycling from sediments, decrease in submerged aquatic vegetation (SAV), eutrophication, and loss of recreation and aesthetic value | Phosphorus: Filtering/settling sediment, high soil exchangeable aluminum and/or iron content, vegetation and aquatic plants, aluminum in pond<br>Nitrogen: Aeration, alternating aerobic and anaerobic conditions, maintaining near neutral pH (7) |
| ***Sediments***: Suspended, dissolved, sorbed pollutants, turbidity | Construction sites, stream bank erosion, washoff from impervious surfaces | Increased turbidity, lower dissolved oxygen, deposition of sediments, aquatic habitat alteration, sediment and benthic toxicity, contaminant transport, filling of lakes and reservoirs, and loss of recreation and aesthetic value | Low turbulence, increased residence time, filtering and settling |
| ***Pathogens***: Total and Fecal Coliforms, Fecal Streptococci, Viruses, E. Coli, Enterococci | Animal waste, failing septic systems, illicit sanitary connections, combined and sanitary sewer overflows | Human health risk via drinking water supplies, contaminated swimming beaches, and contaminated shellfish consumption | High light (ultraviolet radiation), increased residence time, media/soil filtration, disinfection |

| Table 2-2 Summary of Urban Stormwater Pollutants | | | |
|---|---|---|---|
| Stormwater Pollutant | Potential Sources | Receiving Water Impacts | Removal Promoted by[1] |
| ***Organic Materials***: Vegetation, sewage, other oxygen demanding materials (BOD/COD) | Leaves, grass clippings, brush, failing septic systems | Dissolved oxygen depletion, odors, fish kills, algal growth, reduced clarity | Aerobic conditions, high light (ultraviolet radiation), high soil organic content, maintaining near neutral pH |
| ***Hydrocarbons***: Oil and grease | Industrial processes, commercial processes, automobile wear, emissions, and fluid leaks, improper oil disposal | Toxicity of water column and sediments, bioaccumulation in food chain organisms | Low turbulence, increased residence time, physical separation or capture technique, volatilization |
| ***Metals***: Copper, lead, zinc, mercury, cadmium, chromium, nickel, aluminum (soluble) | Industrial processes, normal wear of automobile brake linings and tires, automobile emissions and fluid leaks, metal roofs and pipes | Toxicity of water column and sediments, bioaccumulation in food chain organisms | High soil organic content, high soil cation exchange capacity, maintaining near neutral pH (7), controlling sludge applications |
| ***Synthetic Organic Chemicals***: Pesticides, VOCs, SVOCs, PCBs, PAHs (soluble) | Residential, commercial, and industrial application of herbicides, insecticides, fungicides, rodenticides, industrial processes, commercial processes | Toxicity of water column and sediments, bioaccumulation in food chain organisms | Aerobic conditions, high light (ultraviolet radiation), high soil organic content, low levels of toxicants, near neutral pH (7), high temp. and air movement for volatilization of VOCs |
| ***Deicing Constituents***: Sodium chloride, calcium chloride, potassium chloride, ethylene glycol, other pollutants (soluble) | Road salting and uncovered salt storage, snowmelt runoff from snow piles in parking lots and along roads during the spring snowmelt season or during winter rain and snow events | Toxicity of water column and sediments, contamination of drinking water, harmful to salt-intolerant plants; concentrated loadings of other pollutants as a result of snowmelt | Aerobic conditions, high light (ultraviolet radiation), high soil organic content, low levels of toxicants, near neutral pH (7) |
| ***Trash and Debris*** | Litter washed through the storm drain networks | Degradation of aesthetics, threat to wildlife, potential clogging of storm drainage | Low turbulence, physical straining/capture |
| ***Thermal Impacts*** | Runoff with elevated temperatures from contact with impervious surfaces (asphalt) | Dissolved oxygen depletion, adverse impacts to aquatic organisms that require cold and cool water conditions | Use of wetland plants and trees for shading, increased pool depths |

| Table 2-2 Summary of Urban Stormwater Pollutants | | | |
|---|---|---|---|
| Stormwater Pollutant | Potential Sources | Receiving Water Impacts | Removal Promoted by[1] |
| ***Freshwater Impacts to Saltwater*** | Stormwater discharges to tidal wetlands and estuarine environments | Dilution of the high marsh salinity and encouragement of the invasion of brackish or upland wetland species | Stormwater retention and volume reductions |

1 Factors that promote removal of most stormwater pollutants include: (1) Increasing hydraulic residence time; (2) Low turbulence; (3) Fine, dense, herbaceous plants; and (4) Medium-fine textured soil.

BOD = biological oxygen demand

COD = chemical oxygen demand

SVOC = semi-volatile organic compound

VOC = volatile organic compound

Source: Adapted from Connecticut DEP, 1995, Metropolitan Council, 2001; Watershed Management Institute, Inc., 1997

### 2.1.3.2.4 In-Stream Habitats

In-stream habitats can be substantially degraded as the result of urbanization and development. Impacts can include:

- Reduction in baseflow as the result of reductions in the groundwater table;
- Reduction in wetted habitat area as the result of reductions in base flow;
- Reduction in flow depth as a result of pool filling and channel widening;
- More frequent scour and movement of bottom habitats;
- Reduction in/clogging of deep gravel (hyporheic) habitats that are also key locations of nutrient processing and nitrogen removal;
- Elimination of deep-water pools that provide thermal refuge for cold water fish species;
- Simplification of habitats (depth, velocity) due to increased erosion and depositional processes;
- Removal of inputs of large woody debris;
- Increases in solar radiation;
- Siltation of riffle habitats;
- Increase in stream temperature;
- Elimination of upstream sources of macroinvertebrate colonists; and
- Introduction of invasive species.

The net effect of these changes is often simplification and shift in the biological community.

**Riparian Habitats and Food Webs**

Development and urbanization are often associated with the removal of riparian vegetation. Riparian habitats provide myriad functions for streams including:

- Providing inputs of particulate organic matter, which provides a food source for aquatic invertebrates, bacteria, and fungi;
- Providing inputs of large woody debris, which provides structural habitat for fish and macroinvertebrates;

- Limiting solar radiation, which can stimulate plant growth and lead to excessive growth of algae, and associated reduction in dissolved oxygen;
- Providing root structures that promote bank stability and limit bank erosion; and
- Providing pollutant and nutrient removal.

Impacts to riparian zones depend on the extent of riparian buffer removal/disturbance and the sensitivity of the stream to these impacts.

**Fish Migration Barriers**

Fish migration barriers can occur as the result of several related impacts of development. Migration barriers typically can occur at culvert crossings, which are commonly constructed to facilitate development. Whether a specific culvert presents a migration barrier will depend on the specifics of the culvert, its effect on hydraulics and stream geometry, and the fish species of interest.

Fish migration barriers can also be created or exacerbated by geomorphic changes discussed previously. In particular, as streams incise in response to urbanization, the resulting headcuts can form barriers to fish migration. Loss of habitat associated with reductions in base flow and stream widening can also limit fish passage, particularly if channels become dry, excessively shallow, or unseasonably warm during migratory periods.

**Subterranean Habitats**

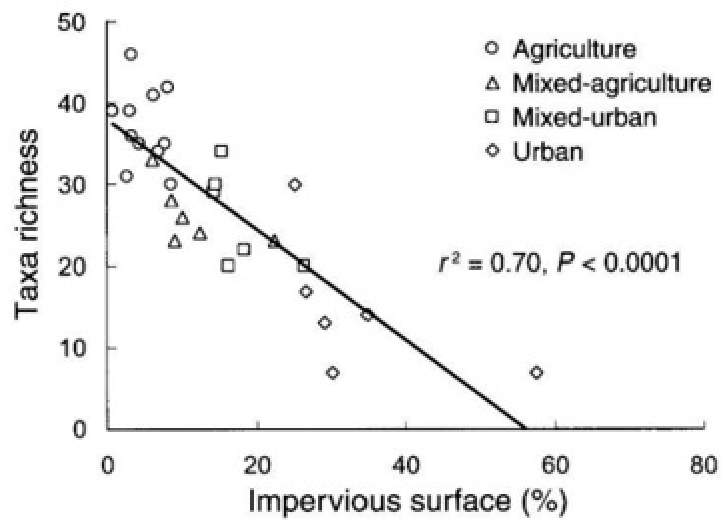
Unmanaged stormwater can also adversely affect subterranean aquatic and subterranean terrestrial habitats. These habitats are generally associated with rare, cave-adapted fauna in karst areas across western Virginia. In addition, springs in which water from karst aquifers/systems returns to the surface are also important habitats and subject to impacts from land development in their recharge areas. For more information on subterranean habitats, please see Appendix E.

### 2.1.3.2.5 Biological Impacts

**Plants and Algae**

Stormwater impacts to geomorphology and habitats can in turn negatively affect naturally occurring plant and algal communities in streams. These impacts can include physical scouring of benthic (bottom) habitats, which can result in the physical removal of macrophytes and periphyton. Unmanaged stormwater and unchecked erosion can also increase nutrient levels, which can result in an increase in plant and algal biomass. While this might seem like a positive impact, as nutrient enrichment proceeds, native plant and algal species may be displaced by invasive species that thrive in nutrient-rich environments.

***Figure 2-15 The Relationship Between Total Macroinvertebrate Richness and % Impervious Surface Cover in 29 Headwater Maryland Streams Sampled in 2001***




*Source: Moore and Palmer 2005*

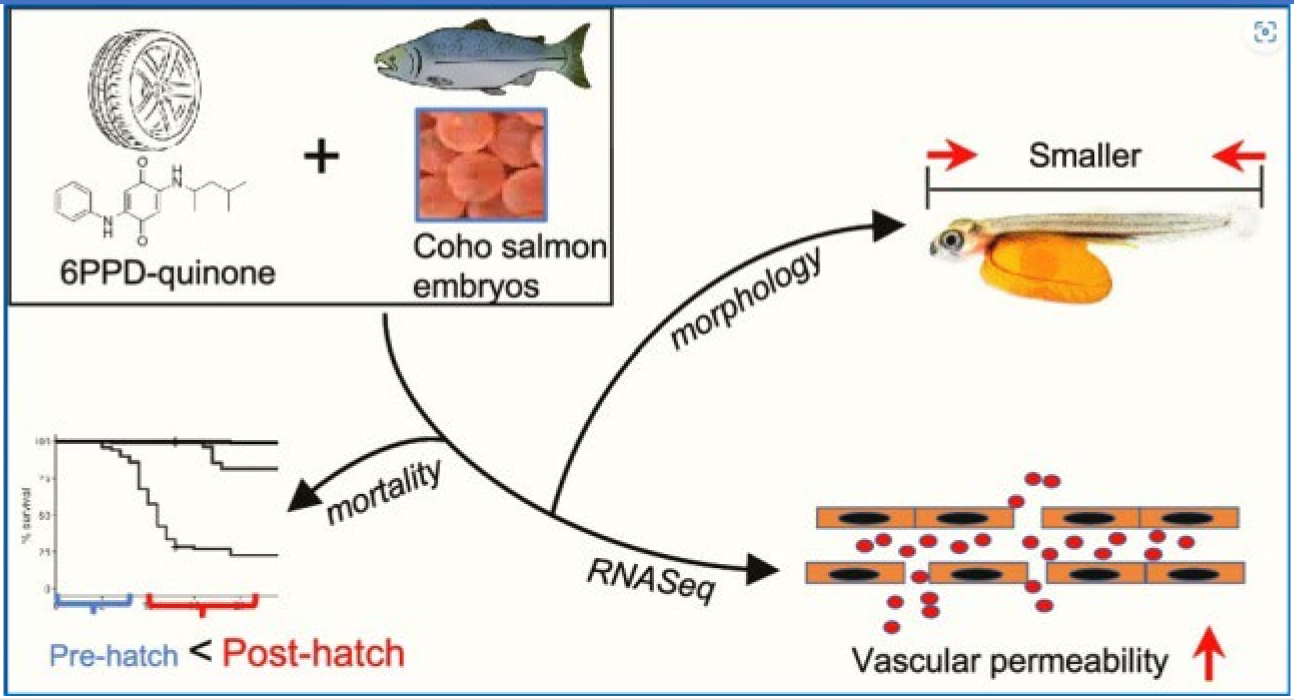
**Macroinvertebrates**

Macroinvertebrates, including many forms of aquatic insects and mussels, exhibit predictable changes in species diversity and composition in response to urbanization (see Figure 2-15). These changes result from a combination of factors relating to reduction in water quality and disruption of habitats. Urban streams often have flashier flow patterns, resulting in a harsher environment for macroinvertebrates. Habitats preferred by many species of aquatic insects, such as rocky and fast flowing areas called riffles, may become clogged with sediment as a result of upstream erosion, reducing the oxygen flow and clogging pore species in the gravels beneath streams that macroinvertebrates use for refuge during high flow events. Stable conglomerations of logs, sticks, and leaves (called woody debris jams) are also key macroinvertebrate habitats that can be washed away or disrupted by streams receiving large volumes of unmanaged stormwater. Similar processes can result in harm to subterranean macroinvertebrates such as those commonly found in caves. Cave-dwelling macroinvertebrates can be highly vulnerable to human activities. For instance, Cardoso et al. 2022 found that the diversity of subterranean macroinvertebrates was negatively impacted by deforestation.

**Fish**

As with macroinvertebrates, the numbers and types of species of fish change predictably as watershed surfaces become impervious. Specifically, a reduction in the number of species is common (Wenger et al, 2008, Wang et al. 2003, Stranko et al. 2008), along with a shift from species that are pollution-intolerant (typically cold-water fish such as trout) to more pollution-tolerant warm-water fish species. Impacts to fish from unmanaged stormwater and unchecked erosion are complex and can involve a combination of physical habitat loss, reduction in water quality (e.g., increases in pesticides, heavy metals, reduction in dissolved oxygen), the development of less suitable and more homogenous flow conditions (e.g., water depth and velocity), and alteration of the type and abundance of food sources. New and emerging compounds, such as 6PPD, an antioxidant used to reduce the breakdown of rubber in tires (see Figure 2-16), have been found to be lethal to salmon species such as Coho Salmon (Greer et al. 2023).

**Figure 2-16 Pathways Through Which the Emerging Contaminant 6PPD Impacts Coho Salmon**




*Source: Greer et al. 2023*

**Flooding Impacts**

Unmanaged stormwater runoff can increase the peak flows and durations of flood events, in some cases dramatically, while severe erosion can cause downstream channels and floodplains to fill with sediment, increasing the frequency of floods. The severity of these impacts depends strongly on existing watershed conditions and the extent of urban development. Stormwater can have negative impacts on several types of flooding. These impacts are additive with the effects of climate change, which in Virginia include increases in precipitation depth and frequency. Flooding impacts range from operational delays (e.g., road closures) to major loss of life and property as well as psychological stress.

Localized/Nuisance Flooding

Localized flooding often occurs when storm inlets, drains, and pipes are insufficiently sized to handle local runoff from streets, rooftops, and other impervious surfaces. This may cause temporary ponding within roadways and adjacent properties. A lack of maintenance of stormwater infrastructure can further worsen localized flooding as stormwater inlets and pipes may become partially or completely filled with debris, leading to a loss of capacity.

Riverine Flooding

Riverine flooding occurs when floodwater overtops the banks of streams and rivers causing flow to spill out onto the adjacent land surface, commonly referred to as a floodplain. Unmanaged stormwater can significantly increase the duration, frequency, and severity of riverine flooding. Small streams draining highly urbanized environments can become “flashy” with dramatic increases in flow depths that quickly lead to dangerous conditions for pedestrians and motorists. Unchecked erosion can lead to the accumulation of sediment within downstream channels, reducing the capacity for conveyance of flood flows.

Coastal Flooding and Compound Events

Coastal flooding occurs when high winds associated with major storms, such as hurricanes and nor'easters, causing an increase in the elevation of tidal waters such as oceans, sounds, estuaries, and tidal rivers. The co-occurrence of coastal flooding and riverine flooding is commonly referred to as compound flooding.

In addition to the flooding types mentioned previously, stormwater can also lead to increases in sinkhole flooding with karst landscapes. Flooding may also be worsened in karst areas if sedimentation reduces the rate at which the karst system can receive runoff.

#### 2.1.3.2.6 Infrastructure Impacts

**Roads, Bridges, and Culverts**

Roads and bridges, despite being hardened infrastructure, are not immune from the challenges that increased stormwater runoff can present. Coupled with the impacts of sea level rise, potential issues that may need to be addressed or may be of concern during the service life may include:

**Roads**

- Pavement saturation, which can reduce service life, pavement degradation through frost heave, potholes, sinkholes, and other issues;
- Rutting asphalt causing irregular ponding and/or drainage patterns; and
- Road closures due to flooding, which in turn impact businesses and emergency service response times.

**Bridges**

- Navigational clearances potentially impacted by increased runoff;
- Loss of freeboard to bridge decking;
- Altered wave loading that may impact bridge footings, piers, and decking;
- Increased corrosion and deterioration of the underside of bridge decking and potential damage to utilities suspended from the undersides of decking; and
- Increased corrosion and risk of mechanical/electrical systems failure due to exposure.

**Culverts**

- Potential for pipe buoyancy, settlement, and joint failure;
- Tidal erosion of end treatments, support foundations; and
- Increased sedimentation.

Impacts to these types of infrastructure can be exacerbated by subsidence and sinkhole formation in karst areas.

**Utilities**

Unmanaged stormwater can pose a significant risk to the condition of linear utilities such as fiber optic, gas, sewer, and electric lines. These impacts are often realized at stream crossings. Specifically, erosional processes, such as bank migration, as well as downcutting of streambeds (see section on geomorphic impacts) can expose or damage utility lines, increasing maintenance costs and operational disruptions. The erosion instigated by unmanaged stormwater can also lead to increased rates of downstream sedimentation, which in turn can result in clogged water intakes and increased water treatment costs.

**Homes and Communities**

Taken collectively, the impacts of unmanaged stormwater and unchecked erosion can have serious economic and social impacts to communities. Stormwater can lead to more severe and more frequent floods, leading to loss of life and property. Stormwater also increases the kind of destruction erosion in stream channels that can undermine bridges, utilities, and other infrastructure. Stormwater also degrades local stream habitats and water quality, meaning fewer recreational opportunities for swimming, fishing, and other water-based activities and increased incidences of waterborne diseases. The effects of unmanaged stormwater can lead to clogged water intakes and increased water treatment costs and can reduce the vitality of commercial seafood harvests. One recent study in New York found that the cost of additional stormwater runoff was approximately $1.20 for each additional cubic foot of runoff (Hellman et al. 2018). Assuming a 10 percent increase in runoff, this equates to about $20,000 of economic impact per acre of developed land.

#### 2.1.3.3 Stormwater As a Resource

Much of this chapter focuses on the negative impacts of unmanaged stormwater and associated impacts of unchecked erosion. Yet, when properly managed, stormwater is a significant natural resource that can provide an inexpensive and sustainable water source for irrigation or other on-site needs including potable and non-potable uses. Stormwater can also feed natural best management practices (BMPs) such as bioretention systems, swales, and wetlands, all of which can serve as landscape amenities within a range of development types.

Keeping stormwater on site, either through infiltration or reuse, can provide significant benefit for communities while keeping downstream habitats healthy and vibrant. This mindset to view stormwater as a resource carries through many of the stormwater site design approaches and BMP design strategies introduced in Chapter 6. Developers and designers who take on this perspective will find creative and practical ways to manage stormwater that offer real benefits for both local residents and the environment.

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# CHAPTER 3 LAWS AND REGULATIONS

**Contents:**

## 3.1 Purpose

This section provides an overview of the Virginia Erosion and Stormwater Management Act, §§ 62.1-44.15:24 through 62.1-44.15:50 of the Code of Virginia, the Erosion and Sediment Control Law for Localities Not Administering a Virginia Erosion and Stormwater Management Program, §§ 62.1-44.15:55 through 62.1-44.15:66 of the Code of Virginia, the Virginia Erosion and Stormwater Management Regulation, 9VAC25-875-10 et seq., and other associated regulations impacting erosion and sediment control and stormwater management. The intent is to provide an overview of the laws and regulations for Handbook users; particularly developers, designers, and engineers engaged in land development projects. The content here is a summary and should be a starting point for a more detailed review of pertinent laws and regulations.

## 3.2 Virginia Erosion and Stormwater Management Act

Chapters 758 and 68 of the 2016 Acts of Assembly combine the stormwater management requirements in the Stormwater Management Act and erosion and sediment control requirements in the Erosion and Sediment Control Law (ESCL) to create the Virginia Erosion and Stormwater Management Act (VESMA). The VESMA, which became effective on July 1, 2024, requires the Virginia Department of Environmental Quality (VDEQ) to permit, regulate, and control Virginia soil erosion and stormwater runoff. VDEQ may also protect the quality and quantity of state waters from the potential harm of unmanaged stormwater and soil erosion. VDEQ has oversight over all erosion control and stormwater management programs including authority approval for localities that operate either a Virginia Erosion and Stormwater Management Program (a VESMP authority) or a Virginia Erosion and Sediment Control Program (a VESCP authority).

Localities operating a regulated municipal separate storm sewer system (MS4) or administering a Virginia Stormwater Management Program (VSMP) as of July 1, 2017, must adopt and administer a VESMP. Other localities can adopt and administer a VESMP, adopt and administer a VESMP with VDEQ conducting plan review, or continue to administer a VESCP and have VDEQ serve as the VSMP authority as required in § 62.1-44.15:27 of the Code of Virginia. Localities that administer a VESCP are subject to the ESCL for Localities Not Administering a Virginia Erosion and Stormwater Management Program, which is the amended version of the Erosion and Sediment Control Law.

## 3.3 Virginia Erosion and Stormwater Management Regulation

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-10 through 9VAC25-875-1420, effective July 1, 2024) combines the requirements in the Virginia Stormwater Management Program (VSMP) Regulation (9VAC25-870-10 et seq.), the Erosion and Sediment Control Regulations (9VAC25-840-10 et seq.), and Erosion and Sediment Control and Stormwater Management Certification Regulations (9VAC25-850-10 et seq.), all of which were repealed on July 1, 2024. By combining requirements from three regulations into one chapter of the Virginia Administrative Code (VAC) and revising, re-ordering, and clarifying requirements for land-disturbing activities, the Virginia Erosion and Stormwater Management Regulation (the Regulation) provides a framework for the administration, implementation, and enforcement of the VESMA and the ESCL for Localities Not Administering a VESMP. The Regulation also describes the procedures and requirements to be followed concerning permits VDEQ issues under the Virginia Pollutant Discharge Elimination System (VPDES) program.

The Regulation provides flexibility for innovative solutions to erosion control and stormwater management issues. It also establishes VDEQ's procedures for the authorization of a qualifying local program, VDEQ's oversight authorities for an authorized qualifying local program, VDEQ's guidelines for administering a local stormwater management program in localities that choose not to adopt and administer a VESMP, and the components of an erosion and stormwater management program including (but not limited to) erosion control and stormwater management standards.

The Regulation is set out in eight parts. The structure differentiates among programmatic requirements for local authorities (VESMP and VESCP) and VDEQ (as a VSMP authority); technical requirements for owners, operators, developers, engineers, and soil scientists for planning and conducting land-disturbing activities; state agencies, federal entities, and other specified entities that conduct land-disturbing activities per VDEQ-approved standards and specifications; certification requirements for inspectors, plan reviewers, and administrators; VPDES program requirements; and fees. The intent of summarizing the Regulation here is to help users find and focus on conditions that apply to them. Brief descriptions of the contents of each part follow.

### Part I. Definitions Applicable to Virginia Erosion and Stormwater Management Programs and Virginia Erosion and Sediment Control Programs (9VAC25-875-10 through 9VAC25-875-30)

This part provides general terms and definitions applicable and used throughout the Regulation to ensure clarity and consistency. Part I also establishes the July 1, 2022, edition of the Code of Federal Regulations (CFR) as the applicable edition wherever the Regulation cites a federal regulation.

### Part II. Virginia Erosion and Stormwater Management Program (9VAC25-875-30 through 9VAC25-875-200)

This part provides the framework and requirements for a locality that administers a VESMP and VDEQ when it is serving as the VSMP authority for a locality that chooses only to adopt and operate a VESCP. This part includes minimum content for local ordinances; requirements for plan review, long-term maintenance of stormwater management facilities, inspections, enforcement, and reports and recordkeeping; and information about VDEQ's assessment and evaluation of VESMPs. Activities not required to comply with either the VESMA or the ESCL for Localities Not Administering a VESMP, discussed below, are listed in Parts II and III, respectively.

A VESMP is a program established by a VESMP authority for the effective control of soil erosion and sediment deposition and the management of the quality and quantity of runoff resulting from land-disturbing activities to prevent the unreasonable degradation of properties, stream channels, waters, and other natural resources. The program includes local ordinances; rules; permits and land-disturbance approvals; policies and guidelines; technical materials; and requirements for plan review, inspection, and enforcement consistent with the requirements of the VESMA.

A VSMP authority is the VDEQ when administering a VSMP on behalf of a locality that has chosen not to adopt and administer a VESMP.

### Part III. Virginia Erosion and Sediment Control Program (9VAC25-875-210 through 9VAC25-875-370)

This part provides the framework and requirements for a locality that administers a VESCP under the ESCL for Localities Not Administering a VESMP. Like Part II, Part III delineates the roles associated with a VESCP, establishes VDEQ's procedures for approving the administration of a VESCP authority, and includes VDEQ's oversight authority over a VESCP.

A VESCP is a program approved by VDEQ that is established by a VESCP authority for the effective control of soil erosion, sediment deposition, and non-agricultural runoff associated with a land-disturbing activity to prevent the unreasonable degradation of properties, stream channels, waters, and other natural resources and includes such items where applicable as local ordinances; rules; policies and guidelines; technical materials; and requirements for plan review, inspection, and evaluation consistent with the requirements of the ESCL for Localities Not Administering a VESMP.

### Part IV. Certification of VESMP, VSMP, and VESCP Personnel (9VAC25-875-380 through 9VAC25-875-460)

This part provides the framework for the certification requirements and process for personnel who work for a VESMP, VSMP, or VESCP authority. This includes descriptions of each classification, eligibility requirements, information about examinations, and disciplinary actions VDEQ may take against certified individuals for fraud, misrepresentation, and failure to demonstrate reasonable care, judgment, or application of knowledge and abilities.

The VESMA requires the following individuals to obtain and maintain a certificate of competency in the areas of erosion and sediment control or stormwater management:

- Staff of any VESCP authority, VSMP authority, or VESMP authority that administers a VESCP, VSMP, or VESMP as may be applicable;
- Anyone contracted by a VESCP authority, a VSMP authority, or a VESMP authority to perform any or all the functions of that authority; or
- Any state agency, federal entity, or public or private entity authorized to implement approved standards and specifications.

VDEQ will issue certifications to individuals who complete the department-approved training program, which includes obtaining a passing score on the applicable certification examination or otherwise fulfilling the requirements for the following classifications:

- Program administrator for Erosion and Sediment Control (ESC);
- Inspector for ESC;
- Plan reviewer for ESC;
- Combined administrator for ESC;
- Program administrator for Stormwater Management (SWM);
- Inspector for SWM;
- Plan reviewer for SWM;
- Combined administrator for SWM;
- Dual program administrator;
- Dual inspector;
- Dual plan reviewer; and
- Dual combined administrator.

Combined certification means the individual performs the combined duties of the program administrator, inspector, and plan reviewer.

Dual certification means the individual is certified to conduct inspections, plan reviews, or administer ESC and SWM programs.

### Part V. Criteria and Requirements for Regulated Land-Disturbing Activities (9VAC25-875-470 through 9VAC25-875-810)

This part provides the technical criteria and requirements for regulated land-disturbing activities. These include:

- Requirements for stormwater pollution prevention plans, stormwater management plans, and pollution prevention plans;
- Information about applying for permit coverage (if required) and long-term maintenance of stormwater management facilities;
- Soil erosion requirements including erosion and sediment control plan requirements and erosion and sediment control criteria, techniques, and methods as outlined in the Minimum Standards;

- Water quantity and water quality technical criteria including water quality design criteria requirements and compliance, water quantity, offsite compliance options, design storms, hydrologic methods, stormwater harvesting, linear development projects, stormwater management impoundment structures or facilities, and comprehensive stormwater management;
- Grandfathered projects and time limits of applicability projects (the limited conditions under which a project would qualify for grandfathering are set out at 9VAC25-875-490);
- Criteria for land-disturbing activities in Chesapeake Bay Preservation Areas and options for rural Tidewater localities; and
- Additional criteria and requirements for land-disturbing activities by state agencies and federal entities.

"Chesapeake Bay Preservation Area" means any land designated by a local government under Part III (9VAC25-830-70 et seq.) of the Chesapeake Bay Preservation Area Designation and Management Regulations and § 62.1-44.15:74 of the Code of Virginia. A Chesapeake Bay Preservation Area consists of a Resource Protection Area and a Resource Management Area as defined in the Chesapeake Bay Preservation Area Designation and Management Regulations (9VAC25-830).

"Rural Tidewater locality" means any locality that is: (i) subject to the provisions of the Chesapeake Bay Preservation Act and (ii) eligible to join the Rural Coastal Virginia Community Enhancement Authority established by Chapter 76 (§ 15.2-7600 et seq.) of Title 15.2 of the Code of Virginia.

### Part VI. Standards and Specifications Program (9VAC25-875-820 through 9VAC25-875-840)

This part defines the program requirements for any authorized entity to submit standards and specifications to VDEQ per § 62.1-44.15:31 of the Code of Virginia.

As an alternative to submitting soil erosion control and stormwater management plans for its land-disturbing activities, the Virginia Department of Transportation shall and any other state agency or federal entity may submit standards and specifications for its conduct of land-disturbing activities for VDEQ approval.

Electric, natural gas, telephone utility companies, interstate and intrastate natural gas pipeline companies, railroad companies, and authorities created under § 15.2-5102 of the Code of Virginia may also submit standards and specifications for VDEQ approval. The types of projects that are suitable for standards and specifications are limited to: (i) construction, installation, or maintenance of electric transmission and distribution lines, oil or gas transmission and distribution pipelines, communication utility lines, and water and sewer lines; and (ii) construction of the tracks, rights-of-way, bridges, communication facilities, and other related structures and facilities of a railroad company.

### Part VII. Virginia Pollutant Discharge Elimination System (VPDES) Permits (9VAC25-875-850 through 9VAC25-875-1280)

This part provides the framework for the administration, implementation, and enforcement of VDPES permits including:

- General program requirements related to MS4s and land-disturbing activities;
- Permit applications;
- Permit conditions;
- Public involvement;
- Transfer, modification, revocation and re-issuance, and termination of permits;
- Enforcement of permits; and
- Electronic reporting requirements.

The VPDES permit is a document issued by the VDEQ under the State Water Control Law authorizing, under prescribed conditions, the potential or actual discharge of pollutants from a point source to surface waters.

The Construction General Permit, required for most land-disturbing activities that disturb 1 acre or more, or less than 1 acre but are part of a larger common plan of development or sale that disturbs 1 acre or more, is a VPDES permit. The Construction General Permit is a regulation, General VPDES Permit for Discharges of Stormwater from Construction Activities (9VAC25-880-10 et seq.), promulgated by the State Water Control Board. It has a 5-year term. The current permit is effective July 1, 2024, through June 30, 2029.

**Part VIII. Fees (9VAC25-875-1290 through 9VAC25-875-1420)**

This part defines the fee requirements and procedures, including applicability, exemptions, and fee schedules for various permits.

## 3.4 Other Regulatory Requirements Impacting Stormwater Management in Virginia

The VESMP does not limit the applicability of other laws and regulations, which may include those identified in this subsection.

### 3.4.1 State Requirements

- General VPDES Permit for Discharges of Stormwater from Construction Activities (9VAC25-880-10 et seq.), required for stormwater discharges associated with large construction activity and stormwater discharges associated with small construction activity. “Large construction activity” and “small construction activity” are defined in the Regulation at 9VAC25-875-20;
- Chesapeake Bay Preservation Act, §§ 62.1-44.15:67 through 62.1-44.15:79 of the Code of Virginia and the Chesapeake Bay Preservation Area Designation and Management Regulation (9VAC25-830-10 et seq);
- Dam Safety Act §§ 10.1-604.1 through 10.1-613.6 of the Code of Virginia, and the Impounding Structure Regulations (4VAC50-20-10 et seq.), which are promulgated by the Virginia Soil and Water Conservation Board and administered by the Virginia Department of Conservation and Recreation (DCR);
- Virginia Wetlands Law and Regulations administered by the Virginia Marine Resources Commission and local Wetlands Boards (Title 28.2, Chapter 13 of the Virginia Administrative Code, and others);
- VPDES requirements (Title 9, Chapter 31 of the Virginia Administrative Code and federal Clean Water Act requirements administered by VDEQ - 40 CFR Parts 122, 123, 124, 403, and 503);
- Guidance documents issued by VDEQ and other agencies which affect permittees’ stormwater compliance strategies. The documents and memoranda on the Virginia Regulatory Town Hall (https://www.townhall.virginia.gov/) and VDEQ’s webpage interpret existing regulations. Previously issued guidance memos related to the withdrawn VSMP and Erosion and Sediment Control regulations and their content incorporated into this Handbook; and
- Endangered plant and insect species requirements. In 1979, the Endangered Plant and Insect Species Act, §§ 3.2-1000 through 3.2-1011 of the Code of Virginia, mandated that the Virginia Department of Agriculture and Consumer Services conserve, protect, and manage endangered and threatened plant and insect species. The impetus for the legislation was to protect species from extinction throughout all or a significant part of its native range.

### 3.4.2 Federal Requirements

- Section 404 of the Clean Water Act administered by the United States Army Corps of Engineers (USACE) and the United States Environmental Protection Agency (USEPA);
- Section 401 of the Clean Water Act administered by VDEQ and covered under the Virginia Water Protection Permits;
- National Flood Insurance Program administered by the Federal Emergency Management Agency (FEMA), DCR, and local Floodplain Administrators; and
- The U.S. Fish and Wildlife Service and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service share responsibility for administration of the Endangered Species Act (ESA).

# CHAPTER 4 REGULATORY COMPLIANCE PROCESS

**Contents:**

## 4.1 Introduction

This chapter of the handbook provides a roadmap for regulatory compliance, which outlines the process through which delegated authorities apply the Virginia Erosion and Stormwater Management Regulation to various types of development and redevelopment projects.

## 4.2 Jurisdictional Authority

As an applicant implementing a project that is potentially regulated under Virginia Erosion and Stormwater Management Act (VESMA, §§ 62.1-44.15:24 through 62.1-44.15:50 of the Code of Virginia) and Virginia Erosion and Stormwater Management Regulation (Regulation, 9VAC25-875-10 through 9VAC25-875-1420), it is important to understand how jurisdictional authority works. The site's location will determine which entity you work with to attain regulatory compliance. This section will detail the various jurisdictional authorities and the process for obtaining regulatory approval from each.

In cases where a state agency, federal entity, or other specified entity with approved standards and specifications engages in land-disturbing activities, those projects are not subject to local VESMP review. Additional information about standards and specifications is in section 4.2.8 and section 4.3.5.

### 4.2.1 Land-Disturbing Activities

Land disturbance or land-disturbing activities (LDAs) are man-made changes to the land surface that may result in soil erosion or have the potential to change runoff characteristics, including construction activity such as the clearing, grading, excavating, or filling of land as defined in 9VAC25-875-20 and 9VAC25-875-210. Chapter 5 discusses in greater detail which LDAs are regulated, the thresholds that trigger regulatory compliance, and the criteria for compliance.

### 4.2.2 Authorities that Regulate Land-Disturbing Activities

All regulated land disturbance will fall under the jurisdiction of either a Virginia Erosion and Stormwater Management Program authority (VESMP authority), a Virginia Erosion and Sediment Control Program authority (VESCP authority), and/or a Virginia Stormwater Management Program authority (VSMP authority). These authorities administer program rules for new development and/or redevelopment projects.

The type of authority with jurisdiction will vary depending on where a project is located and the type of project. Understanding which authority has jurisdiction for your project is a critical first step in navigating the regulatory compliance framework and will impact your review timeline and process. Sections 4.2.3 through 4.2.6 discuss each type of authority in more detail.

### 4.2.3 Projects Subject to Local VESMP Authority

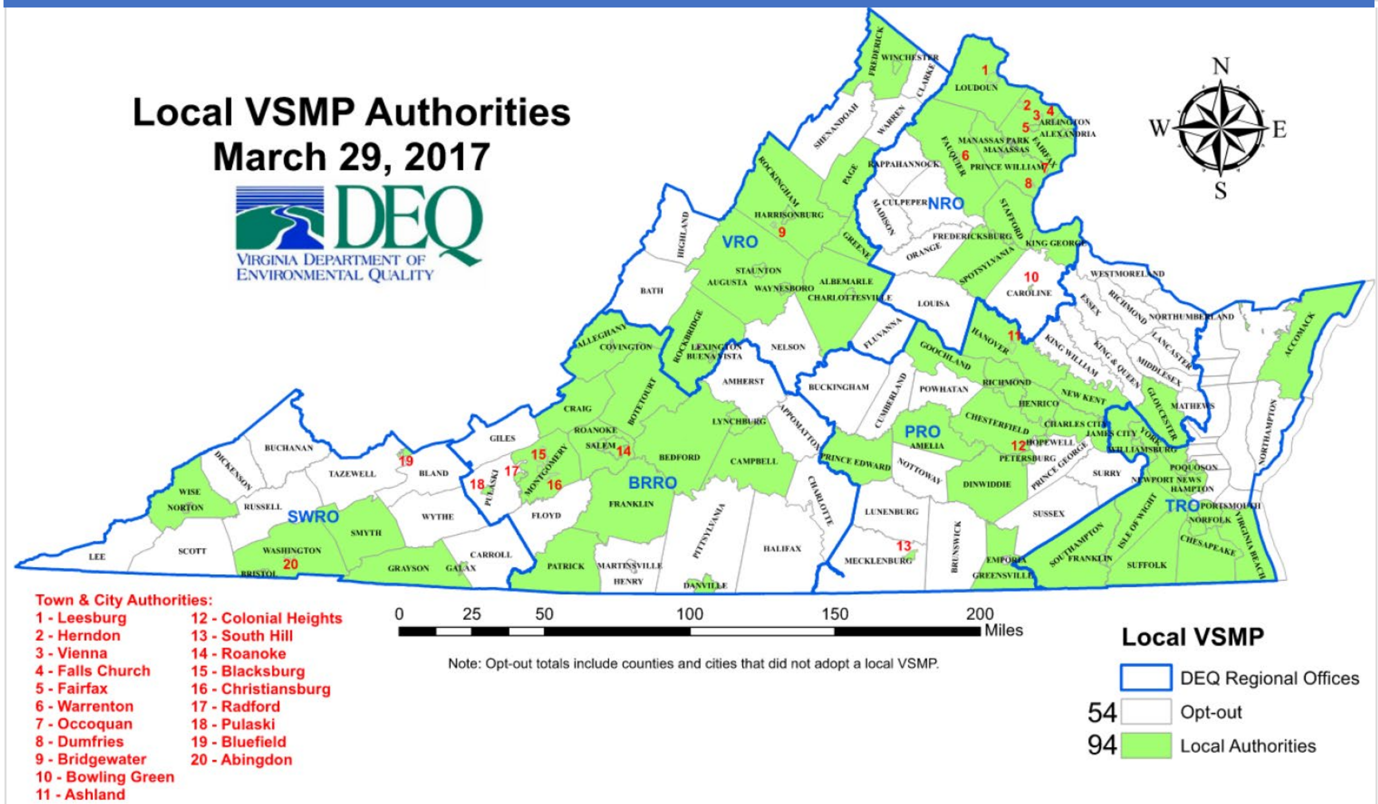
A local VESMP is a program established by a VESMP authority and approved by VDEQ for the effective control of soil erosion and sediment deposition and the management of the quality and quantity of runoff resulting from LDAs to prevent the unreasonable degradation of properties, stream channels, waters, and other natural resources. A VESMP includes local ordinances; rules; requirements for permits and land-disturbance approvals; policies and guidelines; technical materials; and requirements for plan review, inspection, and enforcement consistent with the requirements of the VESMA.

For information on when VDEQ serves as the VESMP Authority, see Section 4.2.4.

Figure 4-1 shows the local Virginia Stormwater Management Program authorities and opt-out localities in Virginia. All of the VSMP authorities have submitted (or will submit) a VESMP to VDEQ for approval after the VESMA becomes effective on July 1, 2024. Figure 4-1 identifies localities that must adopt a VESMP as well as those that, as of January 1, 2024, have the option to adopt a VESMP or continue to operate a VESCP (i.e., "opt out").

A full list of current VESMP Authorities is available on the VDEQ website at:
https://www.deq.virginia.gov/home/showpublisheddocument/8523/637848432776070000

***Figure 4-1 Local VSMP Authorities***




For a development project located in a locality that is a VESMP authority (i.e., not VDEQ), the applicants will typically work directly with the locality throughout the regulatory compliance process for review of the soil erosion control and stormwater management (ESM) plans. A VESMP authority may choose to adopt a streamlined review process, consistent with the process VDEQ follows when it is the VSMP authority.

There may be some cases in which a locality that administers a VESMP has entered into agreements or contracts with soil and water conservation districts, adjacent localities, planning district commissions, or other public or private entities to carry out or assist with plan review and inspections. The developer should consult with the VESMP authority to determine where the plans should be submitted for review and approval.

Erosion and stormwater management programs administered by a locality may include more stringent requirements than the state regulations, and applicants must ensure that they meet the specific requirements of the locality in order to obtain the proper approvals and permits.

### 4.2.4 Projects Subject to VDEQ VESMP Authority

VDEQs is the VESMP authority for all state agencies and federal entities. For qualifying LDAs not covered under approved standards and specifications, erosion and stormwater management (ESM) plans must be submitted directly to VDEQ for review and approval. Entities with approved Standards and Specifications follow an alternative plan review process (see Section 4.3.5) but remain under the jurisdiction of VDEQ as the VESMP authority for administration, compliance, and enforcement (see Section 4.2.8).

Where VDEQ serves as the VESMP authority for plan review and approval, the streamlined review process may also be used (see Section 4.3.4).

VDEQ may also enter into agreements with one or more localities to provide plan review approval where any project may have real or potential multi-jurisdictional impacts (see Section 4.2.7).

### 4.2.5 Projects Subject to Local VESCP Authority

A VESCP is a program approved by the VDEQ that is established by a VESCP authority for the effective control of soil erosion, sediment deposition, and nonagricultural runoff associated with LDAs to prevent the unreasonable degradation of properties, stream channels, waters, and other natural resources.

A VESCP authority is a locality that is approved by the VDEQ to operate a VESCP. Only a locality for which VDEQ administered a VSMP as of July 1, 2017 is authorized to choose to continue to operate a VESCP. All counties and cities identified as opt-out on Figure 4-1 currently operate a VESCP; however, there may be some towns not shown that also operate a VESCP.

For a development project located in a locality that is the VESCP authority (i.e., not VDEQ), applicants will coordinate directly with the VESCP throughout the regulatory compliance process for review and approval of erosion and sediment (ESC) control plans. A VESCP authority may choose to adopt a streamlined review process, consistent with applicable legal requirements and the process VDEQ follows.

For solar project with a rated electrical generation capacity exceeding five megawatts, per § 62.1-44.15:55.1 of the Code of Virginia, the local VESCP may request the VDEQ provide the locality with review of the ESC plan and a recommendation on the plan's compliance with the Regulation. Please note in these cases, the locality is still the VESCP authority in these cases and the applicant will coordinate directly with the VESCP for plan submission and approval.

There may be some cases in which a locality that administers a VESCP has entered into agreements or contracts with soil and water conservation districts, adjacent localities, or other public or private entities to carry out or assist with erosion control plan review, as well as for monitoring, reports, inspections, and enforcement of such LDAs. The developer should consult with the VESCP authority to determine where the plans should be submitted for review and approval.

Projects subject to a local VESCP authority that also meet the LDA threshold to prepare a SWM plan will coordinate with the VESMP or VSMP authority that has jurisdiction for review and approval of the associated SWM plan. This commonly occurs when a locality has opted to only adopt a VESCP and to have VDEQ serve as the VSMP authority. This may also occur when a town acts as the local VESCP authority and is located within a county that has adopted a VESMP authority.

A VESCP authority is authorized to adopt more stringent soil erosion and sediment control ordinance than those necessary to ensure compliance with the regulations, provided the more stringent ordinance meets the requirements specified in § 62.1-44.15:65.A of the Code of Virginia.

### 4.2.6 Projects Subject to VDEQ VSMP Authority

A VSMP is a program established by VDEQ to manage the quality and quantity of stormwater runoff resulting from qualifying LDAs where a locality has opted out of adopting and administering a VESMP program. The program includes items such as: technical design criteria to protect downstream properties; specifications for stormwater management control structures; and requirements for program administration, plan review, inspections, compliance, and enforcement.

Where VDEQ is the VSMP authority, the erosion control plan must be submitted to the locality, as localities are required to act as the VESCP authority. In conjunction with local VESCP review a separate copy of the plans will need to be submitted directly to VDEQ by the applicant for review and approval by VDEQ.

### 4.2.7 Multi-jurisdictional Projects

When LDAs are subject to the jurisdiction of multiple VESMP or VESCP authorities, one or all of the authorities may enter into an agreement with VDEQ to provide review of the erosion control and/or stormwater management plan. If VDEQ conducts the review, a fee may be charged to the jurisdiction(s) requesting the review.

Alternatively, for LDAs within multiple VESMP or VESCP jurisdictions, a program authority may enter into an agreement with an adjacent program authority regarding all or part of the project's administrative procedures. Should adjacent program authorities fail to reach an agreement, each program authority is responsible for the portion of the multi-jurisdictional project that lies within its own jurisdiction.

For all multi-jurisdictional projects, applicants should coordinate with both or all applicable jurisdictions until the lead authority is established.

For plans submitted by federal or state entities involving an LDA across multiple jurisdictions with separate local programs, VDEQ is unable to approve an erosion control plan or stormwater management plan submitted by a state agency or federal entity unless the plan is consistent with the requirements of the state program.

## 4.2.8 Projects Subject to an Approved Standards and Specifications Program

### 4.2.8 Projects Subject to an Approved Standards and Specifications Program

As an alternative to submitting soil erosion control and stormwater management plans for its land-disturbing activities, VDOT shall, and any other state agency or federal entity may, submit standards and specifications for its conduct of land-disturbing activities for VDEQ approval. Electric, natural gas, and telephone utility companies, interstate and intrastate natural gas pipeline companies, railroad companies, and authorities created pursuant to § 15.2-5102 of the Code of Virginia may submit standards and specifications for VDEQ approval that describe how land-disturbing activities shall be conducted. Such standards and specifications may be submitted for the following types of projects:

1. Construction, installation, or maintenance of electric transmission and distribution lines, oil or gas transmission and distribution pipelines, communication utility lines, and water and sewer lines; and
2. Construction of the tracks, rights-of-way, bridges, communication facilities, and other related structures and facilities of a railroad company.

A list of Standards and Specifications (S&S) holders is available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/bmp-design-specifications.

Entities with approved standards and specifications implement an internal plan submission, review, and approval process (see Section 4.3.5) to comply with the regulations. Submission to the individual locality or localities in which the project is located may not be required; however, approval of standards and specifications by VDEQ does not relieve the owner or operator of the duty to comply with any other applicable local ordinances or regulations. In these cases, VDEQ serves as the VESMP authority for administration and may conduct compliance inspections and take enforcement actions.

CGP coverage must be obtained prior to commencement of qualifying land disturbing activities. Each land- disturbance project requires a site-specific approved ESM plan and pollution prevention plan.

Eligible entities that want to conduct LDAs under a standards and specifications program may complete and submit the Standards and Specifications Entity Agreement, which is in Appendix J of the Handbook, for VDEQ review and approval of their program.

The Standards and Specifications Agreement is consistent with section 62.1-44.15:31 D of the Code of Virginia and includes conditions for the following requirements in the standards and specifications program:

- Technical criteria to meet the requirements of the VESMA and regulations developed under it;
- Provisions for the long-term responsibility and maintenance of any stormwater management control devices and other techniques specified to manage the quantity and quality of runoff;
- Provisions for administration of the standards and specifications program, project- specific plan design, plan review and plan approval, and construction inspection and compliance;
- Provisions for ensuring that personnel and contractors assisting the owner in carrying out the LDA obtain training or qualifications for soil erosion control and stormwater management;
- Provisions for ensuring that personnel implementing approved standards and specifications pursuant to the VESMA obtain certifications or qualifications comparable to those required for VESMP personnel;
- Implementation of a project tracking system that ensures notification to VDEQ of all LDAs covered under the VESMA; and
- Requirements for documenting onsite changes as they occur to ensure compliance with the requirements of the VESMA.

All approved Standards and Specifications Agreements will be periodically updated according to a schedule to be established by the VDEQ and will be consistent with the requirements of the VESMA. Approval of an entity's Standards and Specifications Agreement by VDEQ does not relieve the owner or operator of the duty to comply with any other applicable local ordinances or regulations. For state and federal land-disturbing activities, 9VAC25-875-590 establishes responsibility for the operation and maintenance of SWM facilities shall remain with the state agency or federal entity and will pass to any successor or owner. At a minimum, an SWM facility will be inspected by the responsible state agency or federal entity annually and after any storm that causes the capacity of the facility’s principal spillway to be exceeded. During construction of the stormwater management facilities, VDEQ is required to make inspections on a random basis (9VAC25-875-590).

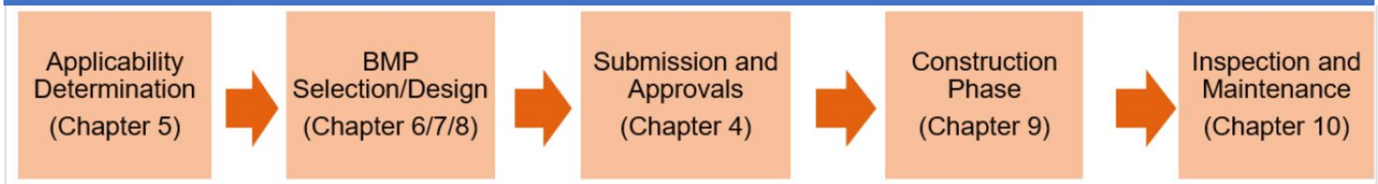
If a state agency does not have an approved Standards and Specifications Agreement, it must submit a plan to VDEQ as described in Section 4.2.4 for review and approval before starting land disturbance.

## 4.3 Regulatory Compliance Process Roadmap

The Regulatory Roadmap (Figure 4-2) provides a pathway for applicants to navigate the regulatory submission and approval process for projects in any locality, whether it is a VESMP authority or a VESCP authority with VDEQ as the VSMP authority. Additional information about projects subject to approved standards and specifications is provided in Section 4.3.5.

This process includes first determining the applicability of the regulations and determining the specific requirements a project will need to meet, which are addressed in Chapter 5. Once applicability is determined, applicants implement a Stormwater Site Design and best management practice (BMP) design process to comply with the requirements. Specific techniques for Stormwater Site Design and BMPs are introduced in Chapter 6, along with a methodology for selecting techniques. Chapters 7 and 8 provide specific design guidance and criteria on each BMP. Following design, applicants will submit plans for approval to the appropriate authority. Details on plan requirements are provided in Section 4.3.3. Once all required approvals and permits are obtained, projects can proceed to construction, which is addressed in Chapter 9. Post-construction activities such as as-builts, permit close-out, and maintenance are covered in Chapter 10.

**Figure 4-2 The Regulatory Roadmap for Virginia Stormwater Projects**




# 4.3.1 Applicability Determination

## 4.3.1 Applicability Determination

The applicability process involves determining what portions of the regulations will apply to your project. This process is described in detail in Chapter 5, but broadly, both the erosion and stormwater management sections of the regulations apply to projects with LDAs that exceed a certain disturbed area threshold. This threshold can vary depending on where a project is located. See Chapter 5 for details on applying these criteria to your project.

Once you have determined what requirements apply to your project, applicants can develop a site-scale compliance strategy, which is described in Section 4.3.2.

## 4.3.2 Stormwater Site Design and BMP Selection

There are many tools and design options for complying with the regulations. Chapter 6 introduces applicants to the Stormwater Site Design and BMP selection process, the stepwise design process by which strategies for compliance with the regulations are chosen. This process starts with considering options for minimizing the impact of the site design itself and proceeds to the use of design strategies to manage erosion, sediment, and stormwater generated by the proposed site design elements. Details and requirements for designing Construction and Post-Construction BMPs features are provided in Chapters 7 (for Construction) and 8 (for Post-Construction).

### 4.3.2.1 Principles for Site Design, Erosion and Sediment Control, and Stormwater Management (Stormwater Site Design)

As applicants work through the Stormwater Site Design process, it is important to understand and apply core principles that reflect VDEQ's preferred strategy for complying with the regulations. These principles emphasize minimizing the creation of additional stormwater runoff, erosion, and sediment during site layout first and implementing runoff reduction (RR) practices to the maximum extent practicable before the use of standardized practices like ponds.

Nearly all new development and redevelopment generates stormwater that has the potential to cause harm to aquatic ecosystems and exacerbate flooding. Thus, implementing stormwater management systems effectively is essential to developing land in ways that minimize the impacts from uncontrolled runoff on existing properties and natural resources.

The VESMA and Virginia Erosion and Stormwater Management Regulation (9 VAC25-875, Regulation) promote the preservation and/or simulation of natural rainfall and natural runoff processes in meeting the requirements for both:

- Water quantity (in terms of restricted stormwater discharge rates and runoff volume reduction for channel and flood protection), and
- Water quality (in terms of restricting total phosphorus loads associated with runoff using RR and other treatment practices).

VDEQ's requirements for all new or re –development projects are to replicate the natural rate and volume of runoff to the greatest extent practicable and maintain or improve upon existing natural drainage systems. This means first addressing the potential for the development to generate stormwater, erosion, and sediment through Stormwater Site Design. Chapter 6 provides an in-depth set of Stormwater Site Design strategies that designers should aggressively employ before considering BMPs. Once this has been completed, the remaining impacts can be addressed using construction and post-construction BMPs. Selection of BMPs can be daunting, as there are many, each with its own set of design criteria, benefits, and siting criteria. The latter sections of Chapter 6 introduce the designer to the suite of BMPs approved for use in Virginia and assist the designer in choosing the best BMPs for a particular site.

#### 4.3.2.2 The Virginia Runoff Reduction Method – Demonstrating Compliance

The Virginia Runoff Reduction Method (VRRM) is the computational framework through which designers demonstrate that the site and BMP design meet the water quality technical criteria that apply to a particular project. The VRRM spreadsheet allows designers to iterate through multiple combinations of Stormwater Site Design and BMPs in ways that are consistent with VDEQ's standards. Appendix B provides further detail on the VRRM.

#### 4.3.2.3 Reducing Pollutant Loads and Beyond

In order to comply with the Regulation, most projects will need to demonstrate a significant reduction in pollutant loading. However, the Regulation also requires reducing runoff volume and peak flows. This integrated approach is captured within the VRRM methodology.

As with past regulations, the reduction of pollutant loads remains the chief compliance metric for those projects required to comply with the technical criteria for both water quality and water quantity. The difference is that runoff volume reduction is now an important – and in some cases a necessary – strategy to achieve the required pollutant load reductions. Runoff volume reduction is also linked with the channel and flood protection criteria in the Regulation (9VAC25-875-600) which applies to all projects subject to the erosion and sediment control criteria, techniques, and methods: minimum standards (9VAC25-875-560). There is still a need to model the peak discharge and hydrologic and hydraulic response characteristics of the developed watershed. However, the hierarchy of treatment objectives to achieve the water quality requirements starts with runoff volume reduction. Many water quality BMPs also provide runoff volume reduction.

#### 4.3.2.4 Karst Considerations

Chapter 6 provides site-specific considerations for development projects in areas that may contain karst features. An in-depth set of Stormwater Site Design strategies for sites in karst areas that designers should employ is included in Appendix E of this handbook.

Due to the nature of karst features, VDEQ will, and local VESMP authorities are expected to carefully consider plans for permanent stormwater management impoundment structures or facilities that will be constructed in areas with karst features. Completion of a geotechnical investigation that identifies any necessary modifications to the BMP will help ensure its structural integrity and maintain its water quality and quantity efficiencies.

#### 4.3.2.5 Erosion Control and Stormwater Management Plan Development

A Soil Erosion Control and Stormwater Management (ESM) Plan describes methods for controlling soil erosion and managing stormwater in accordance with the requirements adopted pursuant to the VESMA. The ESM plan consists of both an ESC Plan and a SWM plan, as each is described in this chapter.

The ESM Plan could be part of a larger plan set that includes other land development requirements (e.g., potable water and sanitary sewer requirements for the local jurisdiction).

#### 4.3.2.6 ESC Plans

An ESC plan contains material for the conservation of soil and water resources of a unit or group of units of land. It may include maps, a soil and water plan inventory and management information with necessary interpretations, and a record of decisions contributing to conservation treatment.

##### 4.3.2.6.1 ESC Plan Components

For an ESC plan to be considered adequate, it must meet the Soil Erosion Requirements in Article 2 of Part V of the Regulation. This includes satisfying the minimum standards specified in 9VAC25-875-560, complying with more stringent local standards as applicable, and including all applicable ESC measures. The Handbook contains standard details and specification of applicable ESC measures. Adequate plans provide sufficient information to assure the plan-approving authority that potential problems of erosion and sedimentation have been adequately addressed.

The length and complexity of the plan should be commensurate with the size of the project, the severity of site conditions, and the potential for off-site impacts. Obviously, a plan for constructing a house on a single subdivision lot will not need to be as complex as a plan for shopping center development. Plans for projects undertaken on flat terrain will generally be less complicated than plans for projects constructed on steep slopes where erosion potential is greater. A multi-phased ESC plan addressing the pre-development, interim grades, and post-development drainage patterns may also be required by a locality to address complex site conditions.

An adequate ESC plan consists of two parts: (1) Narrative, which describes the project in paragraph form; and (2) Illustrative, which shows the project development on map sheets.

Components to be included in the narrative portion typically include:

- A description of the nature and purpose of the LDA and the acreage to be disturbed;
- A discussion on the existing topography, vegetation, and drainage onsite;
- A description of adjacent areas such as streams, lakes, residential areas, roads, and other features;
- Information on any LDAs that will occur offsite (including borrow sites, stockpiles) associated with the project;
- A brief description of the soils on the site including soil name, mapping unit, erodibility, permeability, depth, texture, and soil structure;
- A note of areas onsite that have potentially critical problems (such as steep slopes, channels, wet weather/underground springs, and other features);
- Description of any local, state, or federal permits obtained or applied for;
- A description of the ESC measures that will be used onsite;
- Construction sequence(s) (where installation of ESC measures is one of the first steps);
- A description, including specifications, of how the site will be permanently stabilized following construction;
- A summary of water quantity compliance methods to:

- Meet channel protection requirements;
- Meet flood protection requirements;
- Address increases in sheet flow; and
- Define limits of analysis.

- Calculations for:
  - Water quantity compliance;
  - Design of temporary sediment basins, diversions, and other measures;
  - Design of permanent stormwater detention basins, channels, and other measures; and
  - Pre- and post-development runoff.
- A schedule of regular inspections and repair of ESC structures, as well as who is responsible for that maintenance.

***Figure 4-3 ESC Plan Narrative Components***


Components to be included in the illustrative portion typically include:

- A vicinity map to show the site in relation to the surrounding area;
- North arrows on all maps;
- Limits of clearing and grading;
- Existing contours (represented in dashed or lighter gray lines) to examine pre-development drainage areas, evaluate critical areas, determine where cut and fill is needed, and determine locations for proposed ESC measures;
- Proposed final contours to provide information on changes to the drainage patterns of the site, cut and fill, steep slopes, and allow for the determination of stormwater discharge from the site;
- Adjacent areas, both upstream and downstream of the site;
- Locations and types of existing vegetation;
- A soils map to show the boundaries of the different soil types noted in the narrative;
- Existing drainage patterns with dividing lines and flow arrows;
- Critical areas matching the narrative should be shown on a map;
- Locations of all existing easements;

- All improvements to be built onsite such as buildings, parking lots, access roads, utility construction, and other components;
- Locations of all ESC (and SWM) practices proposed onsite;
- Locations of off-site areas to be disturbed with this project; and
- Detailed drawings for any structural practices to be used.

***Figure 4-4 ESC Plan Illustrative Components***


### 4.3.2.3.2 ESC Variances

The VESCP or VESMP authority may waive or modify any of the requirements that are deemed inappropriate or too restrictive for site conditions by granting a variance (9VAC25-875-350 (VESCP); 9VAC25-875-170(VESMP)). Variance requests are considered judiciously, and VESCP or VESMP authorities take a conservative, responsible approach when they approve variances. Some paramount considerations are the protection of downstream properties and the environment from damage due to soil erosion, sediment deposition, and non-agricultural runoff. Variances should only be approved when they are reasonable and supported by site-specific rationale.

1. A variance may be granted under these two conditions:

   At the time of plan submission, an applicant can request a variance as a part of the approved ESC plan provided that the:

   - Applicant explains reasoning to VESCP or VESMP authority in writing.
   - VESCP or VESMP authority approves or disapproves the variance and documents the variance on plans.
2. During construction, the person responsible for implementing the approved plan can request a variance provided that:
   - The request is made in writing to VESCP or VESMP authority.
   - VESCP or VESMP authority approves or disapproves the request in writing.

If there is no response from the VESCP or VESMP authority within 10 days, the request is disapproved.

An applicant may resubmit a variance request with additional documentation.

### 4.3.2.7 SWM Plans

An SWM Plan describes methods for complying with the requirements of a VESMP or VSMP. An SWM Plan for an LDA will apply the stormwater management technical criteria set forth in the Regulation to the entire LDA. Individual lots in new residential, commercial, or industrial developments, including those developed under subsequent owners, will not be considered separate LDAs (9VAC25-875-510).

#### 4.3.2.7.1 SWM Plan Components

A SWM plan will be developed and submitted to the VESMP authority (or VDEQ when acting as the VSMP authority). Per 9VAC25-875-510, for a SWM Plan to be considered adequate, it must include all of the following:

1. Information on the type and location of stormwater discharges, information on the features to which stormwater is being discharged (including surface waters or karst features if present), and pre- and post- development drainage areas;
2. Contact information including the name, address, telephone number, and email address of the owner and the tax reference number and parcel number of the affected property(s);
3. A narrative that includes a description of current and final site conditions;
4. A general description of the proposed SWM facilities and the mechanism through which the facilities will be operated and maintained once construction is complete;
5. Information on the proposed SWM facilities including:
    a. A detailed narrative on the conversion to a long-term stormwater management facility if the facility was used as a temporary ESC measure;
    b. The type of facilities;
    c. Location (including geographic coordinates);
    d. Acres treated; and
    e. The surface waters or karst features into which the facility will discharge.
6. Hydrologic and hydraulic computations including runoff characteristics;
7. Documentation and calculations verifying compliance with the water quality and quantity requirements of the regulations;
8. A map of the site that depicts the topography of the site and includes:
    a. All contributing drainage areas;
    b. Existing streams, ponds, culverts, ditches, wetlands, other water bodies, and floodplains;
    c. Soil types, geologic formations (if karst features are present in the area), forest cover, and other vegetative areas;
    d. Current land use including existing structures, roads, and locations of known utilities and easements;
    e. Sufficient information on adjoining parcels to assess the potential impacts of stormwater from the site on these parcels;
    f. The limits of clearing and grading and the proposed drainage patterns on the site;
    g. Proposed buildings, roads, parking areas, utilities, and SWM facilities; and
    h. Proposed land use, with a tabulation of the percentage of surface area to be adapted to various uses including planned locations of utilities, roads, and easements.
9. If an operator intends to meet the requirements established I 9VAC25-875-580 or 9VAC25-875-600 using offsite compliance options, where applicable, then a letter of availability from the offsite provider must be included.

10. If payment of a fee is required with the SWM Plan submission by the VESMP authority, the fee and the required fee form in accordance with Part VIII (9VAC25-875-1290 et seq.) must be submitted.

***Figure 4-5 SWM Plan Required Components***


### 4.3.2.7.2 SWM Exceptions

Per 9VAC25-875-170, a request for an exception from the technical criteria of the regulations may be submitted in writing to the VESMP authority or the VSMP authority. The reason for making such request must be provided in detail. The VESMP or VSMP authority may grant exceptions to the technical requirements provided all the following conditions are met:

- The exception is the minimum necessary to afford relief.
- Reasonable and appropriate conditions are imposed so that the intent of the VESMA and regulations is preserved.
- Granting the exception will not grant any special privileges that are denied in other similar circumstances.
- Exception requests are not based on conditions or circumstances that are self-imposed.

Exceptions must not be granted for:

- Economic hardship alone;
- The requirement that the LDA obtain required state permits;
- Use of a water quality BMP not found on the Virginia Stormwater BMP Clearinghouse, except where allowed under 9VAC25-875-670; or
- The requirements for phosphorus reductions, unless off-site options have been considered and found unavailable.

## 4.3.3 Plan Submission and Approval Process

The next step in the regulatory compliance process is to submit plans for review and approval to the appropriate authorities. LDAs cannot begin until the required plans have been reviewed and approved by the VESMP or VESCP authority and VSMP authority. As a reminder, in some areas, the locality serves as the VESMP authority, but in other areas, VDEQ may serve as the VSMP authority and the locality as the VESCP authority (See Section 4.2). Many local jurisdictions also have their own requirements and timelines for submission and approval. We recommend contacting the locality where the LDA will occur for specific details on submissions, review, and approvals processes.

Figure 4-6 provides an example of the regulatory submission and approval process that traditional development project applicants typically follow when thresholds for both ESC and SWM requirements of the regulations are triggered.

***Figure 4-6 Regulatory Submission and Approval Process: ESC and SWM***


Note that additional steps may be required after plan approval before starting LDAs. These additional requirements and the thresholds for each are further explained the following sections.

There are separate plan submission and approval processes for projects under the streamlined approval process outlined in Section 4.3.4 or implemented through approved standards and specifications as outlined in Section 4.3.5.

#### 4.3.3.1 ESM or SWM Plan Submission, Review, and Approval Timelines

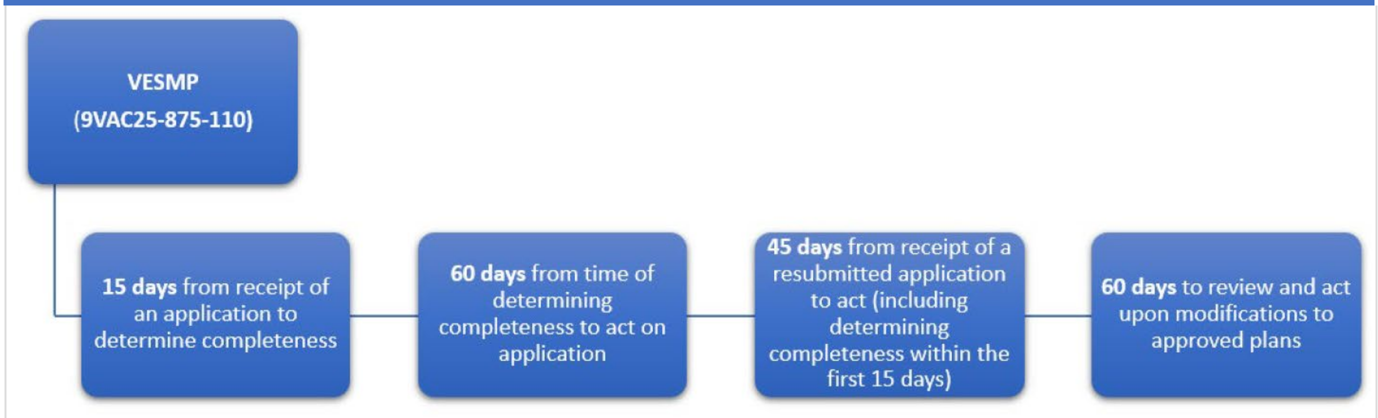
When an ESM or SWM Plan is submitted, a completeness review is conducted to determine if the minimum plan components needed for a technical review are included with the submittal. The VESMP or VSMP authority has 15 calendar days to determine the completeness of the plan in accordance with 9VAC25-875-110 and should notify the applicant, in writing, of its determination. If the plan is not complete, the notification should include the reason(s) why the plan was deemed inadequate.

If a plan is complete and the applicant has been notified within 15 days of submission, the VESMP/VSMP authority has 60 calendar days from the time of notification to review the plan. If no action is taken within the time specified for a plan that meets all the requirements of the Regulation and VDEQ is the VSMP authority, then the plan will be deemed approved.

If VDEQ, when acting as the VSMP authority, does not make a written determination of completeness and communicate it to the applicant within the 15 calendar days, VDEQ will review the plan and notify the operator in writing within 60 calendar days from the date of submission of the decision to approve or disapprove the plan. If the plan is not approved, the reason(s) must be included.

For a plan being resubmitted, the VESMP/VSMP authority has 45 calendar days from the date of resubmission to review it. Figure 4-7 illustrates the response periods for this step.

*Figure 4-7 Response Timeline for Completeness Review: ESM or SWM Plan*




When an operator modifies plans, a VESMP/VSMP should respond in writing with an approval or disapproval for previously approved plans within 60 calendar days. Based on an inspection, the authority may require amendments to the approved ESM or SWM Plan to address any deficiencies. 9VAC25-875-110 E.

A VESMP authority may charge applicants a reasonable fee to defray the cost of program administration for a regulated LDA that does not require permit coverage. Such fee may be in addition to any fee charged pursuant to the statewide fee schedule, although payment of fees may be consolidated in order to provide greater convenience and efficiency. The fee will not exceed an amount commensurate with the services rendered considering the time, skill, and the VESMP authority's expense involved.

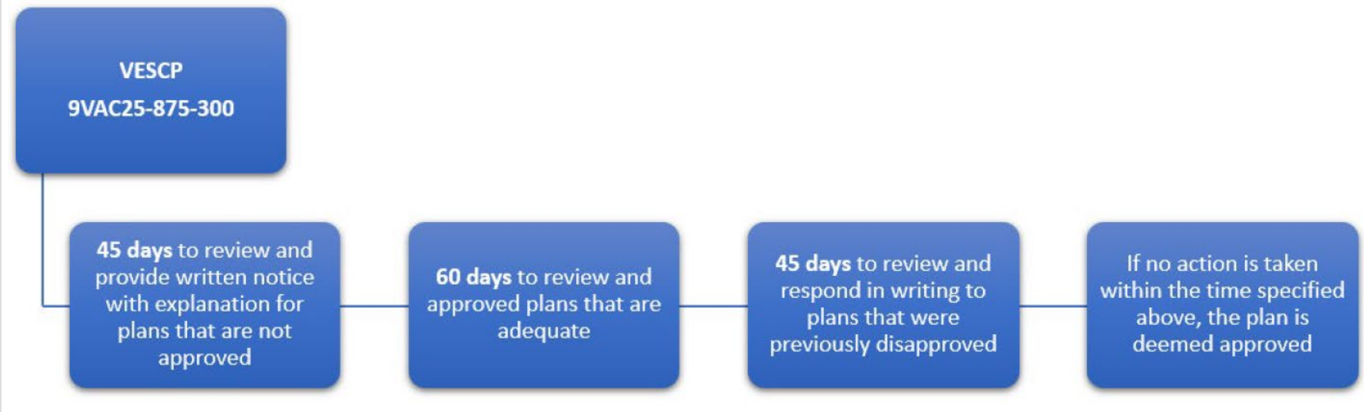
#### 4.3.3.1.1 ESC Plan Submission, Review, and Approval Timelines

Before an LDA can begin on a projects subject only to the Erosion and Sediment Control Law for Localities Not Administering a Virginia Erosion and Stormwater Management Program (ESCL for Localities Not Administering a VESMP), or where the SWM Plan is submitted to VDEQ as the VSMP authority, the VESCP authority must review and approve an ESC Plan, or execute an agreement in lieu of an ESC Plan, if allowed by the VESCP authority, for the construction of a single-family detached residential structure or farm building or structure (see Section 4.3.6).

When determined that the plan meets the minimum criteria, techniques, and methods for erosion and sediment control, the VESCP authority will review erosion and sediment control plans submitted and grant written approval within 60 days of the receipt of the plan.

When the VESCP authority determines a plan is inadequate, written notice stating the specific reasons for disapproval will be communicated to the applicant within 45 days. The notice will specify the modifications, terms, and conditions that are necessary for approval of the plan. If no action is taken by the VESCP authority within 45 days, the plan will be deemed approved, and the proposed activity authorized. This is illustrated on Figure 4-8 and based on 9VAC25-875-300.

**Figure 4-8 Response Timeline for Modification of ESC and SWM Plans**




For sites requiring coverage under the General VPDES Permit for Discharges of Stormwater from Construction Activities (construction general permit or CGP), evidence of such coverage will often be required by the VESCP authority as a pre-requisite to issuance local land disturbance permits. Under the erosion program, an LDA for a project cannot begin until the ESC Plan has been reviewed and approved by the VESCP authority and any applicable permits obtained.

A VESCP authority may charge applicants a reasonable fee to defray the costs of program administration. The fee will not exceed an amount commensurate with the services rendered considering the time, skill, and the VESCP authority's expense involved.

#### 4.3.3.1.2 Administrative Procedures for VDEQ Submissions

Submission of Complete Plans & Digital Data:

- Complete plans and computations ready for construction should be submitted to VDEQ. Advance or preliminary copies of incomplete plans or incomplete computations will not be accepted by VDEQ.
- Normal state work hours are 8:15 am to 5:00 pm. Plans received on or after 5:00 pm will be marked as received the next business day (Monday through Friday, excluding state holidays).
- If produced electronically, an electronic copy in portable document format (PDF) of the required submission materials (e.g., plans, computations, reports, studies) is preferred.

General Standards:

- Cover sheet. The design professional should use the digital cover sheet provided by VDEQ for all plan submissions. The cover sheet in DWG format is posted on the VDEQ website at: https://www.deq.virginia.gov/home/showpublisheddocument/15588/
- Revision block. A revision block should be provided on the cover sheet of the plans. The cover sheet revision block should contain a summary of all revisions made to the plans. All other plan sheets should contain a revision block detailing the revisions applicable to each plan sheet.
- Approval block. An approval block, per the following, should be provided on the cover sheet of the plans.

APPROVAL BLOCK

DEQ PLAN # ____________________

____________________________________
Dept. of Environmental Quality

____________________________________
Date

- Seal and signature. Unless otherwise exempt under § 54.1-401 of the Code of Virginia, the seal, signature, and date of the design professional should be provided on each sheet of the plans. The seal, signature, and date of the design professional should also be provided on the cover pages of all other required submission materials (e.g., computations, reports, studies).

Complete the Plan Submission Checklist in its entirety and include it on the cover sheets of all plans submitted to VDEQ. VDEQ will consider a submission incomplete if an answer is not provided (or indicate "NA" or "not applicable") for all fields on the checklist.

#### 4.3.3.1.3 Additional Requirements

A SWM plan, ESC plan, and ESM plan must be implemented as it was approved and may only be modified with approval by the appropriate VESMP, VESCP, or VSMP authority.

Additional plan review requirements in 9VAC25-875-110 are summarized below. Once the SWM Plan has been approved by the VESMP/VSMP authority, if required, the applicant must submit a Registration Statement to the VESMP/VSMP authority for review. Refer to Section 4.4 for more details.

Before issuance of any land-disturbance approval, the VESMP authority may also require an applicant, excluding state agencies and federal entities, to submit a reasonable performance bond with surety, cash escrow, letter of credit, any combination thereof, or such other legal arrangement acceptable to the VESMP authority. The performance bond and surety will ensure that measures could be taken by the authority at the applicant's expense should they fail (after proper notice, within the time specified) to comply with the conditions imposed by the authority as a result of their LDA (9VAC25-875-110).

The VESMP,VESCP, or VSMP authority may require changes to an approved ESM, ESC, or SWM Plan in the following cases:

- Where inspection has revealed that the plan is inadequate to satisfy applicable regulations or ordinances; or
- Where the owner finds that, because of changed circumstances or for other reasons, the plan cannot be effectively carried out, and proposed amendments to the plan, consistent with the requirements of the VESMA, are agreed to by the VESMP, VESCP, or VSMP authority and the owner.

In order to prevent further erosion, a VESMP, VESCP, or VSMP authority may require approval of an ESM Plan, ESC Plan, and/or an SWM Plan for any land identified as an erosion impact area by the VESMP or VESCP authority.

In addition, as a pre-requisite to engaging in an approved LDA, the name of the individual who will be assisting the owner in carrying out the activity and holds a Responsible Land Disturber certificate pursuant to § 62.1-44.15:30 of the Code of Virginia will be submitted to the VESMP or VESCP authority. Any VESMP or VESCP authority may waive the Responsible Land Disturber certificate requirement for an agreement in lieu of a plan. Failure to provide the name of an individual holding a Responsible Land Disturber certificate before engaging in LDAs may result in revocation of the land disturbance approval and will subject the owner to the penalties established in the VESMA or ESCL for Localities not Administering a VESMP.

#### 4.3.3.1.4 Disclaimer of Liability

Approval of plans by a VESMP authority, VESCP authority, or VSMP authority pursuant to the Regulation, VESMA, ESCL for Localities Not Administering a VESMP, and this Handbook, is not intended and will not be deemed as a guarantee or warranty for any individual, landowner, or developer that any improvements will be designed, planned, constructed, or operated in any particular manner or be free from defects. Such approval will create no duty or result in any liability on the part of the VESMP authority, VESCP authority, or VMSP authority or its employees for any claim, demand, suit, or damages alleged to have resulted from the development, construction, existence, or operation of improvements constructed pursuant to such approved plans. Further, no such approval will operate as or be deemed as an exception to any provision of the VESMA, ESCL for Localities Not Administering a VESMP, or Regulation, unless such exception has been specifically granted in writing by the authority. If any aspect of any such approved plan fails to comply with any provision of the VESMA, ESCL for Localities Not Administering a VESMP, or Regulation in effect at the time of such approval, such provision of the VESMA, ESCL for Localities Not Administering a VESMP, Regulation, or the General Virginia Pollutant Discharge Elimination System (VPDES) Permit for Discharges of Stormwater from Construction Activities will take precedence over the approved plans.

## 4.3.4 Streamlined Review Process

### 4.3.4 Streamlined Review Process

The Streamlined Review Process applies when VDEQ is the plan-approving authority. In these instances, Dual Combined Administrators are permitted to certify plans prepared by a Professional Engineer in Virginia, accelerating the standard plan approval procedure. This process was introduced as a way to reduce delays caused by plan review and to improve the quality of plans submitted for review, and became effective in January 2023. VESMP authorities may adopt these streamlined plan review procedures.

#### 4.3.4.1 Criteria and Process for Streamlined ESC and SWM Plan Review

The streamlined ESC Plan review process only applies when all the following conditions are satisfied:

1. VDEQ is the VESMP authority.
2. The ESC Plan has been prepared by a Professional Engineer licensed to engage in practice in the Commonwealth under Chapter 4 of Title 54.1 of the Code of Virginia. The Professional Engineer must sign, date, and include their seal on the Plan Submission Checklist.
3. The ESC Plan has been prepared in accordance with this Handbook, including all components of Appendix A.

4. The ESC Plan has been pre-reviewed by a person who holds an active certificate as a Dual Combined Administrator for ESC and SWM pursuant to 9VAC25-875-400 E.[1] The Dual Combined Administrator must sign, date, and include their certificate number on the Plan Submission Checklist.[2]
5. The applicant or designer submits with the ESC Plan a complete and accurate Plan Submission Checklist, which includes the specified certifications by the Professional Engineer, Dual Combined Administrator for ESC and SWM, and the owner/operator.

The streamlined SWM Plan review process only applies when all the following conditions are satisfied:

1. VDEQ is the VESMP or VSMP authority.
2. The SWM Plan has been prepared by a Professional Engineer licensed to engage in practice in the Commonwealth under Chapter 4 of Title 54.1 of the Code of Virginia. The Professional Engineer must sign, date, and include their seal on the Plan Submission Checklist.
3. The SWM Plan has been prepared in accordance with this Handbook, including all components of Appendix A.
4. The SWM Plan has been pre-reviewed by a person who holds an active certificate as a Dual Combined Administrator for ESC and SWM pursuant to 9VAC25-875-400 E.[1] The Dual Combined Administrator must sign, date, and include their certificate number on the Plan Submission Checklist.[2]
5. The applicant or designer submits with the SWM Plan a complete and accurate Plan Submission Checklist, which includes the specified certifications by the Professional Engineer, Dual Combined Administrator for ESC and SWM, and the owner/operator.

The streamlined SWM and ESC Plan review process will be initiated when a SWM and/or ESC Plan is received with a completed and signed/sealed Plan Submission Checklist. The VDEQ plan reviewer reviews the Plan Submission Checklist and plan to determine eligibility with the previously enumerated conditions.

Pursuant to 9 VAC 25-875-110, within 15 calendar days of receipt of the SWM or ESC Plan, VDEQ staff should determine if the SWM or ESC Plan is complete (contains elements specified in 9VAC25-875-510 and/or 9VAC25- 875-550). If the SWM or ESC Plan is complete, VDEQ staff should notify the applicant in writing that the SWM or ESC Plan is complete pursuant to 9VAC25-875-110. If no further action is taken 60 calendar days after the written notification of completeness to the applicant, VDEQ staff should inform the applicant that the plan is deemed approved. Otherwise, if VDEQ elects to NOT conduct a completeness review during that initial 15-day period and relies upon the certification by the Professional Engineer and Dual Combined Administrator for ESC and SWM, the 60-day period for streamlined approval will commence upon receipt of the SWM or ESC Plan.

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[1] 9VAC25-875-400 E provides: “Any person who holds a valid and unexpired certificate of competence issued by the board in the classification of ESC or SWM, or who obtains such a certificate, and who later successfully obtains an additional certificate of competence from the board in the parallel ESC or SWM classification may surrender both certificates of competence to the board and request in writing issuance of a dual certificate showing certification in both classifications. Such a request must be made while both of the ESC and SWM certificates of competence obtained are valid and unexpired. The expiration date of the dual certificate shall be three years from the date of expiration of the additional certificate acquired.” Although Professional Engineers are already considered ESC Plan reviewers, for purposes of this streamlined plan review process, a Professional Engineer fulfilling the role of a Dual Combined Administrator for ESC and SWM must have completed the ESC Plan Reviewer training class.

[2] The Dual Combined Administrator for ESC and SWM may be the same person as the licensed design professional who prepared the plan. As noted above, although Professional Engineers are already considered ESC Plan reviewers, for purposes of this streamlined plan review process, a Professional Engineer fulfilling the role of a Dual Combined Administrator for ESC and SWM must have completed the ESC Plan Reviewer training class.

#### 4.3.4.2 Further Review, Audit, Compliance, and Enforcement

VDEQ retains its authority to further review any SWM and ESC Plan submitted under the streamlined SWM and ESC Plan review process and, under its discretion, require modification or re-submittal under the general plan review process. For purposes of this guidance, the 60-day period will be considered the "Audit Period." During the Audit Period, VDEQ may review plans and will provide all comments to the applicant for resubmission and further review. Plans for audit review will be selected by VDEQ based on workload and project risk level. Project risk level will be determined by looking at project disturbance area,[3] percentage of disturbed land with higher risks for erosion,[4] and the percentage of impervious cover.[5] For each of these factors, 30 points will be assigned if the site is high risk, 20 points will be assigned if the site is medium risk, and 10 points will be assigned if the site is low risk. Points for all three factors (project disturbance area, percentage of disturbed land with higher risks for erosion, and the percentage of impervious cover) will be added together to calculate a cumulative project risk level. VDEQ will prioritize plans with the highest cumulative project risk levels for audits, and will proceed in descending numerical order to audit additional plans based on workload availability. In addition, sites with lower cumulative project risk levels will be randomly selected for audits as workload availability allows.

If, during a compliance inspection or investigation, VDEQ staff observes deficiencies in the SWM and/or ESC Plan or impacts to the environment because of an SWM and/or ESC Plan deficiency, VDEQ may require a modification to the SWM and/or ESC Plan. VDEQ retains its authority to elevate violations to enforcement for resolution, and approval through this streamlined SWM and/or ESC Plan review process does not waive any responsibility of the permittee/owner.

If VDEQ observes a trend of deficient SWM and/or ESC Plans that were reviewed by the same Dual Combined Administrator for ESC and SWM, VDEQ reserves the authority to suspend, revoke, or refuse to grant or review the certification pursuant to the process provided in 9VAC25-875-460 and no longer accept that Dual Combined Administrator for ESC and SWM's Certification for the streamlined review unless that person retakes all six required classes and passes the related tests to receive a new certification number. For Professional Engineers, VDEQ will notify the Virginia Department of Professional and Occupational Regulation (DPOR) for their review. For purposes of this guidance, VDEQ defines a trend of deficiency as:

a. Five incomplete review checklists; and/or
b. Three plan reviews that generate comments deemed significant enough to require resubmission in lieu of plan approval.

Qualifying for the streamlined SWM and ESC Plan review process does not alleviate the permittee/owner from the obligation to comply with any statute, regulation, permit condition, VDEQ Guidance, memo or Letter to Industry from VDEQ, Technical Bulletin, other order, certificate, certification, VDEQ Manual, standard, or other applicable requirements.[6]

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[3] For purposes of this guidance, as a rule of thumb, if the project disturbance area is greater than 25 acres, then VDEQ will consider the site to be high risk, if the project disturbance area is greater than or equal to 5 acres but less than or equal to 25 acres, then VDEQ will consider the site to be medium risk, and if the project disturbance area is less than 5 acres, then VDEQ will consider the site to be low risk.

[4] For purposes of this guidance, as a rule of thumb, if greater than 25% of the Limits of Disturbance (LOD) is Highly Erodible Lands (HEL) as defined by the NRCS, then VDEQ will consider the site to be high risk, if 10-25% of the site is HEL then VDEQ will consider the site to be medium risk, and if less than 10% of the site is HEL, then VDEQ will consider the site to be low risk.

[5] For purposes of this guidance, as a rule of thumb, if greater than 25% of the Limits of Disturbance (LOD) is impervious (including unconnected impervious area), then VDEQ will consider the site to be high risk, if 10-25% of the site is impervious then VDEQ will consider the site to be medium risk, and if less than 10% of the site is impervious, then VDEQ will consider the site to be low risk.

[6] This includes documents issued or promulgated initially by the Department of Conservation and Recreation or Soil and Water Conservation Board before the SWM program moved to VDEQ and the State Water Control Board in 2014.

### 4.3.5 S&S Plan Submission, Review, and Approval

Projects conducted under a VDEQ-approved approved Standards and Specifications Agreement (as described in Section 4.2.8) are not required to submit ESM Plans for LDAs to the individual locality in which the project is located. These S&S projects have an internal plan submission, review, and approval process for ESM Plans and obtaining permit coverage before commencement of LDAs.

Some agencies with large numbers of active construction sites, such as Virginia Department of Transportation (VDOT), may keep their inspections and plan review services in house with their own employees rather than engaging a contracted consultant. This varies by agency or entity. For more details on the process, refer to the entity-specific S&S program associated with a project.

S&S entities may also request an ESC variance or an exception from the SWM technical criteria of the regulations (see Sections 4.3.2.6.2 (variances) and 4.3.2.7.2 (exemptions)). These requests must be submitted to and approved by the VDEQ Central Office before implementation.

### 4.3.6 Agreements in Lieu of A Plan

"Agreement in lieu of a plan" is a contract between the VESMP authority, VESCP authority, or VDEQ acting as a VSMP authority and the owner or permittee that specifies methods to be implemented to comply with the requirements of VESMA for the construction of:

- A single-family detached residential structure; or
- A farm building or structure on a parcel of land with a total impervious cover percentage, including the impervious cover from the farm building or structure to be constructed, of less than 5 percent.

For a single-family detached residential structure with less than 1 acre of land disturbance, an agreement in lieu of a plan may be used when:

- It is located within a common plan of development or sale with an approved stormwater pollution prevention plan consistent with 9VAC25-875-500 and a permit, if required; or
- The single-family detached residential structure is located outside of a common plan of development or sale.

Such contract may be executed by the VESMP authority in lieu of an ESC and SWM Plan, by the VESCP authority in lieu of an ESC Plan, or by the VDEQ acting as a VSMP authority in lieu of an SWM Plan. 9VAC25-875-290 and 9VAC25-875-530.

## 4.4 Construction Phase

Before any LDA that affects more than the areas specified in Chapter 5 can begin, the owner/operator for a project needs to have approval from the appropriate VESMP, VESCP, or VSMP authority. Depending on the projected area for LDA, an ESC Plan may need to be reviewed and approved by the VESCP authority; the SWM plan may need to be reviewed and approved; and submission of a registration statement for coverage under the CGP may be necessary. Once all of the proper approvals and permits have been acquired, construction can begin. General regulatory requirements during construction are covered in subsequent sections, and other considerations for construction are covered in greater detail in Chapter 9.

During construction, there are often extreme changes in land cover and drainage patterns. This is when most erosion occurs due to the exposed soil onsite. Consequently, compliance with the approved plan is crucial. A multi-phased ESC Plan addressing the pre-development, interim grades, and post-development drainage patterns is essential to prevent sedimentation and to ensure the measures are properly functioning within their design parameters as well as to show how ESC controls will need to be relocated or adapted as construction proceeds. It is also critical that the Stormwater Pollution Prevention Plan (SWPPP) is updated during construction as the land disturbance progresses. The SWPPP is described more in the following sections.

In the context of stormwater associated with a construction activity, an operator is any person associated with a construction project that meets either of the following criteria:

- The person has direct operational control over construction plans and specifications, including the ability to modify those plans and specifications.
- The person has day-to-day operational control of those activities at a project that are necessary to ensure compliance with a SWPPP for the site or other permit or VESMP authority permit conditions (i.e., they are authorized to direct workers at a site to carry out activities required by the SWPPP or comply with other permit conditions).

LDAs must be carried out by an individual who holds a Responsible Land Disturber certificate pursuant to § 62.1-44.15:30 of the Code of Virginia. This person may or may not also be the operator.

### 4.4.1 Stormwater Pollution Prevention Plan

The SWPPP is the cornerstone of the stormwater program. All of the requirements for the SWPPP that are outlined in this section are in 9VAC25-875-500 and the CGP, 9VAC25-880-70 Part II. Each SWPPP must be site- specific, address the potential sources of pollution that may be generated during and after construction, and be updated throughout construction.

The SWPPP, including copies of the signed registration statement, notice of coverage letter, and permit, must be available at a central location onsite for use by those identified as having responsibilities under the SWPPP whenever they are on the construction site. The SWPPP must also be available upon request for the VESMP authority, locality, VDEQ, S&S inspector, or a member of the public to review. If an onsite location is unavailable when construction site personnel are not present, notice of the SWPPP's location must be posted near the main entrance of the site. The SWPPP must be available for public review in an electronic format or in hard copy. If the SWPPP is not provided electronically, public access to the SWPPP may be arranged upon request at a time and at a publicly accessible location convenient to the operator.

VESMP authority and VDEQ inspectors will review an operator's SWPPP during construction to confirm it has the required documentation. The SWPPP requirements may be fulfilled by referencing other plans such as a spill prevention control and countermeasure plan. All plans incorporated by reference into the SWPPP become enforceable under the CGP. If a plan incorporated by reference does not contain all the required elements of the SWPPP, the operator must develop the missing elements and include them in the SWPPP.

### 4.4.1.1 SWPPP Components

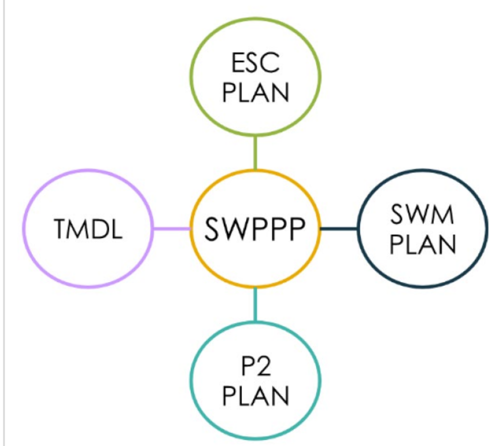
The SWPPP includes (Figure 4-9):

1. An approved ESC plan;
2. An approved SWM plan;
3. A Pollution Prevention (P2) Plan*; and
4. Description of any additional control measures necessary to address a total maximum daily load (TMDL).

** The P2 plan is typically not required for Chesapeake Bay Preservation Act LDAs, but this may vary by locality.*

Construction that is part of a larger common plan of development or sale and disturbing less than 1 acre may use a SWPPP template provided by VDEQ or VESMP authority and need not provide a separate SWM Plan if one has been prepared and implemented for the larger common plan of development or sale.

**Figure 4-9 General Components of a SWPPP**




### 4.4.1.2 P2 Plan Contents

The P2 Plan is a part of the SWPPP. Per 9VAC25-875-520, it must address potential pollutant-generating activities that may reasonably be expected to affect the quality of stormwater discharges from a construction activity including any support activity. As a component of the SWPPP, the P2 Plan needs to be developed before land disturbance commences and updated throughout the construction process. The P2 Plan is a “living” document that should be amended, revised, modified, and updated to prevent pollution of stormwater from construction as operations change and need to be addressed onsite. This will be monitored, as the SWPPP and all its components will be reviewed by the VESMP authority inspector throughout the permitted LDA.

The P2 Plan will:

- Identify any potential pollutant-generating activities.
- Identify the pollutants expected to be exposed to stormwater.
- Describe the location at which the potential pollutant-generating activities will occur.
- Identify all discharges that are or will be commingled with stormwater discharges from the construction including any applicable support activities.
- Identify the person responsible for implementing the pollution prevention practice(s) for each pollutant- generating activity.
- Describe measures to be implemented to minimize or prevent pollution discharge (as follow):

## Prohibition of Discharges

P2 measures must be designed, installed, implemented, and maintained to:

- Minimize discharge of pollutants from equipment and vehicle washing, wheel wash water, and other wash waters. Wash waters must be treated in a sediment basin or alternative control that provides equivalent or better treatment before discharge.
- Minimize exposure of building materials, building products, construction wastes, trash, landscape materials, fertilizers, pesticides, herbicides, detergents, sanitary waste, and other materials present on the site to precipitation and to stormwater.
- Minimize discharge of pollutants from spills and leaks and implement chemical spill and leak prevention and response procedures.

P2 Plan must include effective BMPs to:

- Prohibit discharge of concrete washout wastewater unless managed by an appropriate control.
- Prohibit discharge of wastewater from washout and cleanout of stucco, paint, form release oils, curing compounds, and other construction materials.
- Prohibit discharge of fuels, oils, or other pollutants used in vehicle and equipment operation and maintenance.
- Prohibit discharge of soaps or solvents used in vehicle and equipment washing.
- Prohibit discharge from dewatering, including discharges from dewatering of trenches and excavations, unless managed by appropriate controls.

Approval of the P2 Plan by a VDEQ certified plan reviewer is not required by state regulation or statute. However, a locality VESMP authority may require previous approval as part of a more stringent requirement.

### 4.4.1.3 SWPPP Supporting Document

After obtaining permit coverage for the CGP, additional supporting documentation must be included to address construction. All components required for a SWPPP are identified on Figure 4-10:

***Figure 4-10 Required Components of a SWPPP***


The approved ESM Plan (ESC and SWM Plans), P2 Plan, and information on impaired or exceptional waters and TMDLs are all required before the issuance of the CGP coverage letter (see 9VAC25-880-70, Part II). The remaining sections are all to be prepared before the commencement of construction.

These sections include:

1. General information
   - Signed copy of the registration statement (if required);
   - Copy of the notice of coverage letter;
   - Copy of the CGP;
   - Narrative description of the nature of the construction including the purpose of the project;
   - Legible site plan; and
   - LDA log for dates of major grading activities, temporary or permanent suspension of construction activities on a portion of the site, and when stabilization measures are initiated.
2. SWPPP requirements for discharges to impaired and exception waters, TMDL and polychlorinated biphenyl (PCB) impaired waters (when demolishing any structure with at least 10,000 square feet of floor space built or renovated before January 1, 1980) (See 9VAC25-880-70):
   - Identify the impaired waters, approved TMDLs, and pollutant of concern in the SWPPP.
   - Implement the approved ESC Plan in accordance with Part II B 2 of the CGP.
   - Implement a modified inspection schedule in accordance with Part II G 2 a of the CGP.
   - Dispose of waste materials in compliance with applicable state, federal, and local requirements.
3. Qualified personnel

   List the name, phone number, and qualifications of the qualified personnel conducting operator inspections.
4. Delegation of authority

List the individuals or positions with delegated authority to sign inspection reports or modify the SWPPP.

5. SWPPP signature
   - The SWPPP must be signed and dated by operator or duly authorized representative of the operator with the following certification:

     "I certify under penalty of law that I have read and understand this document and that this document and all attachments were prepared in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."
   - Reports, including inspection reports, must also be signed by the operator. The operator may be the same person that signed the registration statement, or that person may authorize a representative to sign on their behalf. The representative may be an individual or a position having responsibility for the overall operation of the regulated facility or activity.
   - Reports can be signed by:
     - Corporations – Responsible corporate officer;
     - Partnership or sole proprietorship – General partner or the proprietor;
     - Municipality, state, federal, other public agency – Principal executive officer or ranking elected official; or
     - Duly authorized representative empowered to sign on behalf of the operator in accordance with 9VAC25-875-940 B.

#### 4.4.1.4 SWPPP Amendments, Modifications, and Updates

The Regulation and the CGP (see 9VAC25-880-70 Part II C) require the SWPPP to be amended, modified, or updated by the operator when there is a change in the design, construction, operation, or maintenance that has a significant effect on the discharge of pollutants to state waters that has not been previously addressed in the SWPPP. A SWPPP must also be amended if, during inspections by the qualified personnel or by local, state, or federal officials, it has been determined that the existing control measures are ineffective at minimizing pollutants in discharges from the construction. Revisions to the SWPPP must include additional or modified control measures designed and implemented to correct the problems identified. In some cases, approval by the locality VESMP and/or VDEQ, as the VSMP authority, is necessary for the control measure revisions to the SWPPP. In these instances, the locality VESMP authority has 60 days to review modifications to an approved SWM Plan, and the revisions will be completed no later than 7 calendar days following approval.

When amending the SWPPP, the operator will update it as soon as possible, but no later than 7 days following any modification to its implementation. All modifications or updates must be noted and include the following items:

- A record of dates on which major grading occurs, construction temporarily or permanently ceases on a portion of the site, and stabilization measures are initiated;
- Documentation of replaced or modified controls where periodic inspections or other information have indicated that the controls have been inadequate or used inappropriately;
- Areas that have reached final stabilization and where no further SWPPP or inspection requirements apply;

- All properties that are no longer under the legal control of the operator and the dates on which the operator no longer had legal control over each property;
- The date(s) of any prohibited discharges, the discharge volume released, and what actions were taken to minimize the impact of the release;
- Measures taken to prevent the reoccurrence of any prohibited discharge; and
- Measures taken to address any evidence identified as a result of a qualified person's SWPPP inspection.

Any amendments, modifications, or updates to the SWPPP must be signed by the operator or a duly authorized representative of that person. The SWPPP will also be amended to identify any new contractors that will implement and maintain a control measure.

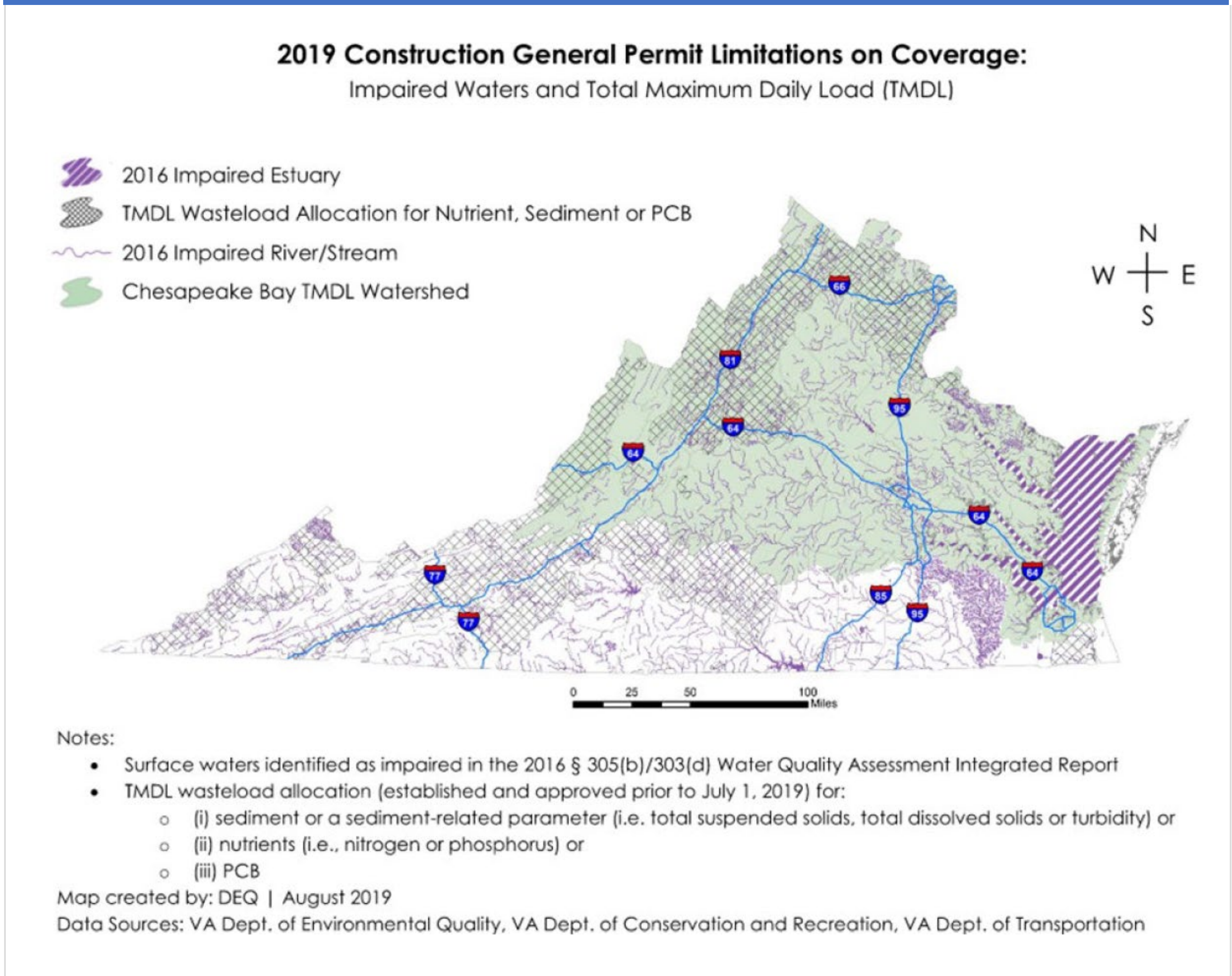
#### 4.4.1.5 Requirements for TMDLs, Impaired, and Exceptional Waterways

TMDLs are regulatory documents that establish a maximum quantity of pollutants that can enter a given waterway. Impaired waters are defined as waterbodies that "are not fully supporting or are partially supporting of the fishable and swimmable goals of the Clean Water Act" in § 62.1-44.19:4 of the Code of Virginia. These waterways need to be protected to ensure they can continue to support natural wildlife, recreation, and other uses. TMDLs are applied to waterways that have a known pollutant present at concentrations exceeding allowable amounts for water quality standards. If your project is in a location draining to a TMDL waterway, there may be specific requirements that must be included in your project's SWPPP.

On the opposite end of the spectrum are Exceptional State Waters (ESWs), which are defined and listed in 9VAC25-260-30 as waters that "provide exceptional environmental settings and exceptional aquatic communities or exceptional recreational opportunities" and have additional protections to keep them of high quality. Currently, there are 30 waterways designated as ESWs in the State of Virginia.

The CGP (see Section 4.4.2) also includes additional requirements for stormwater discharges from construction to surface waters identified as impaired in the 2022 § 305(b)/303(d) Water Quality Assessment Integrated Report and to waters for which a TMDL wasteload allocation has been established and approved before July 1, 2024 for either sediment or a sediment-related parameter (such as total suspended solids or turbidity) or nutrients (such as nitrogen or phosphorus). Addition requirements also apply to projects discharge to surface waters identified as PCB-impaired waters in the 2022 § 305(b)/303(d) Water Quality Assessment Integrated Report or for which a TMDL wasteload allocation was established and approved before July 1, 2024 for PCB. For sites discharging to these waterways, refer to the Construction General Permit Regulation, 9VAC25-880.

***Figure 4-11 Impaired Water in the State of Virginia***




State-wide TMDL stream segments are identified on the VDEQ website at https://www.deq.virginia.gov/our- programs/water/water-quality/tmdl-development/approved-tmdls and localities should be consulted for any TMDLs on a local scale which are updated frequently.

Note that the Chesapeake Bay TMDL includes 40 large watersheds for total nitrogen, total phosphorus, and sediment (120 total watersheds), all contributing to the impairments of the Chesapeake Bay.

### 4.4.2 Construction General Permit

General VDPES Permit for Discharges of Stormwater from Construction Activities, General Permit No.: VAR10, or CGP, authorizes operators of construction to discharge to surface waters within the boundaries of the Commonwealth of Virginia and sets the conditions the operator must meet during construction to comply with permit coverage.

The current permit has a fixed term of 5 years with an effective date of July 1, 2024, and an expiration date of June 30, 2029. Every authorization to discharge under the CGP will expire at the same time, and all authorizations to discharge will be automatically continued if the owner has submitted a complete registration statement at least 90 days prior to the expiration date of the permit and paid all past due general permit maintenance fees. 9VAC25-880-30.

The Fact Sheet for the Construction General Permit is posted on the VDEQ website at:
https://www.deq.virginia.gov/home/showpublisheddocument/4975/637485033255700000

A copy of the full CGP is posted on the VDEQ website at:
https://www.deq.virginia.gov/home/showpublisheddocument/8525/637547667064630000

Coverage under the CGP is required for LDAs that will disturb 1 acre or more or LDAs that are part of a larger common plan of development or sale that will disturb 1 acre or more in total (refer to Chapter 5 for more detail).

A copy of the notice of coverage letter (issued by VDEQ) for the LDA must be posted near the main entrance of the construction. For linear projects, the operator must post the notice of coverage letter at a publicly accessible location near an active part of the construction project. A copy of the notice of coverage letter must remain posted until the CGP is terminated (9VAC25-880-70 Part II D).

#### 4.4.2.1 Construction General Permit Registration Statement

By signing the registration statement, the operator certifies that they have prepared a SWPPP in accordance with the permit requirements. The operator listed on the registration statement is ultimately held responsible when a site is found to be out of compliance.

The registration statement must be signed by a person with signatory authority. This person is typically the operator. The CGP coverage will be issued to the operator listed in the registration statement.

As part of the registration statement, the applicant must provide a map to indicate the locations of the existing or proposed LDAs. The map should include limits of disturbance, construction entrances, and waterbodies receiving stormwater discharges. This may be in the form of aerial imagery maps or topographic maps. The applicant must also report the total acreage of all LDAs to be covered under the permit including offsite areas. This includes the total acreage of the primary development site as approved on the SWM Plans and the primary onsite estimated acreage to be disturbed by the construction as approved under the ESC Plans. The offsite estimated area to be disturbed is the sum of the disturbed acreages for all offsite support activities to be covered under this permit. The permit fee is calculated based on the total land disturbance, meaning the sum of the primary disturbed acreage and the disturbed acreages of all offsite support areas.

The associated fee schedule is posted on the VDEQ website at:
https://www.deq.virginia.gov/home/showpublisheddocument/8524/637547667038400000

The registration statement documents the name of any receiving waters and 6th order hydrologic unit code (HUC), which VDEQ uses to determine if a site is discharging to surface waters identified as impaired, waterways with a TMDL, or exceptional waters. VDEQ uses the HUC to determine if the site is discharging to surface waters identified as impaired for PCB in the 2022 § 305(b)/303(d) Water Quality Assessment Integrated Report or waterways with a TMDL wasteload allocation that was established and approved before July 1, 2024 for PCB contamination.

The permit also authorizes stormwater discharges from onsite and offsite support activities; consequently, the estimated area to be disturbed by all offsite support activities must be provided in Section III. Additionally, appropriate control measures must be identified in a SWPPP and implemented to address discharges from the support activity areas. If the offsite support activity is an excavated material disposal area, the operator must disclose this, as well as the contents of the excavated fill material to be deposited.

The registration statements should be submitted to the VESMP authority or where VDEQ is the VSMP authority directly to VDEQ. The registration statement is posted on the VDEQ website at: https://www.deq.virginia.gov/home/showpublisheddocument/4972/637534797394100000

### 4.4.2.2 Inspections and Reporting during Construction

Construction must always remain in compliance with the CGP. For the owner/operator, this includes verifying that ESC and SWM measures are in place, functional, and adequate; updating the SWPPP as needed; and conducting site inspections at the required frequency (see Table 4-1).

**Table 4-1 Required Site Inspection Frequency**

| Discharges to Impaired Waters, Surface Waters with an Applicable TMDL, or Exceptional Waters | Standard Inspections |
|---|---|
| Inspections must be conducted either:<br>1. At least once every 4 business days; or<br>2. At least once every 5 business days and no later than 24 hours following a measurable storm event | Inspections must be conducted either:<br>1. At least once every 5 business days: or<br>2. At least once every 10 business days and no later than 24 hours following a measurable storm event |

The operator must have a qualified person who, throughout the construction process, carries out inspections to verify that erosion is being minimized as much as is practicable and sediment is being contained onsite. These inspections must be documented in the SWPPP.

If, at any point, measures begin to fail or appear insufficient when implemented onsite, the SWPPP requires an amendment. This is to ensure that no unauthorized discharges occur that could cause the site to be out of compliance with the CGP.

The CGP does not relieve the permittee of the reporting requirements for discharges of hazardous substances or oil in an amount equal to or greater than a reportable quantity established under 40 Code of Federal Regulations (CFR) Part 110, 40 CFR Part 117, 40 CFR Part 302, or § 62.1-44.34:19 of the Code of Virginia that occurs during a 24-hour period. If there is an unauthorized discharge of sewage, industrial waste, other waste, any noxious or deleterious substance, into or upon surface waters or that may reasonably be expected to enter surface waters, the operator must notify VDEQ immediately upon discovery of the discharge, but in no case later than within 24 hours of discovery. A written report of the unauthorized discharge will be submitted to VDEQ and the VESMP authority within 5 days of discovery of the discharge.

The VESMP authority, VESCP authority, or VDEQ may make periodic site inspections during construction and of the installation of stormwater management measures. A VESMP authority may require monitoring and reports from the person responsible for meeting the permit conditions to ensure compliance with the permit and to determine whether the measures required in the permit effectively manage stormwater.

For S&S projects, inspections must be completed according to the approved schedule. All self-inspections conducted on behalf of the S&S entity must be performed by an individual who is certified as an ESC and/or SWM Inspector, as applicable, in accordance with the regulations.

### 4.4.3 Project Closeout Procedures

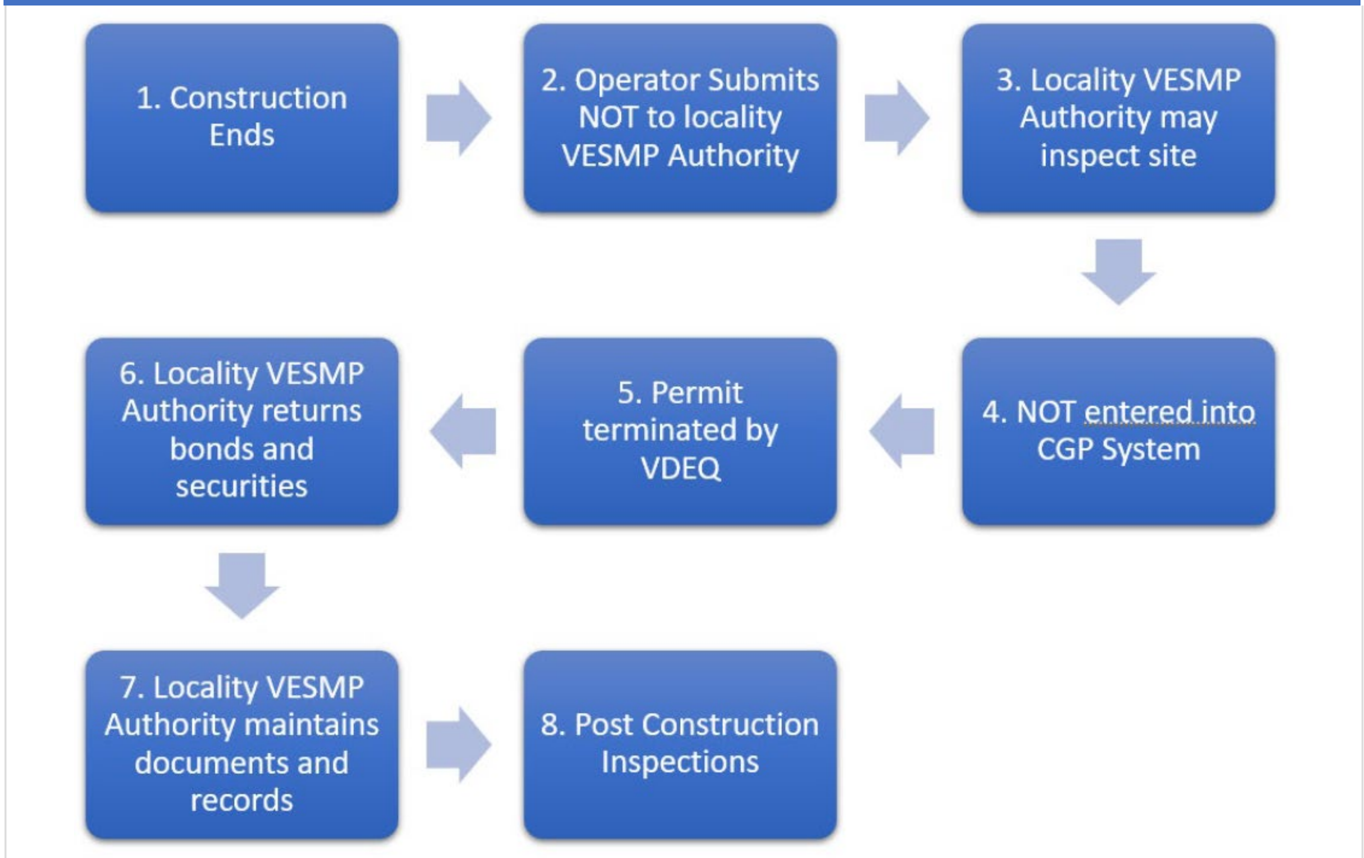
Once construction on a project is completed, a permanent vegetative cover must be established that is uniform, mature enough to survive, and will inhibit erosion, and all ESC measures must be removed within 30 days after final site stabilization or after the temporary measures are no longer needed, unless otherwise authorized by the VESCP or VESMP authority in accordance with 9VAC25-875-560. Typically, for individual lots in residential construction, final stabilization can be accomplished by either the homebuilder completing the final stabilization or the homebuilder establishing temporary soil stabilization, including perimeter controls, for an individual lot before occupancy of the home by the homeowner and informing the homeowner of the need for final stabilization. However, this requirement can vary by locality. Additionally, lands used for agricultural purposes may achieve final stabilization by returning the disturbed land to its pre-construction agricultural use; however, areas not previously used for agriculture, such as buffer strips adjacent to surface waters, and areas not being returned to *pre-construction* agricultural use must achieve final stabilization as listed above per 9VAC25-880-1.

Permanent measures such as SWM facilities and BMPs such as check dams and outlet protection must also be in place and functioning effectively. An agreement establishing the long-term responsibility for inspecting and maintaining SWM facilities must be recorded in the local land records before CGP termination or earlier as required by the locality VESMP authority. 9VAC25-875-535. More information on long-term maintenance agreements and inspections is provided in Section 4.4.3.5. This documentation, as well as construction record drawings and inspection reports, must all be kept following the completion of the project. For more information on record keeping, see Section 4.4.3.1.

Once these requirements are met, the site is completed, and the Notice of Termination (NOT) is ready to be executed. For more information on the NOT documentation, see Section 4.4.3.2. The NOT should be submitted to the VESMP or VSMP authority, which may then conduct an inspection to verify compliance with the closeout requirements. Once the authority confirms the site is completed, the submitted NOT is uploaded to the state-wide online CGP database. From there, the permit is terminated by VDEQ.

Also at the completion of permit requirements, any securities collected at the beginning of the project can be returned. The locality VESMP authority must return or terminate any bonds or securities provided by the operator within 60 days of project completion if conditions are met. (9VAC25-875-110 D) For more information, see Section 4.4.3.3. Figure 4-12 illustrates the sequence of events for project closeout.

**Figure 4-12 Project Closeout Flowchart**




### 4.4.3.1 BMP Record Documents and Certifications

Once construction is complete, a construction record drawing, or as-built, in a format specified by the VESMP authority or VSMP authority for permanent SWM facilities must be submitted to the VESMP authority or VDEQ. The construction record drawing must be appropriately sealed and signed by a Professional Engineer registered in the Commonwealth of Virginia, certifying that the SWM facilities have been constructed in accordance with the approved plan. Some localities may also require a separate BMP certification form or additional information to be included on the record drawings.

Construction record drawings for all permanent stormwater management features should be prepared and submitted to VDEQ prior to project closeout (e.g., prior to terminating coverage under General VPDES Permit for Discharges of Stormwater from Construction Activities).

Construction record drawings of any permanent stormwater BMPs will be maintained by the VESMP authority or VSMP authority in perpetuity or until the SWM facility is removed or retrofitted as part of a new approved SWM Plan.

For S&S projects, the S&S entity typically reviews and certifies their own construction record drawings. However, this process may vary across S&S entities and should be verified in their program documents.

General standards for Construction Record Drawings include:

A. Dimensions and elevations. Construction record drawings should show actual (i.e., field) dimensions and elevations alongside the design (i.e., plan) dimensions and elevations. The actual information should be shown [boxed in] for comparison to the design information.

B. Storm sewers and culverts. Construction record drawings should show the following information at a minimum: pipe materials identified based on visual inspection, sizes, lengths, invert-in and invert-out elevations, and percent grade of pipe as computed.

C. Storm sewer and culvert outlet protection. Construction record drawings should show the following information at a minimum: apron materials (e.g., riprap, concrete) identified based on visual inspection, lengths, widths, invert elevations, and percent grade of apron as computed.

D. Level spreaders. Construction record drawings should show the following information at a minimum: weir materials identified based on visual inspection, lengths, weir elevations and percent grade of weir as computed.

E. Stormwater conveyance channels. Construction record drawings should show the following information at a minimum: top of channel elevations, invert elevations, and percent grade of channel as computed.

F. Stormwater management facilities and best management practices. Construction record drawings should show the following information at a minimum: dimensions and elevations of top of embankments, toe of embankments, principal spillways (including weirs, orifices, and outlet pipes), emergency spillways, and low flow channels (or drainage way to the principal spillway structure). Capacities should be shown topographically and volumetrically with sufficient spot elevations to compute the capacities for as-built verification.

G. Certification statement. A certification statement per the following should be provided on the Cover Sheet of the construction record drawings.

STORMWATER MANAGEMENT FACILITIES CERTIFICATION

DEQ PLAN # ____________________

Pursuant to 9VAC25-875-535, I hereby certify that to the best of my knowledge and belief, the stormwater management facilities shown on these construction record drawings have been constructed in accordance with the approved plans and specifications.

| | |
|---|---|
| ______________________________ | ______________________________ |
| Name | Signature |
| ______________________________ | ______________________________ |
| Virginia License No. | Date |

"Certify" means to state or declare a professional opinion based on sufficient and appropriate onsite inspections, material tests, as-built survey data, and information provided by other professionals and the contractor, conducted during or after inspection.

H. Seal and signature. Unless otherwise exempt under Va. Code § 54.1-401, the seal, signature, and date of the design professional should be provided on each sheet of the plans. The seal, signature, and date of the design professional should also be provided on the cover page of all other required submission materials (e.g., computations, reports, studies, etc.).

I. If Construction Record Drawings do not demonstrate the facility was constructed in accordance with the approved plans and specifications, a modified stormwater management plan and associated computations may be required.

### 4.4.3.2 Notice of Termination

Requirements to terminate coverage under the CGP are set out in 9VAC25-880-60 and are summarized here. The Notice of Termination (NOT) form must be completed and submitted by the operator to the VESMP authority or VDEQ within 30 days of meeting one or more of the following conditions:

- Necessary permanent control measures included in the SWPPP for the site area are in place and functioning effectively, and final stabilization has been achieved on all portions of the site for which the operator is responsible. When applicable, long-term responsibility and maintenance requirements for permanent control measures must be recorded in the local land records before the submission of the NOT.
  - *In these cases, authorization to discharge terminates either 60 days following submittal of complete and accurate NOT or upon notification from VDEQ, whichever occurs first.*
- Another operator has assumed control over all areas of the site that have not been fully stabilized and obtained coverage for the ongoing discharge.
  - The Transfer of Ownership Agreement form is posted on the VDEQ website at: https://www.deq.virginia.gov/home/showpublisheddocument/4971/637485031554670000
- Coverage under an alternative VPDES or state permit has been obtained.
- For residential construction only, temporary soil stabilization has been completed, and the residence has been transferred to the homeowner. The operator must provide the homeowner with written information about the importance of final stabilization and require signed documentation from the permittee that the homeowner has been notified. This documentation is to be kept for 3 years.
  - In the three scenarios above, authorization to discharge terminates at midnight on the date on which the NOT is submitted unless otherwise notified by the VESMP or VSMP authority.

The Notice of Termination form is posted on the VDEQ website at:
https://www.deq.virginia.gov/home/showpublisheddocument/4974/637485033253200000

Special Conditions:

- Single-Family Detached Residential: When a registration statement was not required to be submitted for single-family detached residential structures and which used the coverage letter for single-family detached residential structures, a NOT for each individual single-family detached residential structure is not required.
- S&S Projects: The NOT is submitted directly to VDEQ.

### 4.4.3.3 Release of Security for Performance

Before commencing land disturbance, a security for performance, or bond, may be collected by the local authority. Securities ensure that measures may be taken by the authority, at the applicant's expense, should the applicant fail to initiate or maintain all measures on the approved plan that safeguard against the site damaging neighboring properties. Security requirements vary by locality and department, but typically, there will be securities required for public infrastructure, SWM facilities, and erosion control measures.

For example, ESC, SWM, or BMP performance bond may be collected before commencement of an LDA to ensure all conservation measures included on the approved plan are installed, maintained, or converted into a permanent SWM facility such that, if the operator fails to execute, corrective measures could be taken by the authority at the applicant's expense. If the VESMP authority takes such action upon such failure by the applicant, the VESMP authority may collect from the applicant the difference should the amount of the reasonable cost of such action exceed the amount of the security held.

Once adequate stabilization on any project, or section of project, has been achieved, and the erosion control measures are removed with the inspector’s approval, the security must be refunded to the applicant or terminated, based on the percentage of project completed, within 60 days.

#### 4.4.3.4 Final Acceptance

Remaining steps to fully close out a project once construction is complete, stabilization applied, and construction record drawings submitted are detailed in this subsection. Each locality and permitting office may have slightly different procedures for final acceptance. Contact the applicable entity to verify requirements for final project acceptance.

All easements must be properly recorded with the locality before the final acceptance of a project. Easements may be required for storm sewer, forested and mixed open space, or SWM facilities.

Acceptance of roads into the public system, if applicable, also has its own process to consider. Contact the agency that issued the road permit, if applicable, for a list of items required for public road acceptance and project closure. For most counties in Virginia, that agency is typically VDOT. For independent cities and some counties, such as Henrico, the locality should be contacted directly.

#### 4.4.3.5 Long-Term Inspections and Maintenance

Once construction on a project is complete, the permanent SWM measures must be maintained. Inspections and maintenance can ensure that a facility is operating as intended. Specific procedures for long-term maintenance are covered in greater detail in Chapter 10.

The VESMP/VSMP authority requires the provision of long-term responsibility and maintenance of SWM facilities and any other techniques specified to manage the quality and quantity of runoff be assigned to the owner and recorded in a maintenance agreement.

The long-term maintenance agreement will be set forth and recorded in the local land records before state permit termination, or earlier as required by the VESMP authority or VDEQ, and will at a minimum be submitted to the VESMP authority or VDEQ for review and approval before the approval of the SWM plan. It must be stated to run with the land, provide for all necessary access to the property for purposes of maintenance and regulatory inspections, provide for inspections and maintenance and the submission of inspection and maintenance reports to the VESMP authority or VDEQ, and be enforceable by all appropriate governmental parties.

At the discretion of the VESMP/VSMP authority, such recorded instruments need not be required for SWM facilities designed to treat stormwater runoff primarily from an individual residential lot on which they are located, provided it is demonstrated to the satisfaction of the VESMP/VSMP authority that future maintenance of such facilities will be addressed through an enforceable mechanism at the discretion of the VESMP/VSMP authority.

In addition, any owner of property zoned for residential use and on which is located a privately owned stormwater management facility serving one or more residential properties will record the long-term maintenance and inspection requirements for such facility with the deed for the property.

VESMP authorities and VDEQ must ensure that SWM facilities are inspected by the VESMP/VSMP authority or its designee at least once every 5 years. The inspections must be documented by records. The VESMP/VSMP authority may use the inspection reports of the owner of a SWM facility as part of its established inspection program if the inspection is conducted by a licensed Professional Engineer, architect, landscape architect, or land surveyor; someone working under the direction and oversight of a licensed professional; or a person who holds an appropriate certification from VDEQ.

For state and federal land-disturbing activities, 9VAC25-875-590 establishes responsibility for the operation and maintenance of SWM facilities shall remain with the state agency or federal entity and will pass to any successor or owner. At a minimum, an SWM facility will be inspected by the responsible state agency or federal entity annually and after any storm that causes the capacity of the facility's principal spillway to be exceeded.

# CHAPTER 5 EROSION AND SEDIMENT CONTROL AND STORMWATER MANAGEMENT REQUIREMENTS

**Contents:**

## 5.1 Regulating Land-Disturbing Activities

Land-disturbing activity (LDA) defined in Code of Virginia § 62.1-44.15:24 as "a man-made change to the land surface that potentially changes its runoff characteristics including clearing, grading, or excavation" (unless specifically exempted), may be subject to regulation under the Virginia Erosion and Stormwater Management Act (VESMA), the Virginia Erosion and Stormwater Management Regulation, 9VAC25-875, the Erosion and Sediment Control Law for Localities Not Administering a Virginia and Erosion and Stormwater Management Program (ESCL), and local ordinances. The programs that implement the requirements in the VESMA and ESCL, the Virginia Erosion and Stormwater Management Program (VESMP), Virginia Stormwater Management Program (VSMP), where VDEQ is the VSMP authority, and Virginia Erosion and Sediment Control Program (VESCP), in localities that are not VESMP authorities, are discussed in detail in Chapter 4. A VESMP or VSMP only applies to the following regulated LDAs:

- Those that occupy a surface area greater than or equal to 10,000 square feet;

- Those that occupy a surface greater than or equal to 1 acre;
- Those that are part of a larger common plan of development or sale that is greater than or equal to 1 acre;
- Those that occupy a surface greater than or equal to 2,500 square feet in a Chesapeake Bay Preservation Area (CBPA); and
- Those areas that are subject to more stringent requirements established by the local VESMP Authority.

9VAC25-875-470.

An individual or General VPDES Permit for Discharges of Stormwater from Construction Activities (CGP) is required for LDAs that will disturb 1 acre or more of surface area or are part of a larger common plan of development or sale that will disturb 1 acre or more.

Where CGP coverage is required, an owner or operator must complete a Registration Statement and submit it to the VESMP or VSMP authority before starting land disturbance. 9VAC25-875-530. By signing this statement, the operator is certifying they have prepared a Stormwater Pollution Prevention Plan (SWPPP) with required plan approvals.

### 5.1.1 Regulated Land-Disturbing Activities

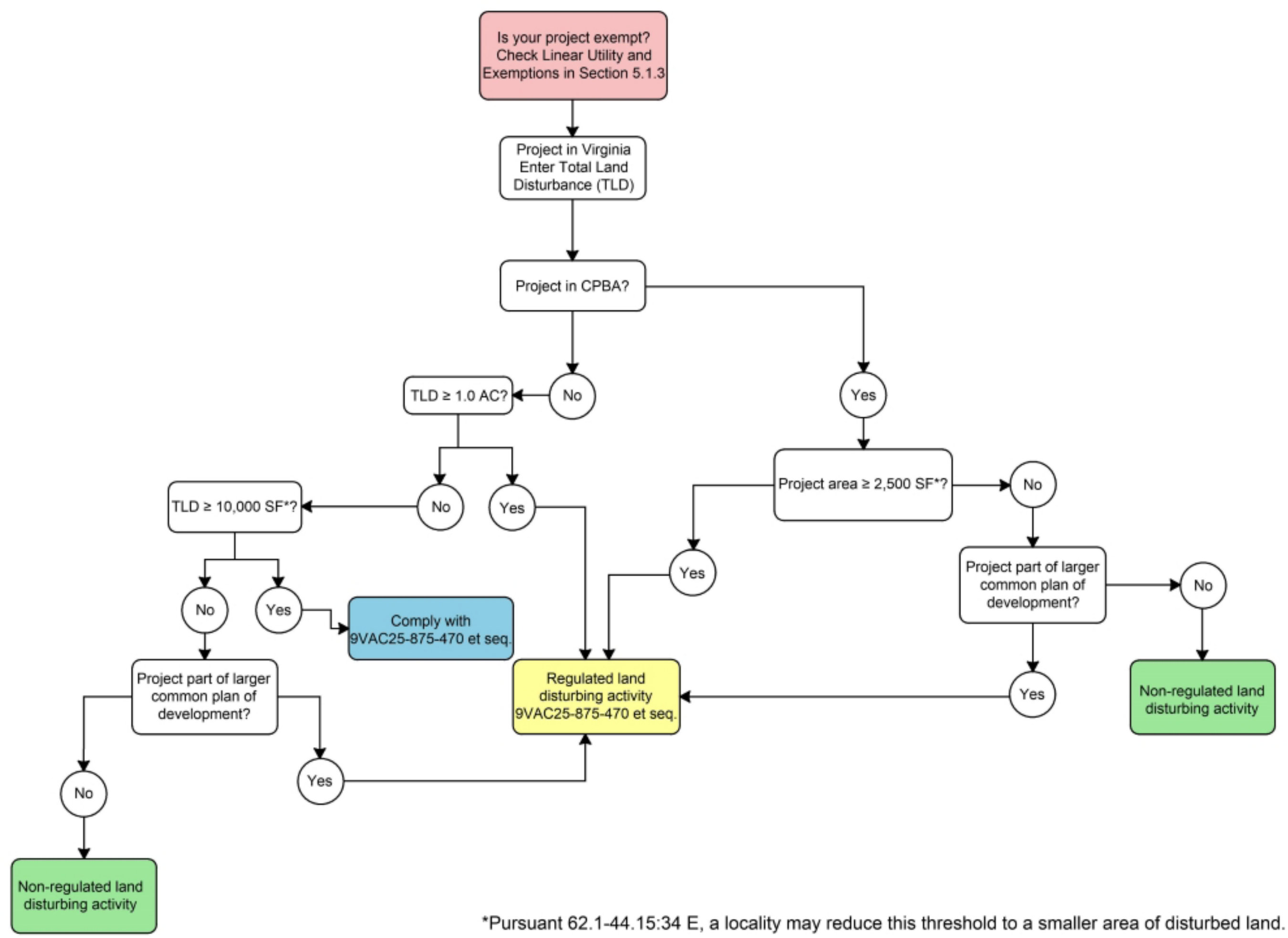
All regulated land disturbance will fall under the jurisdiction of a VESMP authority, a VESCP authority, and/or a VSMP authority. These authorities administer program rules for individual development or redevelopment projects.

Understanding how your project is regulated involves determining the level at which regulated LDAs are associated with your project when considering the pre-development and post-development conditions. "Pre-development" refers to the conditions that exist at the time that plans for the land development of a tract of land are submitted to the VESCP, VESMP, or VSMP authority. Where phased development or plan approval occurs (e.g., preliminary grading, demolition of existing structures, or roads and utilities), the existing conditions at the time prior to the first item being submitted shall establish predevelopment conditions. "Post-development" refers to conditions that reasonably may be expected or anticipated to exist after completion of the land development activity on a specific site. 9VAC25-875-20.

Requirements for regulated LDAs are set out in the Virginia Erosion and Stormwater Management Program Regulation, 9VAC25-875. This information, along with whether your project falls into special categories, such as single-family detached residential structures or linear development, and if your project is in a jurisdiction regulated by the Chesapeake Bay Preservation Act, will determine what erosion and sediment control (ESC) and/or stormwater management (SWM) requirements your project will need to meet. The VESCP and VSMP regulated LDAs are summarized in the table 5-1 below.

LDAs that impact a land surface of equal to or greater than 10,000 square feet are subject to the VESMA unless the LDA is in a locality that is a VESCP authority. The Virginia Erosion and Stormwater Management Regulation, 9VAC25-875, contains requirements for both the VESMA and ESCL. In all areas of the jurisdiction designated as subject to the CBPA Designation and Management Regulations, 9VAC25-830, LDAs that impact a land surface of equal to or greater than 2,500 square feet are subject to the laws and regulations of the VESMA and 9VAC25-875.

***Figure 5-1 Applicability of Regulated Land Disturbance Requirements***




## 5.1.2 Reserved

## 5.1.3 Linear Development Projects

Linear development projects are special projects sometimes handled somewhat differently under the Virginia Laws and Regulations than non-linear projects. A "linear development" project is an LDA that is linear in nature such as, but not limited to: (i) the construction of electric and telephone utility lines and natural gas pipelines; (ii) construction of tracks, rights-of-way, bridges, communication facilities, and other related structures of a railroad company; (iii) highway construction projects; (iv) construction of stormwater channels and stream restoration activities; and (v) water and sewer lines. Private subdivision roads or streets are not considered linear development projects. 9VAC25-875-20.

Linear development projects are required (9VAC25-875-640) to control post-development stormwater runoff in accordance with a site-specific stormwater management plan or a comprehensive watershed stormwater management plan developed in accordance with the Virginia Erosion and Stormwater Management Regulation (Regulation).

The Regulation does not distinguish among types of linear development projects such as aboveground or underground utilities, highway construction, rights-of-way, bridges, tracks, and related structures of a railroad company. VDEQ recognizes that the construction of aboveground or underground linear utilities may not result in changes to the pre-development runoff characteristics of the land surface after the completion of construction and final stabilization. Also, the application of the post-development water quantity and water quality controls to these types of projects and the preparation and implementation of a stormwater management plan may provide minimum water quality benefit. Examples of such projects include:

- The installation of underground utilities (e.g., waterlines, sewer lines, oil and gas distribution pipelines) beneath existing impervious cover (e.g., asphalt pavement, concrete pavement) that will be returned to its pre-development condition after the completion of construction and final stabilization;
- The installation of underground utilities (e.g., waterlines, sewer lines, oil, and gas distribution pipelines) beneath existing pervious cover (e.g., mixed open space, managed turf) that will be returned to its pre-development condition after the completion of construction and final stabilization; or
- The installation of aboveground (i.e., overhead) utility lines.

If the project will not result in changes to the pre-development runoff characteristics of the land surface after the completion of construction and final stabilization, then VDEQ or the local VESMP authority may waive the requirement for the preparation and implementation of a stormwater management plan. VDEQ recognizes that, on a site-specific basis, a stormwater management plan may be required, especially if the linear utility project will significantly alter the pre-development runoff characteristics of the land surface.

Installation of Permanent Gravel Access Roads for Construction and Maintenance of Electric Transmission Lines

An electric utility, defined in 2023 Acts of Assembly Chapters 196 (HB 2126) and 197 (SB1178) as, “any person that generates, transmits, or distributes electric energy for use by retail customers in the Commonwealth, including any investor-owned electric utility, cooperative electric utility, or electric utility owned or operated by a municipality,” may abide by the following criteria for the installation of new permanent gravel access roads for the construction and maintenance of electric transmission lines under DEQ-approved standards and specifications:

(i) the maximum width of the permanent gravel access road is no more than 14 feet with passing areas not more than 100 feet in length and 24 feet in width every 2,000 feet, on average;

(ii) the permanent gravel access road follows the contour of the natural terrain to the extent possible and slopes should not exceed 10 percent;

(iii) the permanent gravel access road is constructed using clean, open-graded, angular aggregate at a depth of no less than six inches; and

(iv) the following conditions are met:

1. The project is managed so that during construction of the permanent gravel access road the area of land-disturbing activity is less than one acre;
2. The area where land-disturbing activity has been completed is adequately stabilized prior to initiating construction of the gravel access road on the next area subject to land-disturbing activity. "Adequately stabilized" means compliance with C-SSM-05, Soil Stabilization Blankets and Matting, in Chapter 7 of this Handbook;
3. The environment is protected from erosion and sedimentation damage associated with the land-disturbing activity; and

4. The project owner or construction activity operator designs, installs, implements, and maintains pollution prevention measures to (i) minimize the discharge of pollutants from equipment and vehicle wash water, wheel wash water, and other wash waters; (ii) minimize the exposure of building materials, building products, construction waste, trash, landscape materials, fertilizers, pesticides, herbicides, detergents, sanitary waste, and other materials present on site to precipitation and to stormwater; (iii) minimize the discharge of pollutants from spills and leaks and implement chemical spill and leak prevention and response procedures; (iv) prohibit the discharge of wastewater from the washout of concrete; (v) prohibit the discharge of wastewater from the washout and cleanout of stucco, paint, form release oils, curing compounds, and other construction materials; and (vi) prohibit the discharge of fuels, oils, or other pollutants used in vehicle and equipment operation and maintenance.

An electric utility that complies with the criteria listed above, shall be deemed to satisfy the water quantity technical criteria in the Virginia Erosion and Stormwater Management Act, §§ 62.1-44.15:24 through 62.1-44.15:50 of the Code of Virginia (effective July 1, 2024, formerly the Stormwater Management Act). As required by the law, the electric utility must incorporate the applicable criteria from the Handbook (above) into a stormwater management plan and an erosion and sediment control plan developed for a project to install a permanent gravel access road under standards and specifications.

### 5.1.4 Exemptions

Certain activities are not required to comply with the VESMA and ESCL as outlined in the following section and in coordination with the local VESMP or VESCP authority. All the following activities are exempt from the ESCL and regulations; however, these activities may be regulated by other agencies or regulations.

- Minor LDAs such as home gardens and individual home landscaping, repairs, and maintenance work;
- Installation, maintenance or repair of any individual service connection;
- Installation, maintenance, or repair of any underground utility line when such activity occurs on an existing hard-surfaced road, street, or sidewalk, provided the LDA is confined to the area of the road, street, or sidewalk that is hard surfaced;
- Installation, maintenance, or repair of any septic tank line or drainage field unless included in an overall plan for LDA relating to construction of the building to be served by the septic tank system;
- Permitted surface or deep mining operations and projects, or oil and gas operations and projects conducted pursuant to Title 45.2 of the Code of Virginia;
- Cleaning of lands specifically for bona fide agricultural purposes; the management, tilling, planting, or harvesting of agricultural, horticultural, or forest crops; livestock feedlot operations; agricultural engineering operations, including construction of terraces, terrace outlets, check dams, desilting basins, dikes, ponds, ditches, strip cropping, lister furrowing, contour cultivating, contour furrowing, land drainage, and land irrigation. However, this exception shall not apply to harvesting of forest crops unless the area on which harvesting occurs is reforested artificially or naturally in accordance with the provisions of Chapter 11 (§ 10.1-1100 et seq.) of Title 10.1 of the Code of Virginia or is converted to bona fide agricultural or improved pasture use as described in subsection B of § 10.1-1163;
- Repair or rebuilding of the tracks, rights-of-way, bridges, communication facilities, and other related structures and facilities of a railroad company.
- Installation of fence and signposts or telephone and electric poles and other kinds of posts or poles;

- Shoreline erosion control projects on tidal waters when all of the LDAs are within the regulatory authority of and approved by local wetlands boards, the Marine Resources Commission, or the United States Army Corps of Engineers; however, any associated land that is disturbed outside of this exempted area will remain subject to the ESCL and Virginia Erosion and Stormwater Management Regulation; and
- Land-disturbing activities in response to a public emergency where the related work requires immediate authorization to avoid imminent endangerment to human health or the environment. In such situations, the VESMP authority shall be advised of the disturbance within seven days of commencing the land-disturbing activity, and compliance with the administrative requirements of subsection A is required within 30 days of commencing the land-disturbing activity.

62.1-44.15:55 F of the Code of Virginia.

The following activities are exempt from the VESMA:

A. Minor land-disturbing activities, including home gardens and individual home landscaping, repairs, and maintenance work;

B. Installation, maintenance, or repair of any individual service connection;

C. Installation, maintenance, or repair of any underground utility line when such activity occurs on an existing hard surfaced road, street, or sidewalk, provided the land-disturbing activity is confined to the area of the road, street, or sidewalk that is hard surfaced;

D. Installation, maintenance, or repair of any septic tank line or drainage field unless included in an overall plan for land-disturbing activity relating to construction of the building to be served by the septic tank system;

E. Permitted surface or deep mining operations and projects, or oil and gas operations and projects conducted pursuant to Title 45.2 of the Code of Virginia;

F. Clearing of lands specifically for bona fide agricultural purposes; the management, tilling, planting, or harvesting of agricultural, horticultural, or forest crops; livestock feedlot operations; agricultural engineering operations, including construction of terraces, terrace outlets, check dams, desilting basins, dikes, ponds, ditches, strip cropping, lister furrowing, contour cultivating, contour furrowing, land drainage, and land irrigation; or as additionally set forth by the State Water Control Board in regulations. However, this exception shall not apply to harvesting of forest crops unless the area on which harvesting occurs is reforested artificially or naturally in accordance with the provisions of Chapter 11 (§ 10.1-1100 et seq.) of the Code of Virginia or is converted to bona fide agricultural or improved pasture use as described in subsection B of § 10.1-1163;

G. Installation of fence and sign posts or telephone and electric poles and other kinds of posts or poles;

H. Shoreline erosion control projects on tidal waters when all of the land-disturbing activities are within the regulatory authority of and approved by local wetlands boards, the Marine Resources Commission, or the United States Army Corps of Engineers; however, any associated land that is disturbed outside of this exempted area shall remain subject to this article and the regulations adopted pursuant thereto;

I. Repair or rebuilding of the tracks, rights-of-way, bridges, communication facilities, and other related structures and facilities of a railroad company;

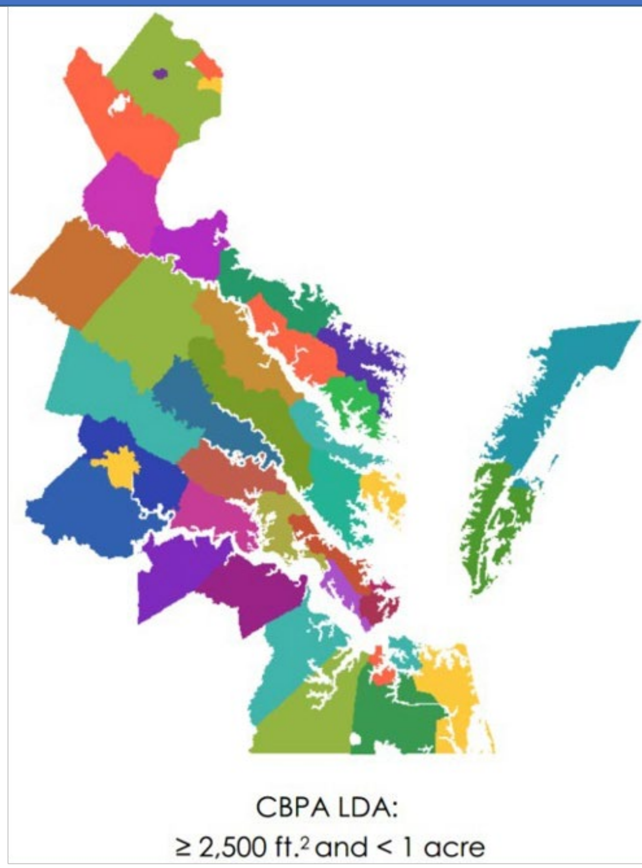
J. Land-disturbing activities in response to a public emergency where the related work requires immediate authorization to avoid imminent endangerment to human health or the environment. In such situations, the VESMP authority shall be advised of the disturbance within seven days of commencing the land-disturbing activity, and compliance with the administrative requirements of 9VAC25-875-530 is required within 30 days of commencing the land-disturbing activity; and

K. Discharges to a sanitary sewer or a combined sewer system that are not from a land-disturbing activity. 62.1-44.15:34 F of the Code of Virginia.

### 5.1.5 Chesapeake Bay Preservation Act LDA

If your project is located with the in jurisdiction subject to the CBPA Designation, be aware that the threshold for regulation is 2,500 square feet instead of 10,000 square feet (unless the area is subject to more stringent requirements established by the locality). A CBPA is an area delineated by a local government in accordance with criteria established pursuant to § 62.1-44.15:72 of the Code of Virginia. In a CBPA, LDAs, include clearing, grading, or excavation, that results in a land disturbance equal to or greater than 2,500 square feet and less than 1 acre. The areas subject to the CBPA are illustrated on Figure 5-2. Specific requirements for local government designation of Chesapeake Bay Preservation Areas are in the CBPA Designation and Management Regulations (9VAC25-830).

***Figure 5-2 Areas Subject to the Chesapeake Bay Preservation Act***




Designers should consult with the locality having jurisdiction for detailed CBPA parcel mapping.

### 5.1.6 Single-Family Detached Residential Structures

Single-family detached residential structures that are not in the CBPA are regulated under the CGP as a regulated LDA and subject to MS-19 requirements (Section 5.3) if the following is true:

- Project disturbs greater than or equal to 1 acre of land or, if less than one acre, is part of a common plan of development or sale.

If the project disturbs 10,000 square feet but less than one acre, if not part of a larger common plan of development or sale, it is subject to MS-19 requirements, but no registration statement is required under the CGP.

Localities subject to the provisions of the CBPA may regulate single-family residences separately built and disturbing less than 1 acre where land disturbance exceeds 2,500 square feet (§ 62.1-44.15:34). After June 30, 2014, land disturbance equal to or greater than 2,500 square feet but less than one acre in a CBPA area shall not require CGP coverage, unless a part of a common plan of development or sale.

As also discussed in Chapter 4, projects involving single-family detached residential structures have some important administration and procedural differences from other projects summarized below:

#### Agreement In-Lieu-Of a Stormwater Management Plan (§62.1-44.15:24)

VDEQ, when acting as the VSMP authority will, and a VESMP authority may, execute a contract with the owner of a single-family detached residential structure that specifies methods that must be implemented to comply with the requirements of the stormwater program instead of a soil erosion control and stormwater management plan (for a VESMP) or stormwater management plan (for a VSMP). Failure to follow the agreement may result in the owner having to prepare a site-specific stormwater management plan. Additionally, these projects can use the VDEQ SWPPP template.

#### Construction General Permit (§ 62.1-44.15:28)

While CGP coverage is required, these projects are not required to submit a registration statement. Instead, operators need to download the coverage letter for single-family detached residential structures after the locality VESMP authority has given approval to start land disturbance.

#### Long-Term Maintenance Agreements (9VAC25-875-535, 9VAC25-880-60)

At the discretion of the VESMP authority, recorded long-term maintenance agreements need not be required for stormwater management facilities designed to treat stormwater runoff primarily from an individual residential lot. It must be demonstrated to the satisfaction of the VESMP authority that future maintenance of such facilities will be addressed through an enforceable mechanism.

Such a strategy may include periodic inspections, homeowner outreach and education, or other methods targeted at promoting the long-term maintenance of such facilities. Such facilities are not subject to the requirement for an inspection by the VESMP authority.

## 5.2 Technical Criteria Applicability

Once the applicant has determined whether the LDA is regulated under the Virginia Erosion and Stormwater Management Regulation, the next step is to evaluate the specific technical criteria applicable to that applicant's project. The Regulation includes technical criteria that must be met in the stormwater management plan. There are two sets of criteria – Water quantity and water quality technical criteria, formerly know as "Part II B," and water quantity and water quality technical criteria for grandfathered projects, formerly known as "Part II C." The following explains how a VESMP authority determines which criteria apply to a project.

### 5.2.1 Time Limits of Technical Criteria Applicability

Refer to 9VAC25-875-490 for time limits of applicability of technical criteria. Land disturbing activities will be subject to Article 3 (9VAC25-875-570 et seq.) of Part V, except as provided for in 9VAC25-875-490, which identifies which land disturbing activities are subject to Article 4 (9VAC25-875-670 et seq.) of Part V.

### 5.2.2 Grandfathering

The grandfathering section of the Regulation (Article 4 of Part V, 9VAC25-875-670 et seq.) lays out conditions for determining whether an LDA is grandfathered under 9VAC25-875-490.

## 5.2.2.1 Locality, State, and Federal Projects

Locality, state, and federal projects considered grandfathered by the VESMP authority will be subject to the technical criteria in Article 4 of Part V of the Regulation (9VAC25-875-670 et seq.) if:

1. There has been an obligation of locality, state, or federal funding for the project, in whole or in part, before July 1, 2012, or VDEQ has approved a stormwater management plan before July 1, 2012;
2. A state permit has not been issued before July 1, 2014; and
3. Land disturbance did not start before July 1, 2014.

LDAs grandfathered under 9VAC25-875-490, except for those mentioned in 5.2.2.1 above, remain subject to the requirements in Article 3 of Part V (9VAC25-875-570 et seq.). Portions of the project not under construction become subject to any new technical criteria adopted by the State Water Control Board as of July 1, 2024.

Where governmental bonding or public debt financing has been issued for a project before July 1, 2012, the project remains subject to the technical criteria of Article 4, 9VAC25-875-670 et seq. without a deadline for completion.

## 5.2.2.2 All Other Land-Disturbing Activities

All other LDAs are considered grandfathered by the VESMP authority and are subject to the Article 4, 9VAC25-875-670 et seq technical criteria provided:

1. A proffered or conditional zoning plan, zoning with a plan of development, preliminary or final subdivision plat, preliminary or final site plan, or any document determined by the locality to be equivalent and satisfy all the following:
    a. Was approved by the locality before July 1, 2012;
    b. Provided a layout (a conceptual drawing sufficient to provide for the specified stormwater management facilities required at the time of approval (9VAC25-875-670));
    c. Complies with the current technical criteria; and
    d. Has not been subsequently modified or amended in a manner resulting in an increase in the amount of phosphorus leaving each point of discharge, and such that there is no increase in the volume or rate of runoff.
2. A state permit had not been issued before July 1, 2014; and
3. Land disturbance had not started before July 1, 2014.

### 5.2.2.3 End Dates for Projects Eligible for Grandfathering (formerly "Part IIC") Criteria

Article 4, 9VAC25-875-670 et seq. of Part V of the Regulation will be applied until June 30, 2024 for eligible projects. After June 30, 2024, the portions of the project not under construction must comply with the requirements of the current criteria, e.g., Article 3 of Part V. “Under construction” means construction has commenced. Section 20 of the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-20) defines construction activity as “any clearing, grading, or excavation associated with large construction activity or associated with small construction activity.”

See the flow charts on Figure 5-3 and Figure 5-4 for more assistance with determining time limits on applicability of approved design criteria and grandfathering.

## *Figure 5-3 Grandfathering Decision Tree*

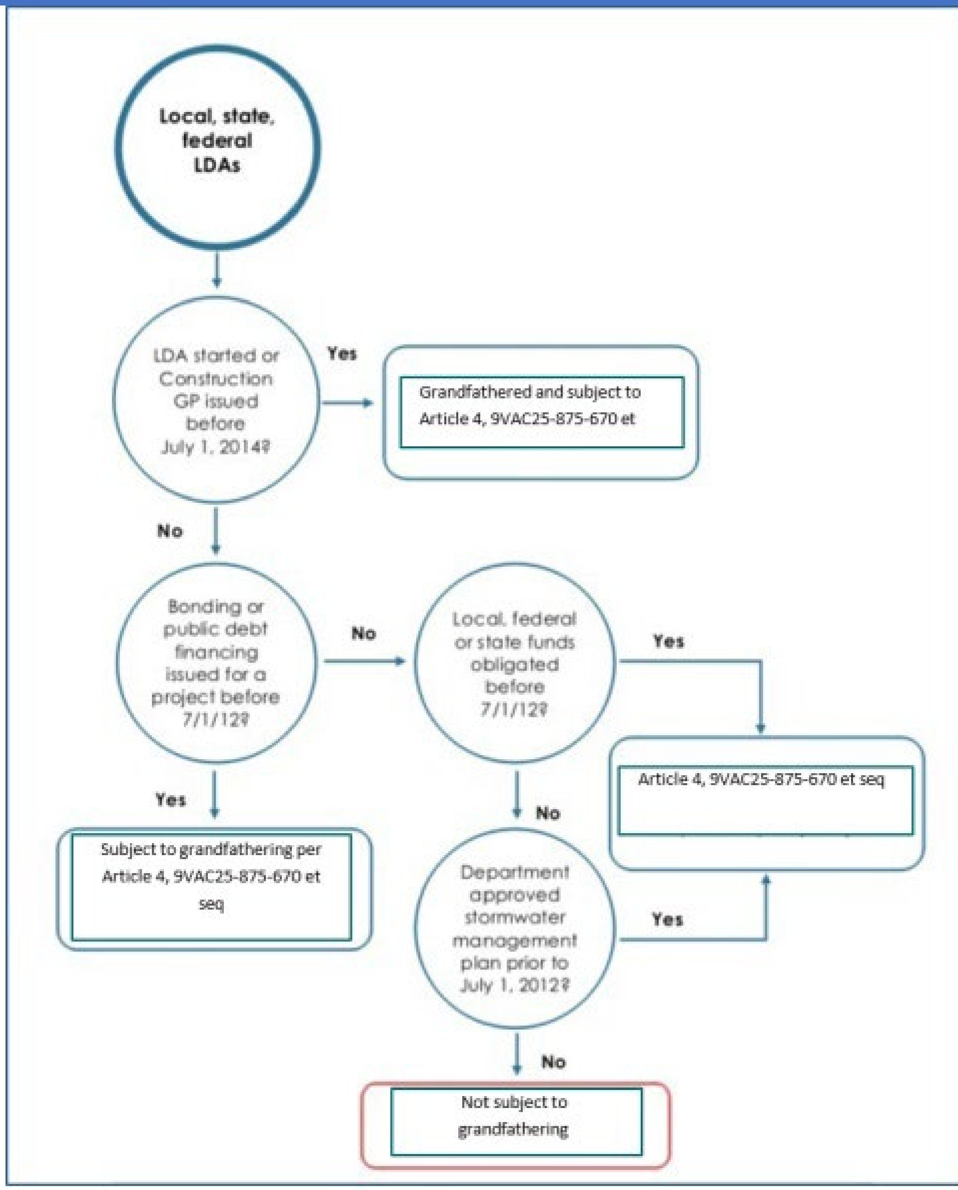
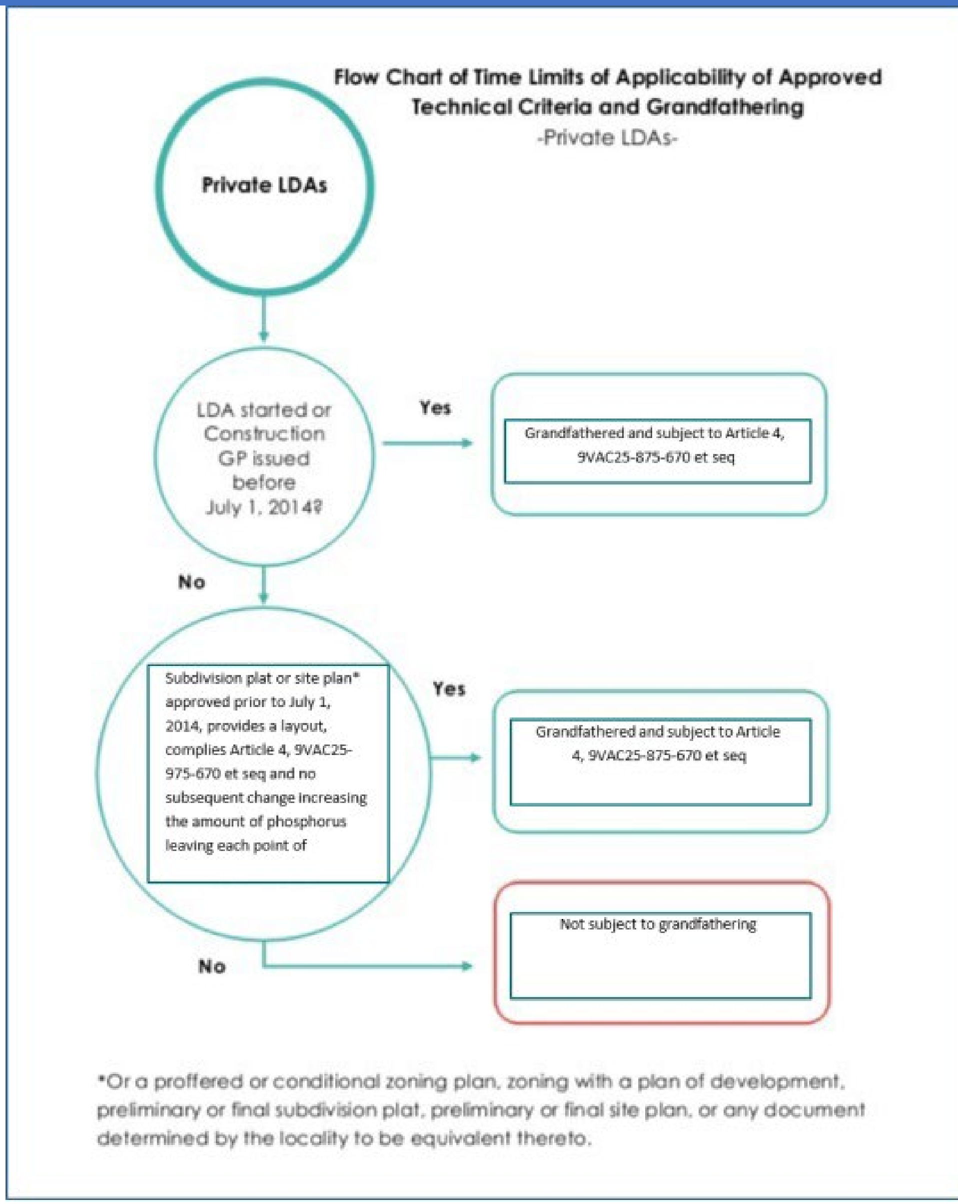


*Figure 5-4 Time Limits of Applicability and Grandfathering*




## 5.2.3 Alternatives for Meeting the Water Quantity and Water Quality Technical Criteria

(§62.1-44.15:35, 9VAC25-875-580, 9VAC25-875-590, 9VAC25-875-600, 9VAC25-875-610, 9VAC25-875-660, 9VAC25-875-730)

The following sections describe a VESMP or VSMP authority's authorization to allow an operator to meet the water quantity or water quality technical criteria fully or partially using nutrient credits and other offsite options.

### Offsite Compliance Options (§62.1-44.15:35, 9VAC25-875-610)

1. Offsite controls used in accordance with a comprehensive stormwater management plan (9VAC25-875-660) for the local watershed within which a project is located;
2. A locality pollutant loading pro rata share program (§15.2-2243) or similar local funding mechanism;

3. The non-point nutrient offset program established pursuant to §62.1-44.15:35;
4. Other offsite options approved by an applicable state agency or state board; and
5. When an operator has additional properties available within the same hydrologic unit code (HUC) or upstream HUC to which the LDA directly discharges or within the same watershed as determined by the VESMP or VSMP authority, offsite stormwater management facilities on those properties may be used to meet the required phosphorus nutrient reductions from the LDA.

A VESMP or VSMP authority shall allow an operator to use offsite options under any of the following conditions:

1. Less than 5 acres of land will be disturbed;
2. The post-construction phosphorus control requirement is less than 10 pounds per year; or
3. The operator demonstrates the following to the satisfaction of the VESMP or VSMP authority:
    a. Alternative site designs have been considered that may accommodate on-site best management practices (BMPs);
    b. Onsite BMPs have been considered in alternative site designs to the maximum extent practicable;
    c. Appropriate onsite BMPs will be implemented; and
    d. Full compliance with the post-development non-point nutrient runoff compliance requirements cannot practicably be met onsite.

If an applicant demonstrates onsite control of at least 75% of the required phosphorus nutrient reductions, the applicant is deemed to have met the requirements of items 3.a. through 3.d. as stated above. However, where an applicant cannot demonstrate onsite control of at least 75% of the required phosphorus nutrient reduction, the applicant must demonstrate to the satisfaction of the VESMP or VSMP authority items that the project complies with items 3a through 3d as stated above.

***Offsite options must not be allowed unless necessary nutrient reductions are achieved before the start of land disturbance. For phased projects, the operator may acquire or achieve offsite nutrient reductions before the start of each phase of LDA in sufficient amount for each phase.***

### Comprehensive Stormwater Management Plans (9VAC25-875-660)

A locality's VESMP authority may develop a comprehensive or regional stormwater management plan to meet the water quality and/or quantity criteria. The plan must be approved by VDEQ. During the plan's implementation, the authority must document nutrient reductions accredited to the BMPs specified in the plan.

State and federal agencies may develop comprehensive stormwater management plans and may participate in locality-developed comprehensive stormwater management plans where practicable and permitted by the locality VSMP authority.

### Nutrient Offset Program (§62.1-44.15:35, 9VAC25-875-610)

A VESMP or VSMP authority is authorized to allow the use of nutrient credits for compliance with water quality and water quantity technical criteria in the Virginia Erosion and Stormwater Management Regulation. The credits must be generated in the same or adjacent fourth order subbasin, as defined by the hydrologic unit boundaries of the National Watershed Boundary Dataset, as the land-disturbing activity. If no credits are available within these subbasins when the VESMP or VSMP authority accepts the final site design, credits available within the same tributary may be used. The following requirements apply to the use of nutrient credits:

1. Documentation of the acquisition of nutrient credits shall be provided to the VESMP authority and VDEQ or the VSMP authority in a certification from the credit provider documenting the number of phosphorus nutrient credits acquired and the associated ratio of nitrogen nutrient credits at the credit-generating entity.
2. For that portion of a site's compliance with water quality technical criteria being obtained through nutrient credits, the land disturber shall (i) comply with a 1:1 ratio of the nutrient credits to the site's remaining post-development nonpoint nutrient runoff compliance requirement being met by credit use and (ii) use credits certified as perpetual credits pursuant to Article 4.02 of the State Water Control Law (§ 62.1-44.19:12 et seq. of the Code of Virginia).
4. A VESMP or VSMP authority shall allow the full or partial substitution of perpetual nutrient credits for existing onsite nutrient controls when (i) the nutrient credits will compensate for 10 or fewer pounds of the annual phosphorous requirement associated with the original land-disturbing activity or (ii) existing onsite controls are not functioning as anticipated after reasonable attempts to comply with applicable maintenance agreements or requirements and the use of nutrient credits will account for the deficiency. Upon determination by the VESMP or VSMP authority that the conditions established by clause (i) or (ii) have been met, the party responsible for maintenance shall be released from maintenance obligations related to the onsite phosphorous controls for which the nutrient credits are substituted.

Nutrient credits must also:

- Achieve necessary nutrient reductions before the start of land disturbance.

Nutrient credits cannot be used to:

- Address water quantity control requirements or
- Violate local water quality-based limitations, including any limitations imposed by the locality or MS4 owner.

The use of offsite compliance options should comply with the Regulation (9VAC25-875-610).

### Requesting an Exception from the Water Quality and Water Quantity Technical Criteria (9VAC25-875-170)

A request for an exception from the technical criteria, including the reason for making the request, may be submitted in writing to the VESMP authority.

A VESMP authority may grant exceptions to the technical requirements provided all of the following conditions are met:

- The exception is the minimum necessary to afford relief.
- Reasonable and appropriate conditions are imposed so that the intent of the Virginia Erosion and Stormwater Management Act and Regulation are preserved.
- Granting the exception will not confer any special privileges that are denied in other similar circumstances.
- Exception requests are not based on conditions or circumstances that are self-imposed or self-created.

Exceptions must not be granted for:

- Economic hardship alone;
- Obtaining required state permits; or
- Use of a water quality BMP not found on the Virginia Stormwater BMP Clearinghouse, except where allowed under Article 4 of Part V, as described in 5.2.2.

***Exceptions to requirements for phosphorus reductions are not allowed unless offsite options have been considered and found not available (9VAC25-875-170).***

# 5.3 Technical Requirements

Technical requirements include both Erosion and Sediment Control Minimum Standards (Section 5.3.1) and Stormwater Management Standards (Section 5.3.2). This section is intended to introduce the requirements but does not provide guidance on how to meet these requirements for individual projects. This guidance is provided in Chapter 6, which uses an integrated approach and provides advice on selecting BMPs. While many of the Erosion and Sediment Control Minimum Standards and Stormwater Minimum Standards are separate, it is important to understand that the stormwater standard described in this section does interact with the Stormwater Management Standards in important ways. This is discussed in detail within Section 5.3.2.1.

## 5.3.1 Erosion and Sediment Control Minimum Standards

The Minimum Standards (MS) are listed in section 560 of the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-560) and state when and where ESC practices must be used for the effective control of soil erosion and sediment deposition. Every VESMP and VESCP authority must require compliance with the MS. They should be incorporated in all ESC plans and implemented in all LDAs.

The plan preparer, plan reviewer, developer (operator), and inspector should mutually understand the MS. As such, they allow for consistent enforcement and compliance throughout the state.

The MS can be divided into several distinct groups:

- Erosion control and soil stabilization (MS-1, 2, 3, and 5);
- Sediment control (MS-4 and 6);
- Slope protection (MS-7, 8, and 9);
- Channels, culverts, and outlets (MS-10 and 11);
- Watercourses (MS-12, 13, 14, and 15);
- Underground utilities (MS-16);
- Construction entrances (MS-17);
- Project completion (MS-18); and
- Water quantity stormwater management (MS-19).

In Chapter 7 Design Specifications for Construction BMPs, the potential minimum standard application of selected construction BMPs are identified with the specification under Stormwater Performance Summary.

In the discussion below, MSs are described, including application examples.

### 5.3.1.1 MS-1: Stabilization

Permanent or temporary soil stabilization will be applied to denuded (bare soil) areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization will be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization will be applied to areas that are to be left dormant for more than 1 year.

If final grade is reached on any portion of the site, vegetation must be established to prevent erosion. Because ground cover can reduce erosion potential by more than 90%, temporary seeding must be applied if any portion of the site will remain dormant for more than 14 days.

***Figure 5-5 Not at Final Grade***

- Stabilize within 7 days if dormant > 14
- Temporarily seed
- Mulch
- Permanently stabilize if dormant > 1 year

**Figure 5-6 At Final Grade**

- Stabilize within 7 days
- Permanent seeding
- Mulch

### 5.3.1.2 MS-2: Stockpiles, Waste, and Borrow Areas

During construction of the project, soil stockpiles and borrow areas will be stabilized or protected with sediment trapping measures. The applicant is responsible for the temporary protection and permanent stabilization of all soil stockpiles onsite as well as borrow areas and soil intentionally transported from the project site Locations of stockpiles and borrow pits should be identified on site plans, and stockpiles should have perimeter erosion and sediment control measures installed as well as located with enough setback distance from streams, waterways, and entrances/line of sight. Soil stockpile slopes should not exceed 2:1 (horizontal: vertical).

*Figure 5-7 Mulch on Stockpile and Protected with Silt Fence*

Per MS-1, apply temporary soil stabilization (i.e., mulch, matting or annual vegetation) to a stockpile within 7 days if it will remain dormant for more than 14 days. If the stockpile will remain onsite for more than 1 year, stabilize it using permanent stabilization (i.e., permanent seeding mixes. landscaping, stone, trees). This also applies to offsite borrow and spoil areas.

Purpose: Mulch prevents erosion by protecting the surface from raindrop impact, and silt fence intercepts and detains sediment from disturbed areas.

### 5.3.1.3 MS-3: Permanent Vegetation

A permanent vegetative cover will be established on denuded areas that are not otherwise permanently stabilized. Permanent vegetation will not be considered established until a ground cover is achieved that is uniform, mature enough to survive, and will inhibit erosion. See C-SSM-10 for requirements to consider turf established.

VESCP and VESMP authorities should verify compliance with MS-3 before releasing a site's bonds or surety.

Figure 5-8 Permanent Vegetation

Purpose: Reduce erosion and decrease sediment yield from disturbed areas.

### 5.3.1.4 MS-4: First-Step Measures

Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any LDA and will be made functional before upslope land disturbance takes place.

This MS is meant to ensure that sediment does not leave the perimeter of the LDA once site clearing, grading, and construction commences.

A certain amount of initial land disturbance may be required to provide access for equipment to install the perimeter controls, but site clearing and grading should be kept to a minimum until the perimeter controls are in place.

**Figure 5-9 Stabilized Perimeter Diversion**

**Figure 5-10 Silt Fence Perimeter Control**

Purpose: Intercept and detain small amounts of sediment from disturbed areas during construction to prevent sediment from leaving the site and decrease velocity of sheet flows and low-to-moderate level channel flow.

### 5.3.1.5 Earthen Structure Stabilization

Stabilization measures will be applied to earthen structures, such as dams, dikes, channels, and diversions, immediately after installation.

In this case, immediate stabilization is required so that the earthen erosion and sediment control structures that were installed do not become a source of sediment. Earthen structures are generally intended to impound, convey, or divert water; therefore, immediate stabilization is needed to prevent damage or failure of the structure.

**Figure 5-11 Earthen Diversion Structures Seeded and Mulched Immediately After Construction**

Purpose: Reduce erosion and sedimentation and reduce damage from sediment and runoff to downstream or offsite areas.

### 5.3.1.6 MS-6: Traps and Basins

Sediment traps and sediment basins will be designed and constructed based on the total drainage area to be served by the trap or basin. Sediment traps should be not used for more than 18 months unless they are designed as a permanent impoundment.

The minimum storage capacity of a sediment trap will be 134 cubic yards per acre of drainage area (134 cubic yards per acre is equivalent to 1 inch of runoff), and the trap will only control drainage areas less than 3 acres.

Provide a combination of man-made stormwater conveyance system improvement, stormwater detention, or other measures that is satisfactory to the VESMP or VESCP authority. Surface runoff from disturbed areas that is composed of flow from drainage areas greater than or equal to 3 acres will be controlled by a sediment basin. The minimum storage capacity of a sediment basin will be 134 cubic yards per acre of drainage area. Temporary sediment basins should be designed and constructed based on the total drainage area to be served by the sediment basin. The maximum total drainage area to be served by a temporary sediment basin should be 100 acres. The outfall system will, at a minimum, maintain the structural integrity of the basin during a 25-year storm of 24-hour duration. Runoff coefficients used in runoff calculations will correspond to a bare earth condition or those conditions expected to exist while the sediment basin is used.

The minimum storage capacity of a temporary sediment trap should be 134 cubic yards per acre of total drainage area, half of which should be in the form of a permanent pool or wet storage to provide a stable settling medium. The remaining half should be in the form of a drawdown or dry storage to provide extended settling time during less frequent, larger storm events. Concentrated stormwater flow from a temporary sediment basin should be released into an adequate stormwater conveyance system. Demonstrate that the total drainage area at the point of discharge within the stormwater conveyance system is at least 100 times greater than the drainage area served by the temporary sediment basin in question.

Sediment trapping devices should be:

- Placed at, or as near as possible to, the lowest drainage points within the disturbed area and/or where there is a connection to an offsite system;
- Installed as a first-step measure (MS-4);
- Stabilized immediately (MS-5); and
- Designed to included outlet protection for basins (MS-11)

A sediment basin may be used for drainage areas 3 acres or less in size if desired by the designer.

***Figure 5-12 Sediment Trap***
***(for < 3 acres)***

***Figure 5-13 Sediment Basin***
***(for drainage area > 3 acres)***

### 5.3.1.7 MS-7: Cut and Fill Slopes

Cut and fill slopes will be designed and constructed in a manner that will minimize erosion. Slopes that are found to be eroding excessively within 1 year of permanent stabilization will be provided with additional slope stabilizing measures until the problem is corrected.

Cut and fill slopes are susceptible to erosion due to increased runoff flow velocity, so they must be constructed in the best way possible to decrease erosion by reducing slope length and grade. Plans must clearly show slope length and grades that will remain stable. It is important that slopes are properly seeded and mulched to establish permanent vegetation so erosion by concentrated flow does not occur.

Roughening the surface of the slope can also help decrease runoff by lowering the velocity of flow and increasing water retention, which leads to better seed germination. This practice should generally be implemented unless the slope will require a high degree of maintenance mowing after vegetative establishment.

Figure 5-14 Vegetated/Stabilized Slope (left); Surface Roughening (right)

### 5.3.1.8 MS-8: Concentrated Runoff

Concentrated runoff will not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume, or slope drain structure.

Concentrated runoff flowing down a cut or fill slope will cause erosion; therefore, concentrated flow must be controlled at the outlet and down the slope through a temporary or permanent channel, flume, or slope drain.

The ends of these slope drains need outlet protection to prevent erosion from concentrated flows. Check dams in stormwater conveyances on cut/fill slopes should be used at the top and bottom of the slope and as needed along the length of the channel.

Figure 5-15 Slope Stabilization with Slope Drains to Reduce Concentrated Runoff

### 5.3.1.9 MS-9: Water Seeps

When water seeps from a slope face, adequate drainage or other protection will be provided.

Cut and fill operations may expose shallow aquifers, perched aquifers, or groundwater tables from which water may seep through the side of a slope. The water seeps can cause slopes to erode, or slough, from the soil's weight. Interception drains should be used to collect and safely convey groundwater away from unstable slopes. Riprap revetments or retaining wall may be used on steeper slopes. These areas should be clearly shown on the plans and the SWPPP.

***Figure 5-16 Slope Failure from Water Seep***

***Figure 5-17 Riprap Installation Against Failure***

### 5.3.1.10 MS-10: Inlet Protection

All storm sewer inlets that are made operable during construction will be protected so that sediment-laden water cannot enter the conveyance system without first being filtered or otherwise treated to remove sediment.

Storm sewers are designed to efficiently transport stormwater. When sediments enter the storm sewers, the following could occur:

- When the velocity of flow is high, much of the sediment will be quickly transported to the nearest receiving channel or

- When the velocity of the flow is low, the sediment will deposit in the pipes, resulting in clogging and potential flooding of a site during storm events.

Either of these scenarios can cause detrimental impacts to receiving channels and areas tributary to the channels. Proper inlet protection should be placed and maintained during all LDAs.

Inlet protection may be the outfall for the site, and additional sediment trapping measures may be needed. Inlet protection can be provided in several different configurations. These should be clearly shown on the plans and described in the SWPPP.

### 5.3.1.11 MS-11: Outlet Protection

Before newly constructed stormwater conveyance channels or pipes are made operational, adequate outlet protection and any required temporary or permanent channel lining will be installed in both the conveyance channel and receiving channel.

Outlet protection and channel lining is a component of MS-5 as well. These should be clearly shown on the plans and described in the SWPPP. Outlet protection provides energy dissipation of the concentrated discharge from a pipe or channel to prevent erosion and provide a stable transition. Temporary or permanent channel lining helps to ensure that the channel itself will not erode once water is flowing through it.

### 5.3.1.12 MS-12: Watercourse Construction

When work in a live watercourse is performed, precautions will be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material will be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if they are armored by non-erodible cover materials. Check dams, silt fence, and other perimeter controls should not be placed across a live watercourse. Ensure that proper permits (see MS-14) are included in the SWPPP.

### 5.3.1.13 MS-13: Temporary Vehicular Stream Crossing

When a live watercourse must be crossed by construction vehicles more than twice in any 6-month period, a temporary vehicular stream crossing constructed of non-erodible material will be provided.

When two different construction vehicles cross a stream, one right after the other, the stream has now been crossed twice and can no longer be crossed within the next 6 months without violating this minimum standard.

This minimum standard allows one construction vehicle to cross a stream, then return within any 6-month period without further treatment; otherwise, a temporary stream crossing must be constructed. Temporary vehicle crossings need to be properly permitted per MS-14. Temporary culverts need to be properly sized per MS-19.

Purpose: Provide a means for construction traffic to cross flowing streams without damaging the channel or banks and keep sediment generated by construction traffic out of the stream.

*Figure 5-18 Temporary Stream Crossing*

### 5.3.1.14 MS-14: Other Watercourse Regulations

All applicable federal, state, and local requirements pertaining to working in or crossing live watercourses will be met.

Activities in live watercourses usually fall under the jurisdiction of other agencies and/or regulations including:

- U.S. Army Corps of Engineers (404 Permit);
- VDEQ's 401 permitting regulations;
- Virginia Marine Resources Commission (VMRC); and
- Department of Game and Inland Fisheries (DGIF) or local wetland board time of year restrictions.

All applicable permits need to be obtained and available onsite before construction in live watercourses may start.

Water bodies may be identified through wetland delineation followed by a jurisdictional determination by the U.S. Army Corps of Engineers. Wetlands, streams, and other water bodies and the impact on these water bodies are usually indicated on plans and sometimes include permit numbers.

### 5.3.1.15 MS-15: Bed and Bank Stabilization

The bed and banks of a watercourse will be stabilized immediately after work in the watercourse is completed.

Stabilization at the end of each day or immediately after work is completed will ensure that sediment is not impacting other parts of the watercourse. Protective measures will be needed when work cannot be completed in a day.

When working in water, the safety of the workers and equipment is important. The weather also factors in heavily when deciding to continue working in a watercourse due to potentially high flows of water. Stabilization matting or rock revetment should be used from the water line to the bank full elevation, and additional measures may be necessary up to the 10-year water surface elevation. Any work within a Resources Protection Area requires local approval.

***Figure 5-19 Vegetative and Structural Streambank Stabilization Methods***


### 5.3.1.16 MS-16: Utility Construction

Underground utility lines will be installed in accordance with the following standards in addition to other applicable criteria:

1. No more than 500 linear feet of trench may be opened at one time.
2. Excavated material will be placed on the uphill sides of trenches.
3. Effluent from dewatering operations will be filtered or passed through an approved sediment trapping device (or both) before being discharged in a manner that does not adversely affect flowing streams or offsite property.
4. Material used for backfilling trenches will be properly compacted in order to minimize erosion and promote stabilization.
5. Re-stabilization will be accomplished in accordance with Part V of the Regulation, 9VAC25-875-470 et seq.
6. Applicable safety requirements will be met.

The basic principle of controlling erosion and sedimentation on utility projects is to have the trench backfilled and stabilized as soon as possible.

Greater open trench lengths are allowed if the Professional Engineer seals the drawings and provides a written narrative description and graphical depiction of the installation process that explains why a larger open trench length is necessary based upon installation process, pipe material, pipe diameter, and soil and slope characteristics. The purpose is to demonstrate the maximum practicable open trench length per installation spread (i.e., length of a linear utility being installed by one crew). Large projects may have multiple “spreads” under construction at one time.

### 5.3.1.17 MS-17: Vehicular Tracking and Construction Entrances

Where construction vehicle access routes intersect paved or public roads, provisions will be made to minimize the transport of sediment by vehicular tracking onto the paved surface. Where sediment is transported onto a paved or public road surface, the road surface will be cleaned thoroughly at the end of each day. Sediment will be removed from the roads by shoveling or sweeping and transported to a sediment control disposal area. Street washing will be allowed only after sediment is removed in this manner. This provision will apply to individual development lots as well as to larger LDAs.

During wet weather, construction traffic can transport a significant amount of sediment (i.e., mud) onto paved public roads, creating not only a sedimentation problem but also a safety hazard and public nuisance. Many jurisdictions have local ordinances requiring public roads to be kept clean, regardless of the applicability of the erosion and sediment control regulations.

The operator is responsible for keeping public roads adjacent to their project clean.

Mud should be swept or shoveled off the road and deposited on areas where it will not cause another sedimentation problem. Construction road stabilization accessing staging areas and stockpiles will help minimize sediment transport.

#### 5.3.1.18 MS-18: Temporary Control Removal

All temporary erosion and sediment control measures will be removed within 30 days after final site stabilization or after the temporary measures are no longer needed, unless otherwise authorized by the VESMP or VESCP authority. Trapped sediment and the disturbed soil areas resulting from the disposition of temporary measures will be permanently stabilized to prevent further erosion and sedimentation.

Temporary erosion and sediment control measures can become a problem if left in place beyond their useful life.

- Sediment fences can trap wildlife and small animals.
- Sediment basins can become drowning hazards or sources of sediment in cases of failure, and they become unsightly.

Temporary control measures should be removed as soon as their function has been completed, and the area should be stabilized.

#### 5.3.1.19 MS-19: Adequate Stormwater Conveyance to Adequate Stormwater Outfall

Properties and waterways downstream from development sites will be protected from sediment deposition, erosion, and damage due to increases in volume, velocity, and peak flowrate of stormwater runoff for the stated frequency storm of 24-hour duration.

MS-19 of the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-560) requires designers to evaluate the adequacy of the downstream artificial and/or natural channels to safely convey the developed condition runoff. See Section 5.3.2.1 for more detailed information on how MS-19 interacts with the Stormwater Quantity Requirements.

Temporary sediment basins and traps should be designed to discharge to a channel after outfall.

## 5.3.2 Stormwater Management

Stormwater management requirements principally consist of managing stormwater in the post-construction condition. Requirements consist of Stormwater Quantity Requirements (5.3.2.1) and Stormwater Quality Requirements (5.3.2.2).

### 5.3.2.1 Stormwater Quantity Requirements

Stormwater quantity requirements require designers to provide stormwater management to meet channel protection and flood control requirements. Designers should note that, in meeting these requirements, the stormwater management strategy will also need to satisfy MS-19 (Stormwater Standard) within the erosion and sediment control requirements.

#### The Evolution of Minimum Standard 19 Channel Protection Criteria

MS-19 (9VAC25-875-560) requires designers to evaluate the adequacy of the downstream man-made and/or natural channels to safely convey the developed condition runoff and to verify the adequacy of all channels and pipes in the following manner:

1. If not using energy balance methodology (see Section 5.3.2.3 Channel Protection if you are unfamiliar with this method), demonstrate that the total drainage area to the point of analysis within the channel is 100 times greater than the contributing drainage area of the project (in which case, the channel or pipe system is assumed to be adequate based on the correspondingly small impact of the project's runoff to the larger stream or channel system).
2. Natural channels will be analyzed using a 2-year storm to verify that stormwater will not overtop channel banks or cause erosion of channel bed or banks.
3. All man-made channels will be analyzed using a 10-year storm to verify that stormwater will not overtop its banks and by the use of a 2-year storm to demonstrate that stormwater will not cause erosion of channel bed or banks; and
4. Pipes and storm sewer systems will be analyzed by the use of a 10-year storm to verify that stormwater will be contained within the pipe or system.
5. If the existing or man-made channels or pipes are not adequate, the applicant will:

   5.1 Improve the channel to a condition that meets the artificial channel criteria previously described. Improve the pipe or pipe system so that the 10-year storm is contained within the system.

   5.2 Develop a site design that:

   a. Will not cause the pre-development peak runoff rate from a 2-year storm to increase when runoff outfalls into a natural channel; or
   b. Will not cause the pre-development peak runoff rate from a 10-year storm to increase when runoff outfalls into a man-made channel; or
   c. Provide a combination of channel improvement, stormwater detention, or other measures satisfactory to the VESMP authority to prevent downstream erosion.

#### Safe Harbor Provision

The Safe Harbor Provision in § 62.1-44.15:28 13.a. of the Code of Virginia can be used at any site but may be particularly useful for those projects discharging to an eroded channel that could not be made adequate without implementing offsite stream restoration and/or stabilization.

The requirement to implement downstream channel improvements or restoration is often impracticable in urban areas where impacts to stream channels have been ongoing for decades and the burden of repair or stabilization cannot be equitably assigned to any single new development. Further, site design or onsite detention strategies on the new development project cannot effectively improve or reduce the existing rate of erosion and impact. As such, this lack of an adequate channel could be interpreted as disallowing any further development in the watershed until significant stream restoration is accomplished.

While a watershed-scale restoration project may be under consideration in a jurisdiction, the Safe Harbor Provision was intended to allow the new development to proceed with onsite requirements that would minimize additional impacts to the channel to the maximum extent practicable (within the construct of onsite detention).

Any LDA that provides a stormwater management design in accordance with the following will satisfy the Virginia stormwater quantity requirements and will be exempt from any flowrate capacity and velocity requirements for natural or man-made channels:

- 48-hour Extended Detention of the water quality volume (WQv);
- 24-hour Extended Detention of the runoff resulting from the 1-year, 24-hour storm; and
- Proportional reduction of the allowable peak discharge resulting from the 1-, 5-, 2-, and 10-year, 24-hour storms using forested condition.

## 5.3.2.2 Sheet Flow

Compliance with stormwater quantity regulations can be demonstrated under a sheet flow scenario as follows.

Increased volumes of sheet flow resulting from pervious or disconnected impervious areas, or from physical spreading of concentrated flow through level spreaders, must be identified and evaluated for potential impacts on downgradient properties or resources. See 9VAC25-875-600.

> *Increased volumes of sheet flow that will cause or contribute to erosion, sedimentation, or flooding of down-gradient properties or resources shall be diverted to a stormwater management facility or a stormwater conveyance system that conveys the runoff without causing down-gradient erosion, sedimentation, or flooding. See 9VAC25-875-600.*

Where pre- and post-development stormwater runoff occur as sheet flow, AND the runoff volume and velocity will not increase from pre-development to post-development, the plans, narrative, computations, and existing and proposed grades should demonstrate no increase in the 10-year, 24-hour storm post-development runoff volume and velocity compared to the pre-development volume and velocity.

Where pre- and post-development stormwater runoff occur as sheet flow, AND the runoff volume will increase from pre-development to post-development, the 10-year, 24-hour post-development sheet flow velocity should be less than or equal to the values in Table 5-1.

**Table 5-1 Allowable Sheet Flow Velocities by Slope and Cover**

| Land Slope | Land Cover | Velocity (ft/sec)* |
|---|---|---|
| 0% - 5% | Bermudagrass | 6 |
| 0% - 5% | Reed canarygrass Tall fescue<br>Kentucky bluegrass | 5 |
| 0% - 5% | Grass-legume mixture | 4 |
| 0% - 5% | Red fescue Redtop<br>Annual lespedeza Small grains<br>Temporary vegetation | 2.5 |
| 5% - 10% | Bermudagrass | 5 |

| Table 5-1 Allowable Sheet Flow Velocities by Slope and Cover | | |
|---|---|---|
| **Land Slope** | **Land Cover** | **Velocity (ft/sec)*** |
| 5% - 10% | Reed canarygrass Tall fescue Kentucky bluegrass | 4 |
| 5% - 10% | Grass-legume mixture | 3 |
| Greater than 10% | Bermudagrass | 4 |
| Greater than 10% | Reed canarygrass Tall fescue Kentucky bluegrass | 3 |
| Any | Earth, sandy silt | 2 |
| Any | Earth, silt clay | 3.5 |
| Any | Earth, clay | 6 |
| Any | Rock, sedimentary | 10 |
| Any | Rock, sandstone | 8 |
| Any | Rock, shale | 3.5 |
| Any | Rock, igneous or metamorphic | 20 |

Sources: Virginia Erosion & Sediment Control Handbook, Table 5-14; NRCS National Engineering Handbook, Part 654, Chapter 8, Table 8-4)

*For highly erodible soils (i.e., soils with an erodibility factor [K factor] greater than 0.35), permissible velocities should be decreased by 25%.

The 10-year, 24-hour post-development sheet flow depth should be less than or equal to 0.1 foot for the entire length of the flow path to the downgradient stormwater conveyance system.

The length of sheet flow should be less than or equal to the following (Natural Resources Conservation Service [NRCS] National Engineering Handbook, Equation 15-9):

$$LSF = (100\sqrt{S})/n$$

Where:

LSF = maximum length of sheet flow (ft)

S = land slope (ft/ft)

n = Manning's roughness coefficient (see Table 5-2)

| Table 5-2 Manning's Roughness Coefficients by Land Cover Type | |
|---|---|
| **Land Cover** | **Manning's n** |
| Smooth surface (concrete, asphalt, gravel, or bare soil) | 0.011 |
| Fallow (no residue) | 0.05 |
| Cultivated soils (Residue cover ≤ 20%) | 0.06 |
| Cultivated soils (Residue cover > 20%) | 0.17 |
| Short-grass prairie | 0.15 |

| Table 5-2 Manning's Roughness Coefficients by Land Cover Type | |
|---|---|
| **Land Cover** | **Manning's n** |
| Dense grasses* | 0.24 |
| Bermudagrass | 0.41 |
| Range (natural) | 0.13 |
| Light underbrush woods ** | 0.40 |
| Dense underbrush woods** | 0.80 |

(Source: NRCS National Engineering Handbook, Table 15-1)

* Includes weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

** When selecting n, consider cover to a height of about 0.1 foot, as this is the only part of the plant cover that will obstruct sheet flow.

Provide documentation and/or calculations demonstrating that increased volumes of sheet flow meet the following conditions:

1. Will not adversely impact any downgradient property (i.e., cause erosion and/or cause or worsen localized flooding);
2. Will not adversely impact any downgradient environmental features (e.g., wetlands, streams); and
3. Will be conveyed within any downgradient man-made stormwater conveyance system without causing erosion of the system for the 2-year, 24-hour storm AND will be confined within any downgradient man-made stormwater conveyance system without causing or worsening localized flooding for the 10-year, 24-hour storm.

### 5.3.2.3 Channel Protection Requirements

Channel protection requirements are intended primarily to control moderate flows that can produce channel degradation and erosion. An overview of the Channel Protection criteria is provided on Figure 5-21.

When concentrated stormwater runoff is discharged from a site, it must be discharged to a stormwater conveyance system.

> For discharges to natural conveyance systems:
>
> - Restore using natural channel design; or
> - Energy balance; or
> - Safe Harbor Provision.

When determining the channel protection requirements for a site, the designer should first determine the type of receiving stormwater conveyance system that will receive discharge from the site. The criteria for channel protection are distributed across three types of receiving channels or stormwater conveyance systems:

Natural stormwater conveyance system means the main channel of a natural stream and the flood-prone area adjacent to the main channel.

When stormwater from a development is discharged to a natural stormwater conveyance system, the maximum allowable peak flowrate from the 1-year, 24-hour storm following the LDA must be calculated either using the Energy Balance method or another methodology demonstrated by the VSMP authority to achieve equivalent results and approved by the Water Control Board. It is important to note that all stormwater quantity methods like energy balance must be computed for each point of discharge (i.e., outfall) from the site. Each outfall point should be analyzed independently. Where applicable, the allowable peak flow rate should be based on the area of the site that drains to the point of discharge in the pre-development condition.

Man-made stormwater conveyance system is defined as a pipe, ditch, vegetated swale, or other stormwater conveyance system constructed by man except for restored stormwater conveyance systems.

When stormwater from a development is discharged to a man-made stormwater conveyance system (9VAC25-875-600):

- The man-made stormwater conveyance system must convey the post-development peak flowrate from the 2-year, 24-hour storm event without causing erosion of the system. A “non-erosive velocity” is a modelled or designed velocity that does not exceed the permissible velocity for the type of lining used for the channel. Permissible velocities for each lining should be provided as a reference (e.g., Virginia Department of Transportation [VDOT] Drainage Manual Chapter 7). Detention of stormwater or downstream improvements may be incorporated into the approved LDA to meet this criterion at the discretion of the VSMP authority; or
- The peak discharge requirements for concentrated stormwater flow to natural stormwater conveyance systems (Energy Balance) must be met.

**MS-19**: *“…Stream restoration and relocation projects that incorporate natural channel design concepts are not man-made channels and shall be exempt from any flow rate capacity and velocity requirements for natural or man-made channels.”*

## Figure 5-20 Channel Protection "Road Map"

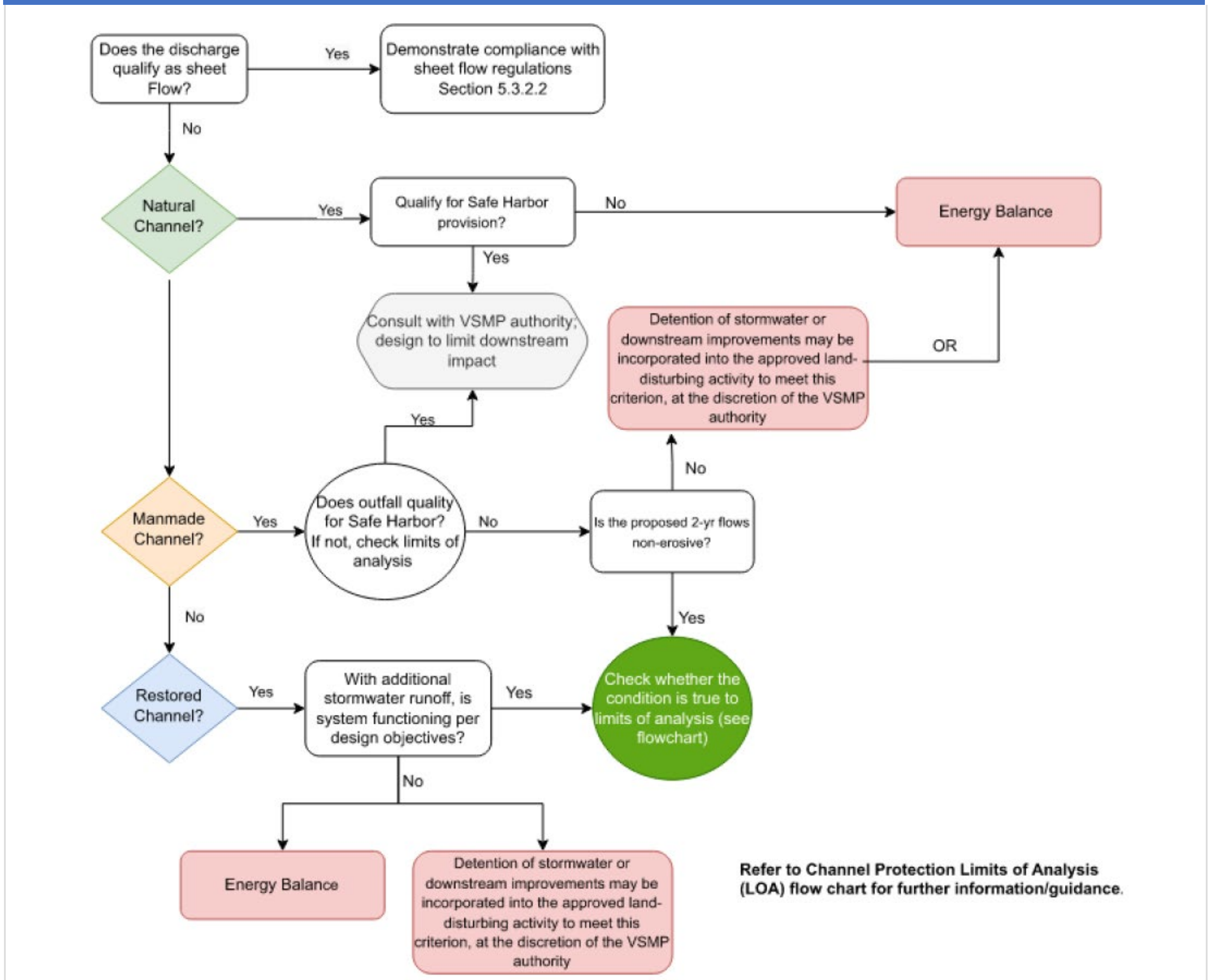
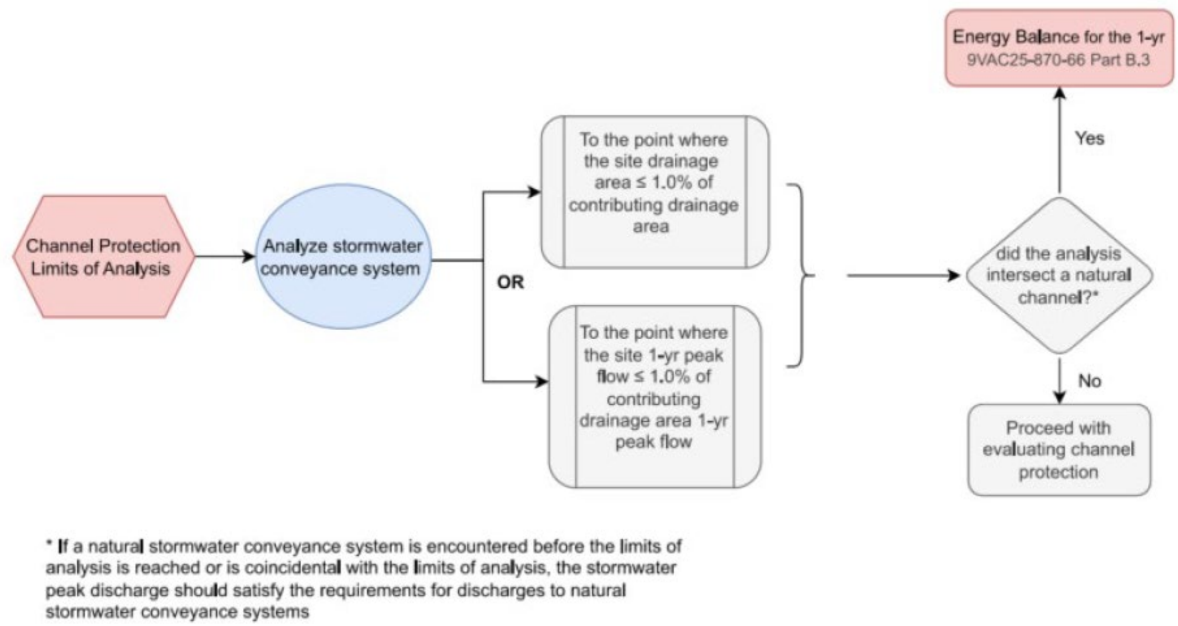


***Figure 5-21 Channel Protection Limits of Analysis***




Restored stormwater conveyance system is defined as a conveyance system that has been designed and constructed using natural channel design concepts. Restored stormwater conveyance systems include the main channel and the flood-prone area adjacent to the main channel.

When stormwater from a development is discharged to a restored stormwater conveyance system that has been restored using natural design concepts following the LDA, either (9VAC25-875-600):

- The development must be consistent, in combination with other stormwater runoff, with the design parameters of the restored stormwater conveyance system that is functioning in accordance with the design objectives; or
- The peak discharge requirements for concentrated stormwater flow to natural stormwater conveyance systems (Energy Balance) must be met.

If an existing restored stormwater conveyance system is not adequate, the applicant should develop a BMP to ensure that stormwater flow, in combination with other stormwater runoff, is consistent with the design parameters of the restored stormwater conveyance system.

## 5.3.2.4 Limits of Analysis for Channel Protection

***"Limits of Analysis" or the requirement to analyze the downstream system, and therefore the criteria for how far downstream to carry the analysis, applies only where the Energy Balance criteria are not being used.***

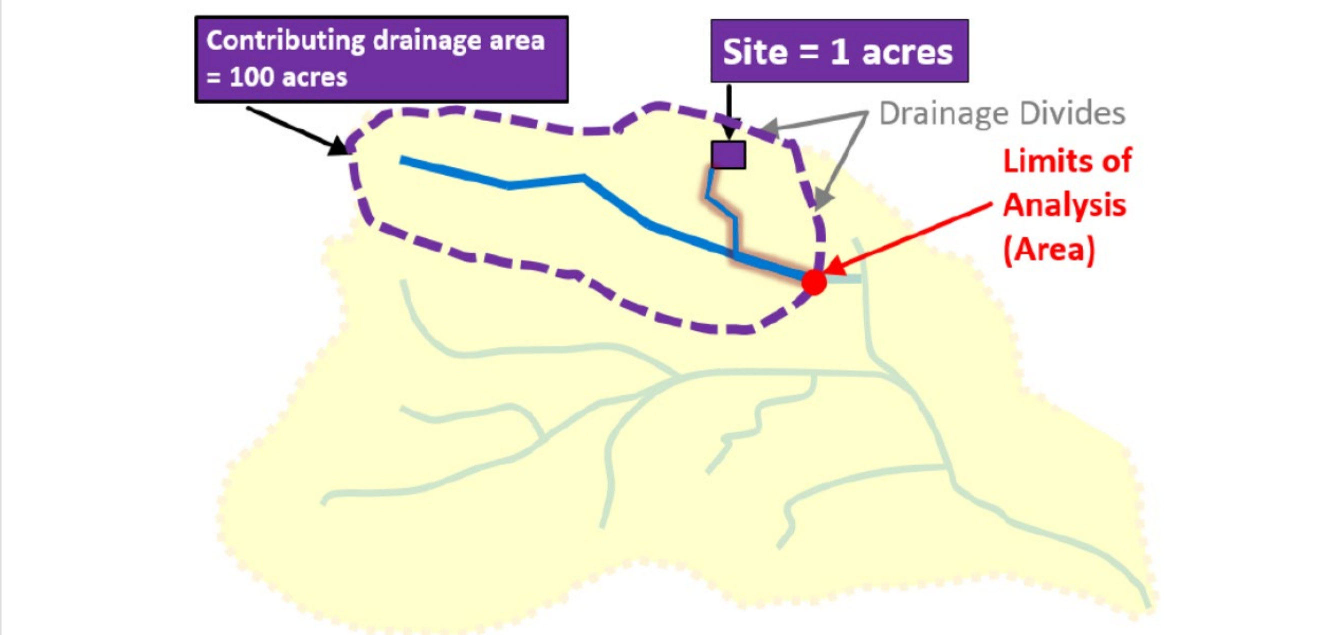
For projects that will not satisfy the channel protection requirements using the Energy Balance method (detailed in Section 5.3.2.1.2), the designer will need to establish the limits of analysis and ultimate study point for the stormwater management analysis.

The limits of analysis establish the study point downstream of the LDA to which the capacity and adequacy of the stormwater system should be analyzed to check compliance with quantity regulations.

The designer must choose one of the following two options when establishing the limits of analysis and study point. Channel protection analysis is carried to a study point where:

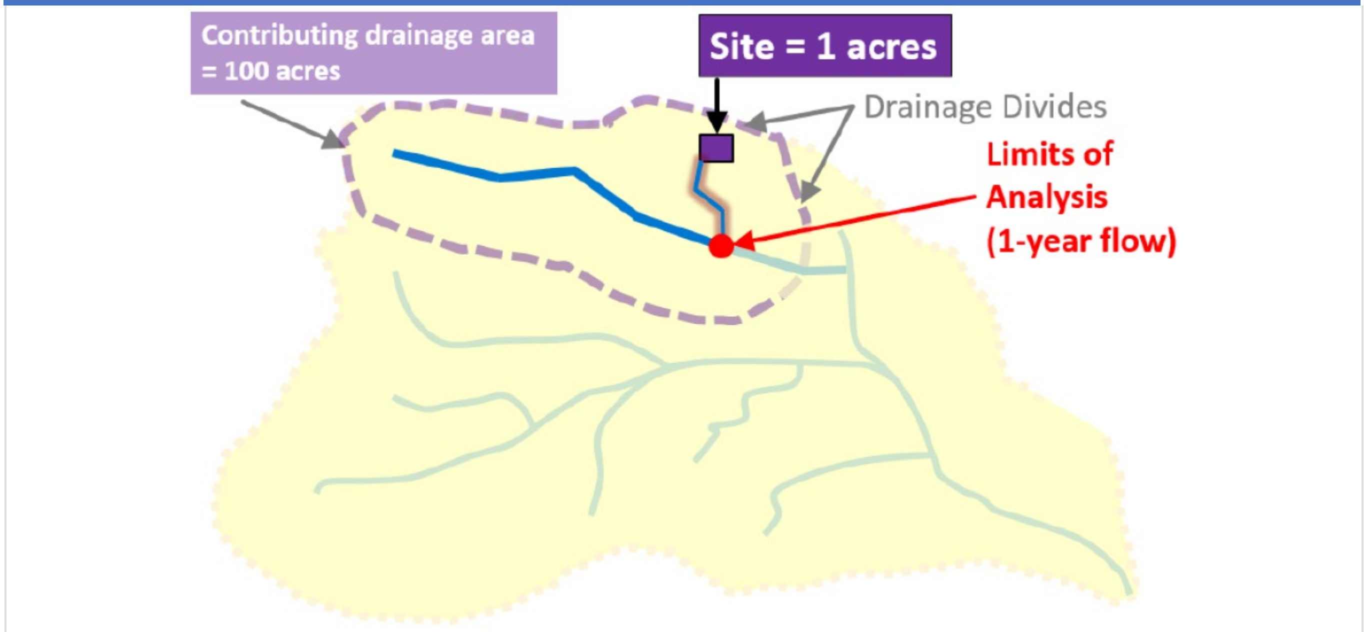
Drainage Area – The site's contributing drainage area is less than or equal to 1.0% of the total watershed area draining to the study point in the downstream stormwater conveyance system; or

***Figure 5-22 Limits of Analysis (Area)***




Peak Flowrate – The site's peak flowrate from the 1-year, 24-hour storm event is less than or equal to 1.0% of the existing peak flowrate from the 1-year, 24-hour storm event before the implementation of any stormwater quantity control measures. The designer must analyze the stormwater conveyance system using acceptable hydrologic and hydraulic methodologies to the defined study point, as described in Appendix A – Hydrologic and Hydraulic Computations and Methods.

**Figure 5-23 Limits of Analysis (Flow)**




### The Energy Balance Method (9VAC25-875-600)

The Energy Balance method is an effective strategy for targeting volume reduction and/or release rates so that channel flows are protected from extended significant flows (e.g., near bank-full flows that keep channel banks wet and susceptible to erosion).

When the Energy Balance method is applied to each discharge point leaving the site in question, no downstream analysis of the stormwater conveyance system is required, as described in Limits of Analysis for Channel Protection.

The Energy Balance method is used to determine the allowable post-development discharge for channel protection from a site. The Energy Balance method must be used to calculate the maximum allowable peak flowrate from the 1-year, 24-hour storm for those sites that discharge to a natural stormwater conveyance system, unless an alternate methodology to achieve equivalent results is approved by the VSMP authority.

The maximum allowable discharge from every concentrated (i.e., non-sheet flow) discharge point of a site for the 1-year, 24-hour storm in the post-development condition is determined by the following equation:

**Figure 5-24 Energy Balance Equation**

$$Q_{1\text{-yr-Developed}} \leq I.F.*(Q_{1\text{-yr-Pre-developed}} * RV_{1\text{-yr-Pre-Developed}})/RV_{1\text{-yr-Developed}}$$

Under no condition shall:

$$Q_{1\text{-yr-Developed}} > Q_{1\text{-yr-Pre-Developed}}$$

$$Q_{1\text{-yr-Developed}} < (Q_{1\text{-yr-Forest}} * RV_{1\text{-yr-Forest}})/RV_{1\text{-yr-Developed}};$$

I.F. (Improvement Factor) = 0.8 for sites > 1 acre or 0.9 for sites ≤ 1 acre

$Q_{1\text{-yr-Developed}}$ = the allowable peak flow rate of runoff from the developed site

$RV_{1\text{-yr-Developed}}$ = the volume of runoff from the site in the developed condition

$Q_{1\text{-yr-Pre-Developed}}$ = the peak flow rate of runoff from the site in the pre-developed condition

$RV_{1\text{-yr-Pre-Developed}}$ = the volume of runoff from the site in pre-developed condition

$Q_{1\text{-yr-Forest}}$ = the peak flow rate of runoff from the site in a forested condition

$RV_{1\text{-yr-Forest}}$ = the volume of runoff from the site in a forested condition

### Energy Balance and Run-On

When run-on or drainage from offsite areas is conveyed as concentrated flow through a post-development site, the designer should be aware that it is not required to manage this run-on flow. When the Energy Balance equation is being used to determine the allowable discharge, the improvement factor would need only be applied to the "site" as per the regulatory language of 9VAC25-875-600. In this case, the application of Energy Balance to the discharge from the site would be calculated using the following equation:

**Figure 5-25 Energy Balance Equation with Run-On**

$$q_{1post} \leq q_{1pre,site}\left(\frac{RV_{1pre,site}}{RV_{1post,site}}\right)(IF) + q_{1pre,offsite}$$

*$q_{1post-}$ = 1-year allowable post-development peak discharge from site (includes offsite run-on)*

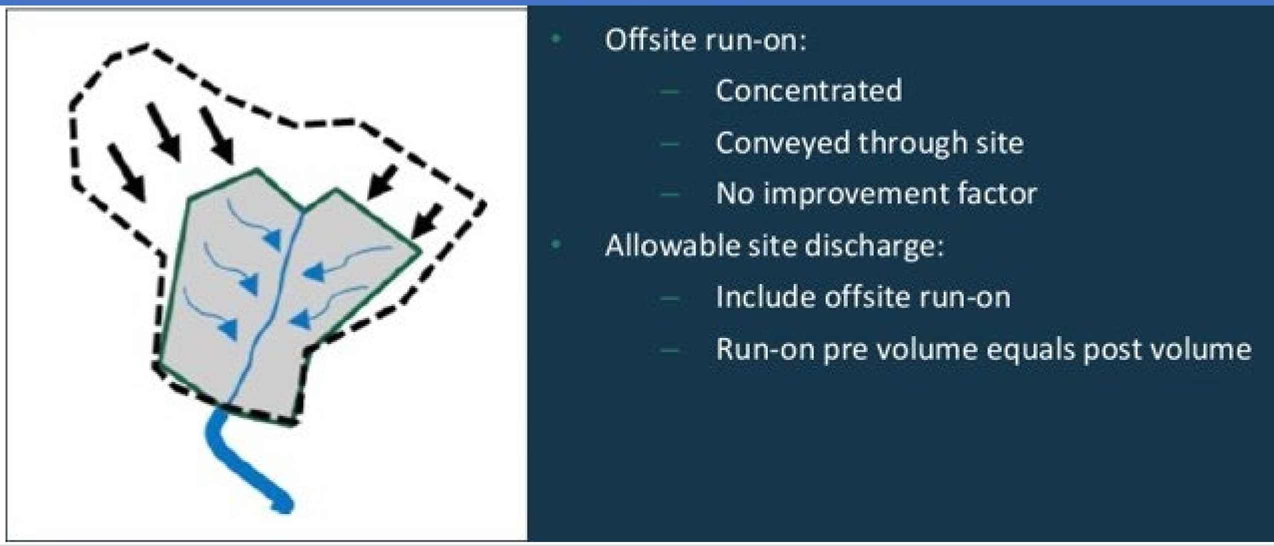
*$q_{1pre-}$ = 1-year pre-development peak discharge from site ($q_{1pre,site}$) or offsite area ($q_{1pre,offsite}$)*

*$RV_{1pre-}$ = 1-year pre-development runoff volume from site ($RV_{1post,site}$) or offsite area ($RV_{1post,offsite}$)*

*$RV_{1post-}$ = 1-year post-development runoff volume from site ($RV_{1pre,site}$) or offsite area ($RV_{1pre,offsite}$)*

*IF = improvement factor*

**Figure 5-25A Graphical Depiction of Energy Balance with Run-on**



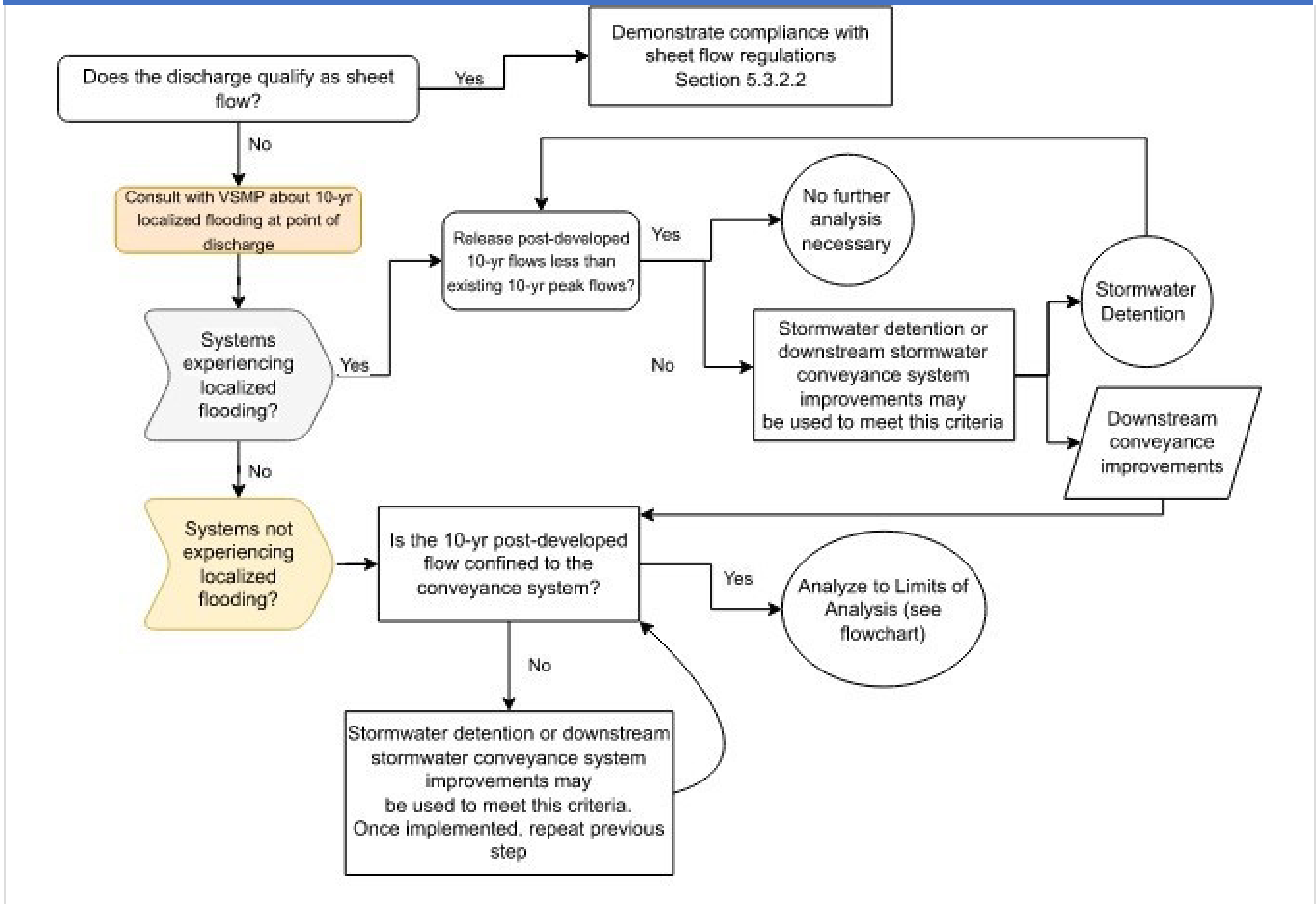

Note: The assumption in the calculation on Figure 5-26 is that the site equals the LDA. The definition for "site" is not clearly defined in the regulations, but LDAs are defined as regulated. The water quantity criteria are applied to the site as per the regulations.

This nuance can be addressed by a VESMP authority on a case-by-case basis or as standard policy, although more stringent application of water quantity technical criteria should appear in local ordinances for locality VESMP authorities.

### 5.3.2.5 Flood Protection Requirements

Unlike the channel protection requirement, the flood protection requirement focuses on addressing stormwater runoff from a flooding perspective. Flood protection is applied at each point of concentrated stormwater discharge (POD). This can be at the end of a ditch, storm sewer, or stormwater management facility (SWMF). Each point of concentrated flow will need to be analyzed to the limits of analysis. An overview of the Flood Protection criteria is provided on the flowchart on Figure 5-26.

## *Figure 5-26 Flood Protection Road Map*




**Refer to Flood Protection Limits of Analysis (LOA) flow chart for further information/guidance.**

When determining the flood protection requirements for a site, the designer should first determine the adequacy of the receiving stormwater conveyance system that will receive discharge from the site.

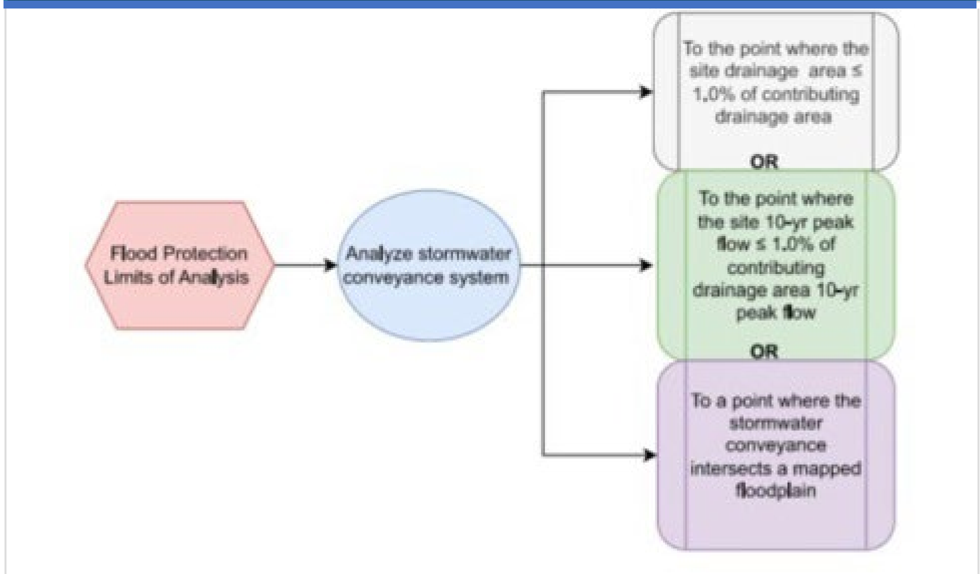
The criteria for flood protection depend on the existing condition of the receiving stormwater conveyance system. Specifically, discharges from a site to a stormwater conveyance system will meet one of the following criteria:

> Localized flooding is defined in the regulations as smaller scale flooding that may occur outside of a stormwater conveyance system, which may include high water, ponding, or standing water from stormwater runoff, which is likely to cause property damage or unsafe conditions. Since this definition may lead to subjective determinations of the presence (or lack of) localized flooding, the VESMP Authority may identify areas to be subject to the criteria.

- When concentrated stormwater runoff is discharged to a stormwater conveyance system that does not experience pre-development localized flooding (within the limits of analysis) during the 10-year 24-hour storm, the stormwater conveyance system should confine the post-development peak flow rate from the 10-year 24- hour storm within the system AND the system should be analyzed from the POD until it reaches the limits of analysis. Detention of stormwater or downstream improvements may be incorporated into the approved LDA to meet this criterion at the discretion of the VESMP authority.

- If the point of discharge is at or below the limits of analysis (see Section 3.303.1.C herein), then no additional downstream stormwater conveyance system analysis is required.
- Concentrated stormwater flow to stormwater conveyance systems that currently experience localized flooding during the 10-year, 24-hour storm event; the POD either:
  1. Confines the post-development peak flowrate from the 10-year, 24-hour storm event within the stormwater conveyance system to avoid the localized flooding. Detention of stormwater or downstream improvements may be incorporated into the approved LDA to meet this criterion at the discretion of the VESMP authority; or
  2. Releases a post-development peak flowrate for the 10-year, 24-hour storm event that is less than the pre-development peak flowrate from the 10-year, 24-hour storm event. Downstream stormwater conveyance systems do not require any additional analysis to show compliance with flood protection criteria if this option is used. Q10PRE ≥ Q10POST

**Figure 5-27 Flood Protection Limits of Analysis**




To determine whether an area is flood-prone, the following should be considered:

A. The limits of a natural stormwater conveyance system’s flood-prone area should be determined by mapping the water surface elevation associated with the pre-development 1-year 24-hour storm event. Computations supporting the natural system’s 1-year 24-hourwater surface elevation should be provided with the plan.

B. VDEQ may consider discharges to other areas adjacent to main channel (e.g., mapped Federal Emergency Management Agency (FEMA) floodplain, FEMA floodway, FEMA floodway fringe, wetlands, riparian buffers, Resource Protection Areas) on a case-by-case basis.

C. If the 10-year 24-hour pre-development water surface elevation is determined to be higher than the bank of the channel, then an existing localized flooding condition is present.

### Limits of Analysis for Flood Protection (9VAC25-875-600)

Unless the Energy Balance method is used to comply with the flood protection criteria, stormwater conveyance systems will be analyzed for compliance with flood protection criteria to a point where:

- The site's contributing drainage area is less than or equal to 1.0% of the total watershed area draining to a point of analysis in the downstream stormwater conveyance system; OR
- The site's peak flowrate from the 10-year, 24-hour storm event is less than or equal to 1.0% of the existing peak flowrate from the 10-year, 24-hour storm event before the implementation of any stormwater quantity control measures; OR

- The stormwater conveyance system enters a mapped floodplain or other flood-prone area, adopted by ordinance, of any locality.

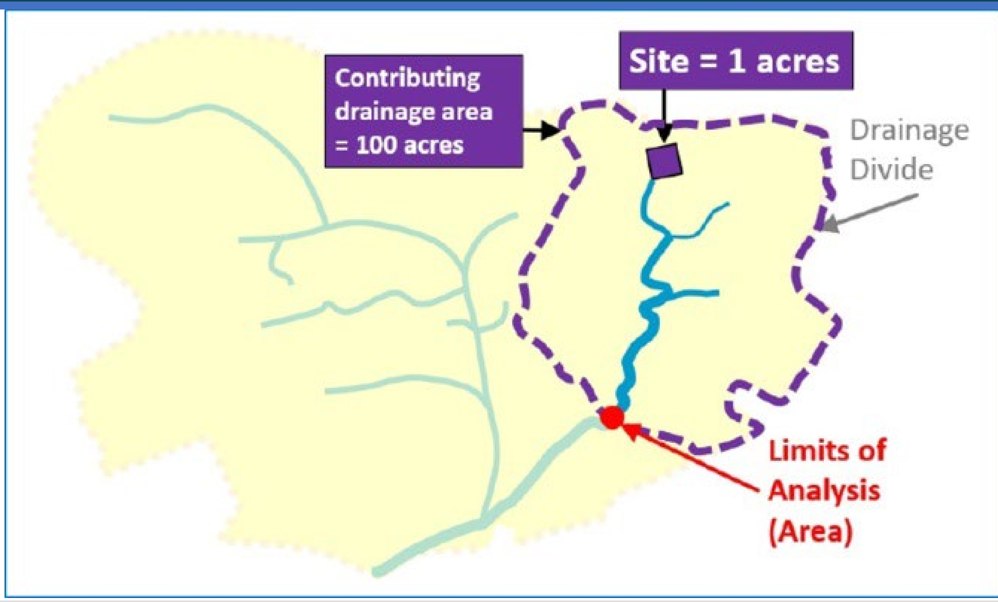
The designer must analyze the stormwater conveyance system using acceptable hydrologic and hydraulic methodologies to the defined limit of analysis.

Where the receiving conveyance system experiences localized flooding, and the post-development peak flowrate is less than the pre-developed peak flow in the 10-year storm, the limit of analysis is the POD from the site.

Otherwise, the limit of analysis for flood protection is a function of the site's contributing drainage area as follows:

- The site's contributing drainage area is less than or equal to 1.0% of the total watershed area draining to a point of analysis in the downstream stormwater conveyance system; OR

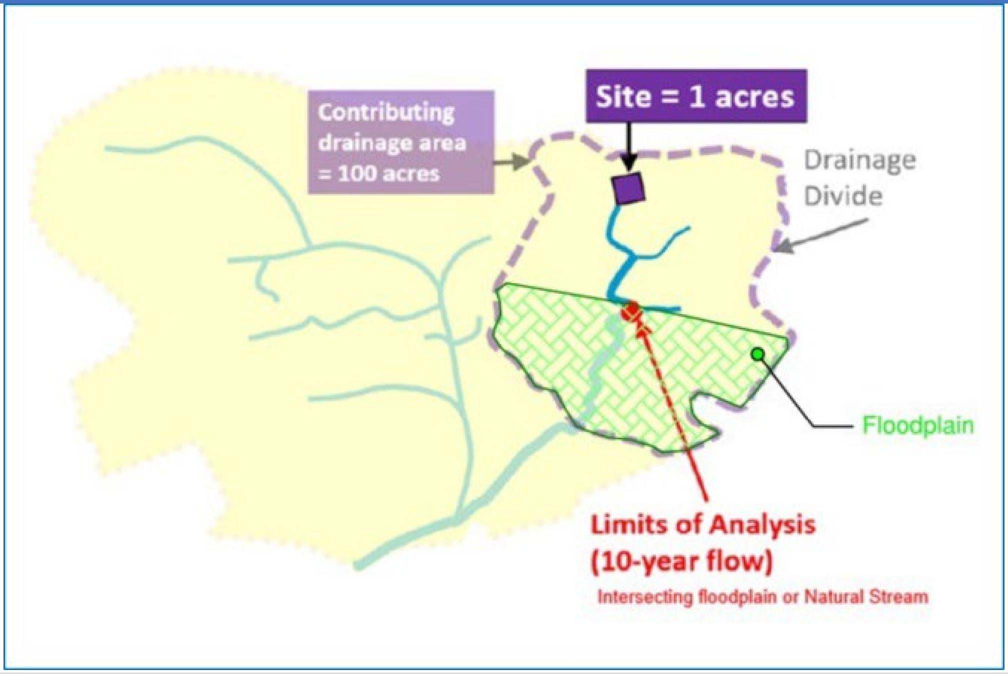
***Figure 5-28 Limits of Analysis by Area***




*Source VDEQ Plan Reviewer for SWM Training Manual*

- The site's peak flowrate from the 10-year, 24-hour storm event is less than or equal to 1.0% of the existing peak flowrate from the 10-year, 24-hour storm event before the implementation of any stormwater quantity control measures; OR
- The stormwater conveyance system enters a mapped floodplain or other flood-prone area, adopted by ordinance, of any locality.

**Figure 5-29 Limits of Analysis by Intersecting Floodplain**




*Source VDEQ Plan Reviewer for SWM Training Manual*

### 5.3.2.6 Water Quality Design Criteria Requirements

The Water Quality Design Criteria focus on the removal of pollutants from stormwater runoff. These criteria focus strongly on phosphorus removal, the level of which depends on the development characteristics. The criteria state:

To protect the quality of state waters and to control the discharge of stormwater pollutants from regulated activities, the following minimum design criteria, and state-wide standards for stormwater management will be applied to the site. Compliance should be determined by using the Virginia Runoff Reduction Method.

1. New development. The total phosphorus load of new development projects will not exceed 0.26 pound per acre per year as calculated pursuant to 9VAC25-875-590. In no instance should the total phosphorus load be required to be reduced below 0.26 pounds per acre per year. When a land-disturbing activity discharges stormwater runoff to more than one 6th order (12-digit) hydrologic unit code, the total phosphorus load reduction requirement in this section shall be applied independently within each HUC.
2. The post-development total phosphorus load should be reduced at least 20% via the implementation of stormwater management facilities or best management practices.
3. Development on previously developed lands.
    a. For LDAs disturbing greater than or equal to 1 acre that result in no net increase in impervious cover from the pre-development condition, the total phosphorus load will be reduced at least 20% below the pre-development total phosphorus load.
    b. For regulated LDAs disturbing less than 1 acre that result in no net increase in impervious cover from the pre-development condition, the total phosphorus load will be reduced at least 10% below the pre-development total phosphorus load.
    c. For LDAs that result in a net increase in impervious cover over the pre-development condition, the design criteria for new LDAs (0.26 pound per acre per year) should be applied to the

increased impervious area. Depending on the area of disturbance, the criteria of subdivisions a or b above will be applied to the remainder of the site.

d. In lieu of subdivision c of this subsection, the total phosphorus load of a linear development project occurring on previously developed lands will be reduced 20% below the pre-development total phosphorus load.

e. In no instance should the total phosphorus load be required to be reduced below 0.26 pound per acre per year.

#### 5.3.2.6.1 Requirements for Total Maximum Daily Loads, Impaired, and Exceptional Waterways

Total maximum daily loads (TMDLs) are regulatory documents that establish a maximum quantity of pollutants that can enter a given waterway. For the local stormwater manager, addressing water quality will require an effort to tailor certain stormwater criteria, watershed plans, and BMPs to help meet TMDL pollutant reduction benchmarks. Local TMDLs are established for multiple impairments to a specific section of state waters such as ammonia, fecal coliform bacteria, and chlorides. Pollutants may be added to the regional list as approved by VDEQ with scientific support. Contact the locality for information about additional requirements for local TMDLs, which may come into play for different permitted activities such as industrial operations, wastewater handling, construction, and more.

Depending on the nature of the TMDL and the implementation plan, local stormwater criteria can help address TMDL requirements. The following three general approaches are discussed in order of decreasing sophistication. Other approaches can applied, and a local program may find that a hybrid of several approaches is most applicable:

1. Site-Based Load Limits

   Some pollutants that are the basis for TMDLs are understood well enough that site-based load calculations can be performed for each development and redevelopment site. These pollutants generally include sediment, phosphorus, and nitrogen. In some areas, other pollutants (such as ammonia and fecal coliform bacteria) can be added to the list if adequate local or regional studies have been conducted.

   If the entire load reduction cannot be achieved (or is impractical) on the site, the applicant might be eligible to implement equivalent offsite BMPs within the impaired watershed. These offsite BMP may be implemented by the applicant on developed land that is currently not served by stormwater BMPs. As an alternative, the applicant can pay an appropriate fee (fee in lieu) to the local program to implement stormwater retrofits within the impaired watershed. In either case, full onsite compliance is being “traded” to implement other BMPs that can help achieve TMDL goals.

2. Surrogate Measures for Sources of Impairment

   If site-based load limits cannot be used because of the type of impairment (e.g., aquatic life) or limited data, surrogates that have a strong link to the cause of impairment can be used. For instance, various TMDLs have used impervious cover as surrogates for stormwater impacts on aquatic life, stream channel stability, and habitat (United States Environmental Protection Agency [USEPA] 2007). However, the U.S. District Court for the Eastern District of Virginia has held that stormwater flow should not be used as a surrogate for a pollutant in a TMDL (see VDOT v U.S. EPA, Civil Action No. 1:12-CV-775 (E.D. Va. Jan. 3, 2013)). In these cases, the surrogates are relatively easy to measure and track through time. The TMDL might have a goal to reduce impervious cover and/or to apply BMP treatment to a certain percentage of impervious cover within the impaired watershed.

3. Presumptive BMP Performance Standards

Perhaps the most widespread and simplest method to link TMDL goals with stormwater criteria is to presume that implementation of a certain suite of BMPs will lead to load reductions, and that monitoring and adaptive management can help adjust the appropriate template of BMPs over time.

A wide variety of "presumptive" BMPs can be included in local stormwater criteria for an impaired watershed, and these should be adapted based on the pollutant(s) of concern.

Additionally, the operator must implement the following:

- Identify the impaired water(s), approved TMDL(s), and pollutant(s) of concern, when applicable, in the SWPPP.
- Apply permanent or temporary soil stabilization to denuded areas within 7 days after final grade is reached on any portion of the site (MS-1).
- Apply nutrients in accordance with manufacturer's recommendations or an approved nutrient management plan, and do not apply during rainfall events.
- Employ enhanced inspection schedules (9VAC25-880-70 Part I B 4, B 5, and Part II A 5).

During plan review, the VESMP authority can identify any additional stormwater or erosion and sediment control design requirements that may be needed to satisfy the assumptions and requirements of a waste load allocation (WLA) applicable to the CGP for a local TMDL. Most of the TMDLs in Virginia do not have additional stormwater/construction-related assumptions and requirements; however, the Chesapeake Bay TMDL does apply to regulated construction within the Chesapeake Bay watershed. Table 5-3 summarizes the considerations that are of importance during the site design.

**Table 5-3 Considerations of Importance during Site Design**

| To Address | Plan Requirement |
|---|---|
| • Impaired waters identified in 2016 §305(b)/303(d) Water Quality Assessment Integrated Report;<br>• TMDL waste load allocation established before July 1, 2019;<br>• Exceptional waters as per 9VAC25-260-30A3c. | SWPPP must incorporate:<br>• Rapid stabilization (7 days)<br>• Appropriate use of fertilizers and nutrient management plans<br>• Enhanced inspection schedules (pursuant to 9VAC25-880-70 Part IB4, B5, and Part IIA5 of the permit) |
| By local ordinance:<br>• Protection of water resources or exceptional state waters<br>• TMDL requirements<br>• Specific existing water pollution:<br>  ○ Nutrient and sediment loadings<br>  ○ Stream channel erosion<br>  ○ Depleted groundwater resources<br>  ○ Excessive localized flooding within watershed | Implementation of any other more stringent requirements included in local stormwater management ordinance in accordance with Virginia Code §62.1 – 44.15:33. |

### 5.3.2.6.2 Solar Panel Arrays

Due to the large amount of unconnected impervious surface that is present in solar panel arrays, it is crucial that effective planning related to stormwater runoff and its effects on stormwater quality and quantity be considered both during and post-construction. See handbooks sections 6.3.1.5.2 Solar Panel Arrays through 6.3.1.5.5 Solar Installation Soil Compaction and Plant Selection/Establishment for planning, design, and operation and maintenance guidelines for solar panel installations.

## 5.4 References


VDEQ Inspector for Erosion and Sediment Control Participant Guide, Version 4.1, December 2022.

VDEQ Plan Reviewer for Erosion and Sediment Control Participant Guide, Version 4.0, July 2021.

VDEQ Plan Reviewer for Stormwater Management Participant Guide, Version 4.2, September 2020.

# CHAPTER 6 STORMWATER SITE DESIGN AND BMP SELECTION

**Contents:**

## 6.1 Introduction

This chapter provides guidance for stormwater site design and best management practice (BMP) selection while integrating environmental conservation and ecological restoration principles and concepts. Readers of this chapter should understand the regulatory compliance process (Chapter 4) and supporting regulations and laws (Chapter 3), as well as which regulations and requirements apply to their specific development or redevelopment site (Chapter 5). The objective of this chapter is to develop a compliance strategy to meet a site's regulatory requirements using available Virginia Department of Environmental Quality (VDEQ) approval methods and tools.

Good stormwater site design should enhance existing water resources, like wetlands, promote the critical functions of floodplains, and integrate with riparian buffer systems, while satisfying stormwater management and erosion and sediment control requirements. This approach maximizes the value achieved for the money spent while reducing the environmental impact from site's "footprint." A comprehensive stormwater site design integrates site characteristics and proposed development with both structural and/or non-structural onsite BMPs.

- **Structural BMPs** are physical stormwater treatment and/or storage facilities. For example, a wet pond or bioretention may be located at a point source discharge, such as at the end of a pipe or channel that routes flow to a facility for treatment.
- **Non-structural BMPs** are practices to avoid and/or minimize damage associated with stormwater volumes and runoff from development by preventing the problem. For example, by minimizing compaction of disturbed areas and reducing imperviousness.

Stormwater site design should mimic the natural hydrology and prevent any adverse downstream effects while maintaining local habitats. Implementation of the following measures can help achieve these overarching goals:

- Prevent stormwater impacts rather than having to mitigate them.
- Manage stormwater (quantity and quality) as close to the source as possible and minimize the use of large or regional collection and conveyance.
- Preserve natural areas and native vegetation.
- Reduce the impact on watershed hydrology.
- Use natural drainage pathways as a framework for stormwater site design.
- Utilize simple, non-structural methods for stormwater management that are lower cost and lower maintenance than structural controls.
- Create a multifunctional landscape.

Each of the above stormwater site design practices incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required. Principles and practices of stormwater site design are considered at the earliest stages of design, implemented during construction, and sustained in the future as a low-maintenance natural system.

While reducing the impacts from stormwater runoff may be achieved through both regulatory and non-regulatory techniques, this chapter focuses on site-level planning and design tools that provide the best opportunity to accomplish the above goals.

## 6.2 Site Inventory and Assessment

The first step in developing a site-scale compliance strategy is to complete the site inventory and assessment. This process will allow applicants to map and identify key environmental features including specific watershed and regional information, water features, topography, drainage, bedrock and groundwater, existing infrastructure, steep slopes, geology, soils and geotechnical conditions, environmental contamination, and any regulatory factors. These features are then used to guide the stormwater site design and BMP selection process outlined later in this chapter.

### 6.2.1 Watershed Scale and Regional Factors

All sites exist within a system of watersheds ranging from local drainage areas to the larger river systems of which they are a part. Responsible stormwater site design does good – working to protecting the health and vitality of downstream waters, with practical site-specific compliance strategies. The Virginia Department of Conservation and Recreation (VDCR) has developed extensive mapping resources for Virginia's system of watersheds. Designers should visit the Hydrologic Unit Geography section of the VDCR website[1] for downloadable data and online watershed mapping tools.

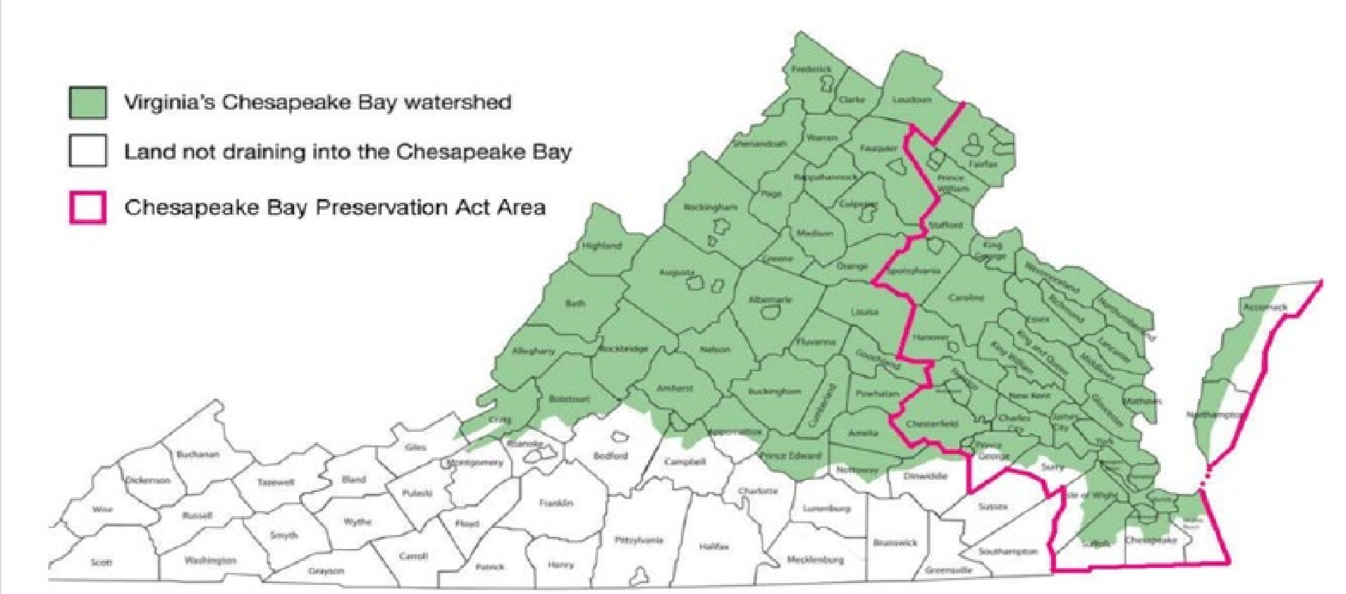
**Regional or Watershed-Wide Stormwater Plans**

Section 660 of the Virginia Erosion and Stormwater Management Regulation (9 Virginia Administrative Code [VAC] 25-875-660) allows local governments that are Virginia Erosion and Stormwater Program (VESMP) authorities to develop comprehensive stormwater management plans (that are subject to VDEQ approval) as an alternative way to comply with water quantity requirements, water quality requirements, or both. State agencies and federal entities intending to develop large tracts of land also may develop or participate in comprehensive stormwater management plans where practicable. 9VAC25-875-660. Linear development projects, such as streets and highways, are required to control post-development stormwater runoff in accordance with a site-specific stormwater management plan or a comprehensive watershed stormwater management plan. 9VAC25-875-640.

Relative to site-specific compliance, 9VAC25-875-610 allows watershed plans to provide compliance offsets (e.g., offsite mitigation, compliance trading, or fee-in-lieu options) where compliance is not feasible or cost-effective on the development site (e.g., due to physical constraints). It is important to investigate whether a site is part of a regional or watershed-wide stormwater plan, as this will have implications for BMP selection and provide information about any offsets available to address site deficits in runoff reduction (RR) or pollutant removal (PR).

Beyond regional or watershed plans, some watersheds have special design constraints (such as nutrient credit availability) or objectives (such as the requirements of Chesapeake Bay Preservation Act [Bay Act][2]) that must be considered when developing a site-scale strategy. Different watersheds will have unique needs and different methods for meeting those needs. Figure 6-1 shows the area in Virginia that is within the Chesapeake Bay watershed and the area that is subject to requirements in the Bay Act. In the Bay Act, the affected area is defined as "Tidewater Virginia" and includes the Counties of Accomack, Arlington, Caroline, Charles City, Chesterfield, Essex, Fairfax, Gloucester, Hanover, Henrico, Isle of Wight, James City, King and Queen, King George, King William, Lancaster, Mathews, Middlesex, New Kent, Northampton, Northumberland, Prince George, Prince William, Richmond, Spotsylvania, Stafford, Surry, Westmoreland, and York, and the Cities of Alexandria, Chesapeake, Colonial Heights, Fairfax, Falls Church, Fredericksburg, Hampton, Hopewell, Newport News, Norfolk, Petersburg, Poquoson, Portsmouth, Richmond, Suffolk, Virginia Beach, and Williamsburg (§ 62.1-44.15:68 VAC). Localities in Tidewater Virginia are required to determine the extent of the Chesapeake Bay Preservation Area (CBPA) within their jurisdictions.

**Figure 6-1 Chesapeake Bay Watershed in Virginia and Area Subject to the Bay Act**




For instance, whether a site is located within the Bay Act watershed meaningfully changes the land disturbance area trigger at which stormwater management and erosion and sediment control regulations are applied to site-scale developments. This is discussed in detail within Chapter 5. CBPAs are comprised of areas that ultimately drain to the Chesapeake Bay, including areas that drain to tributaries feeding the bay such as the James, York, and Rappahannock Rivers, among others. CBPAs and regulations implemented by local governments contain restrictions on development within certain buffer areas of wetlands, streams, and other sensitive water resources. Contact the appropriate representative from VDEQ's Local Government Liaison Network and the local government prior to design development to identify any restrictions or other design requirements of the Bay Act and associated regulations (9VAC25-830), which can be more stringent than the state law.

Additionally, sites draining to watersheds subject to the requirements of an approved Total Maximum Daily Load (TMDL) may also be subject to additional requirements that may influence BMP selection (see the discussion of *Critical Water Resources* within Section 6.3.3.4). TMDLs apply to waterbodies with a known pollutant. As the TMDL sets the maximum amount of a pollutant that can enter a waterbody while continuing to meet water quality standards, they are important to consider throughout development of a site. Many waterways in Virginia have at least one TMDL designation that must be accounted for. An approved list of TMDLs is provided on the VDEQ website.[3] Sites draining to pristine cold water streams (e.g., Natural Trout Waters as defined in 9VAC25-260-50) and other exceptional value resources may also require additional considerations when selecting onsite BMPs.

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[1] https://www.dcr.virginia.gov/soil-and-water/hu

[2] https://www.deq.virginia.gov/our-programs/water/chesapeake-bay/chesapeake-bay-preservation-act

[3] https://www.deq.virginia.gov/our-programs/water/water-quality/tmdl-development/approved-tmdls

## 6.2.2 Site Scale Mapping

Map existing site features as a first step in the stormwater site design process. These features can be used to develop an initial site layout that minimizes environmental impacts, identifies regulated features such as wetlands and steep slopes that may require additional approvals, and assists in selecting and locating construction and post-construction BMPs that are best suited for the particular challenges and opportunities associated with each development project. For each type of feature, a variety of mapping resources and levels of accuracy are possible, ranging from existing desktop sources to varying levels of site-specific mapping. The following sections review the types of site features that should be mapped and available resource options and techniques.

### 6.2.2.1 Wetlands, Waters, and Floodplains

Wetlands: Wetlands provide unique habitats for both plants and wildlife, including many threatened and endangered species. Wetlands are also valued for aesthetic and recreational reasons. Additionally, they provide valuable flood storage, groundwater recharge, and pollutant-filtering functions.

Wetlands are widely scattered throughout Virginia and commonly encountered on development sites and throughout watersheds. To determine the presence of wetlands on a site, the U.S. Fish & Wildlife Service's National Wetlands Inventory (NWI)[4] website provides a suitable initial assessment tool. Geographic Information System (GIS) resources from the locality are also likely to provide mapped wetlands. If online mapping systems indicate wetlands are present onsite, the exact location of wetlands should be established in the field by a professional. A complete wetland delineation is recommended prior to development of a site for permitting purposes. Protecting the natural functions of wetlands is a critical element of the site development process and watershed management planning. Early coordination with resource agencies is recommended to avoid project delays and pitfalls. Disturbance in a wetland may require a separate permit from VDEQ and/or the U.S. Army Corps of Engineers (USACE), which have the potential to cause construction delays if not properly managed. The Virginia Marine Resources Commission (VMRC) and local wetlands boards may also exercise regulatory authority over certain wetlands and activities within them.

Waters: Waterbodies are critical features that need to be mapped early in the stormwater site design process. Locality GIS maps and the NWI are good resources for evaluation of water sources on a site. Perennial flow determinations may be required on sites with apparent drainageways to determine permit requirements and whether any buffers are required that may impact the site footprint. Protecting and preserving these drainageways to the greatest extent possible is important for maintaining the health of the local watershed and minimizing the impact of development. Land disturbing activities in a stream, lake, pond, or other surface water may require a separate permit from VDEQ, VMRC, and/or the USACE, which have the potential to cause construction delays if not properly managed.

Floodplains and Stream Corridors: Floodplains and stream corridors include waterways and adjacent riparian lands that may be subject to flooding. Development in floodplains and riparian corridors can impair their function and subject nearby structures to damage from flooding and the meandering of natural streams. Development in floodplains is regulated by the Federal Emergency Management Agency (FEMA) and local floodplain management programs.

These sensitive areas should be properly mapped prior to beginning stormwater site design. Mapped floodplain locations for large watersheds can be found using the FEMA Flood Map Service Center, which provides information on the applicable Flood Insurance Rate Map for a site. However, not all floodplains are mapped by FEMA; for smaller drainage areas, typically under one square mile in urban areas or larger acreages in rural areas, mapping is typically not available from FEMA. In these instances, consult the locality requirements to determine what constitutes an unmapped floodplain for proper evaluation and modeling. Unmapped floodplains can be determined and defined using the USACE's Hydrologic Engineering Center River Analysis System (HEC-RAS) software, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Technical Release 55, *Urban Hydrology for Small Watersheds*, *TR-55* (1986), and other tools deemed technically appropriate by the locality and/or authority. Some localities have mapped non-FEMA floodplains as an effort to prevent future property damage and identify areas that would benefit from drainage improvements.

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[4] https://www.fws.gov/program/national-wetlands-inventory

## 6.2.2.2 Topography and Drainage Patterns

Topography: Understanding a site's topography is critical to preparing a stormwater site design that appropriately responds to, rather than reworks, the existing landscape and minimizes environmental impacts. Take advantage of topographic features to move water, create shading, stimulate visual interest, and eliminate the need for mass grading. Topography also strongly influences BMP placement. For instance, infiltration above steep slopes can lead to landslides and slope failures.

To support design, a small-scale topographic map of the site should be prepared to show the existing contour elevations at intervals from 1 to 5 feet, depending on the slope of the terrain. Existing topographic maps (e.g., U.S. Geological Survey [USGS] and locality GIS maps) are a suitable basis initially; however, the information should be field verified; if extensive grading is proposed, then field run topography would be the most accurate for grading and establishing cut and fill quantities. In some areas, high-definition light detection and ranging (LiDAR) technology can be used to generate survey-quality topographic maps. From initial mapping, slope maps can be prepared to identify steep slopes that limit grading operations or the placement of BMPs.

Drainage Patterns: Topographic features directly influence drainage patterns. All existing swales and drainage features on the site should be located and clearly marked on the topographic map, including live or intermittent streams. Existing drainage area boundaries should be mapped at a small scale to understand in detail how water flows move through the site. This information is invaluable in computing existing flow rates for regulatory purposes and defining drainage sheds to individual BMPs. Drainage patterns in highly urban areas are often different than that suggested by topographic mapping and must be field verified.

The existing drainage patterns, which consist of overland flow, swales and depressions, and natural watercourses, should be identified as critical areas where water will concentrate for design planning purposes. Some existing drainage features may be regulated wetlands or waters and must be delineated as such.

## 6.2.2.3 Bedrock and Groundwater

Bedrock: The presence of bedrock close to the surface can have a significant impact on a development project. The cost of excavation can vary considerably, especially if blasting is required. It also affects stormwater management based on infiltration characteristics. General information on the historical geology of a site can be found through the USGS Mineral Resources Online Spatial Database.[5] To determine the site-specific depth to bedrock, multiple types of testing are available. The most prevalent of these is using a drill rig to collect boring samples for laboratory evaluation and soil profiling. Ground penetrating radar and electrical resistance meters can both be used to determine underground features without drilling or boring samples. The level of accuracy and type of information gathered (e.g., characteristics such as soil, weathered rock, water, or voids) depends on the technology used, which is constantly evolving.

Groundwater: The presence of groundwater close to the surface can also have a significant impact on a development project. A high water table can impact the proper functioning of a BMP. Use of infiltration BMPs is limited since a high water table will prevent the percolation of stormwater into the soils, which is the key function for this BMP type. A high water table may cause dry detention BMPs to devolve into wet facilities; while this may enhance PR by encouraging a marsh environment, it may not be the choice of design based on maintenance, aesthetics, and water quantity requirements. An existing wet pool in a facility designated as dry decreases the available storage volume during storm events.

A high water table may also impact the construction of the embankment or impoundment facilities by making it difficult to achieve the proper compaction of the underlying foundation. Special geotechnical recommendations may be necessary to address stormwater site design or construction impacts associated with a high water table.

Desktop resources such as the USDA-NRCS Soil Survey (2019b)[6] and locality-specific GIS mapping resources can show indicators such as hydric soils, wetlands, ponding, and surface waters, which provide basic information as a first step. A field visit can be used to map more specific indicators, such as springs not shown on mapping, topographic changes, hydric soils and hydrophytic plants, and impacts to hydrologic conditions from recent development that is not captured in historical mapping.

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[5] https://mrdata.usgs.gov/

[6] https://websoilsurvey.nrcs.usda.gov/app/

### 6.2.2.4 Built Features (Existing Structures, Utilities)

A stormwater management plan for new development or for the alteration of an existing development must include a map of the site that depicts existing onsite permanent features. These include, but are not limited to, the location of existing roads, buildings, parking areas, any impervious surfaces such as sidewalks, fences, existing utilities such as water, sewer, gas, telephone, electric including overhead and underground lines, fiber optic, cable, water supply wells, and septic systems.9VAC25-875-510. Check with the local authority to confirm whether additional information is required on a plan, as this would typically be provided in a locality checklist. The plan should clearly designate whether the existing features are to be conserved, removed, or relocated, and account for that in the design.

Existing features are typically picked up in a survey that would be obtained for a development or redevelopment project. A title report as a part of the survey can identify any encumbrances on the property such as easements and may indicate the location of existing or proposed onsite features. Other sources to check for this information includes plats, aerial imagery, existing plans of development, and locality GIS resources for both the site parcel and adjacent parcels.

One aspect that is often overlooked is the presence of existing subsurface infrastructure such as underground utilities, systems, and foundations. Typically, and especially in urban areas or redevelopment areas, a utility locating service is engaged to map utilities using various methods. These may include indirect methods, such as mapping surface features like manholes, direct physical methods such as potholing or exploratory excavation, closed-circuit television, or geophysical methods such as ground penetrating radar or seismic methods. The American Society of Civil Engineers (ASCE) National Consensus Standard, *ASCE C-I 38-02, Standard Guidelines for the Collection and Depiction of Existing Subsurface Data*, specifies general requirements for data collection for a variety of survey quality levels and is an excellent resource for scoping of subsurface utility surveys. Designers should be aware that utilities on private properties are typically not mapped (e.g., as would be marked out via VA 811) and must be located in the field in most instances. The Virginia Department of Health has information available on existing wells and septic systems for sites that do not have public utilities.

### 6.2.2.5 Karst Topography

Karst is a landform produced by the dissolution of soluble bedrock (most commonly limestone or dolostone) along fractures, faults, and boundaries between different rock layers over hundreds of thousands of years or more of geologic time. Karst is frequently characterized by landscape features such as sinkholes, sinking and losing streams, swallets, caves, and springs. Karst areas develop voids and connective channels as groundwater gradually dissolves the bedrock. In these terrains, groundwater flow can be extremely unpredictable and move much more quickly than in solid areas. Additionally, concentrated runoff has the potential to accelerate the formation of sinkholes, so it is important to manage it properly. Sinkholes can develop as flowing water exposes and then washes into the mouths of near-surface openings of subterrain channels and caverns. Rapid degradation of groundwater resources can result when sediment-laden or pollutant-laden runoff percolates into karst bedrock aquifers. It can also travel to downstream receiving channels unnoticed without surface indicators until it daylights potentially miles downstream.

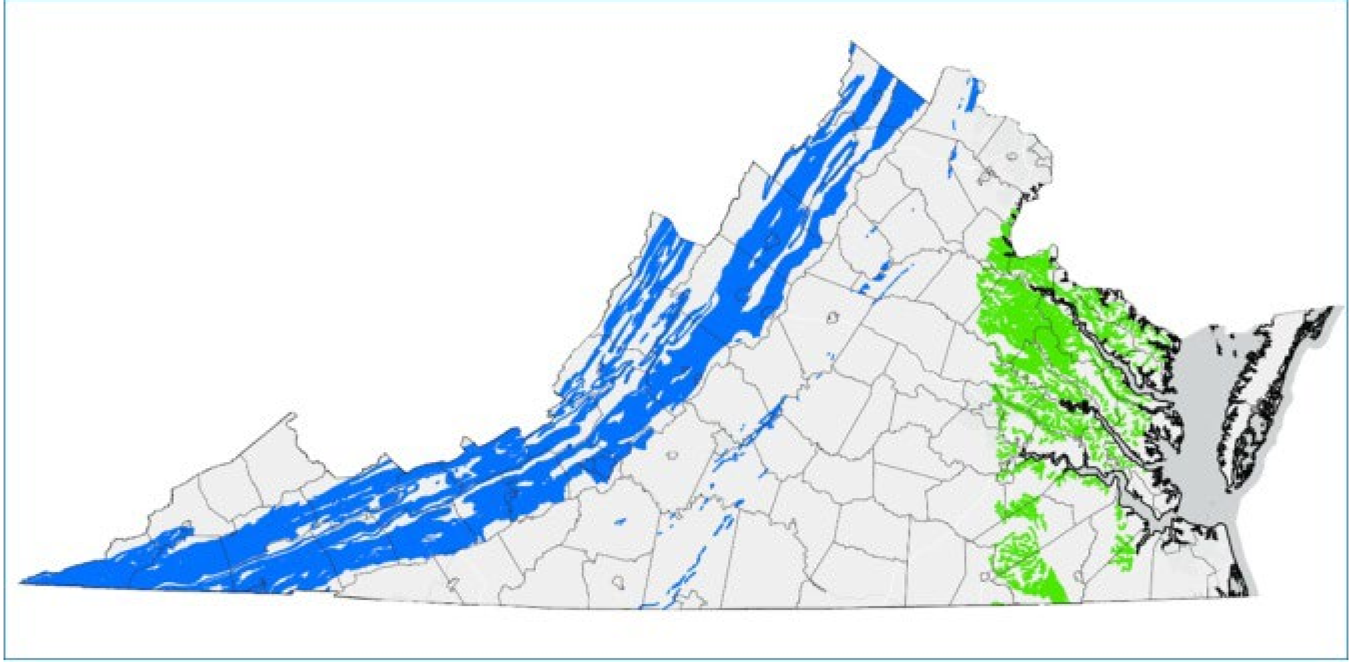
**Karst Resources**

Mapping resources and data relating to karst geology are available from the following state and federal agencies:

- **VDCR Natural Heritage Environmental Review** – dye tracing studies;
- **VDCR Division of Natural Heritage** – cave inventories;
- **Virginia Division of Mineral Resources** – GIS layers for sinkholes;
- **USDA-NRCS** – county soil survey maps; and
- **USGS, the Virginia Department of Energy, and the Virginia Department of Energy's Geology and Mineral Resources** – geological maps.

Several areas of Virginia, generally in the western region, are underlain by limestone, dolomite, or marl carbonate rocks, which are potentially susceptible to the development of karst conditions. These areas are shown on Figure 6-2. Local resources can be found through the VDCR's Natural Heritage Karst Program.[7] VDCR maintains links to other relevant data sources such as the Virginia Department of Energy, the Virginia Department of Energy's Geology and Mineral Resources, the Virginia Department of Wildlife Services, the U.S. Forest Service, and private partners such as The Cave Conservancy of the Virginias. If an area is prone to sink hole development, site drainage should be planned to minimize the concentration of runoff in those areas. Additional detail on design strategies in karst areas is provided in Section 6.3.3.5.5 and in Appendix E, *Site Assessment and Design Guidelines for Stormwater Management in Karst*.

**Figure 6-2 Karst in Virginia**



*Notes: Blue is karst developed on carbonate bedrock (Weary and Doctor 2014); green is karst in poorly consolidated sediments of the coastal plain (McFarland 2017).*

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-650) states, "Construction of stormwater management impoundment structures or facilities may occur in karst areas only after a study of the geology and hydrology of the area has been conducted to determine the presence or absence of karst features that may be impacted by stormwater runoff and BMP placement." This study process typically involves first conducting a preliminary site investigation prior to initial site layout. The preliminary assessment is then followed by a more detailed investigation that occurs once a preliminary site layout has been performed.

Preliminary assessments involve collection and review of existing data to understand the likelihood of karst features within the project area and to identify potential problem areas. These include topographic maps, LiDAR data, geologic maps, county soil surveys, aerial imagery, and sinkhole, cave mapping, and GIS layers. The preliminary assessment may also include preliminary site reconnaissance during which a visual assessment of suspected karst features is performed. Additional detail on methods for conducting preliminary site assessment in karst regions are found in Appendix E, *Site Assessment and Design Guidelines for Stormwater Management in Karst*.

Regions suspected to include karst topography are then subjected to a detailed site investigation to map and describe karst features more accurately; this is typically performed after an initial stormwater site design. Geophysical methods, direct sampling (soil borings and rock coring), and/or dye tracing are commonly used during this phase. Suggested methods for conducting a detailed site investigation are provided in Appendix E *Site Assessment and Design Guidelines for Stormwater Management in Karst*. These activities are commonly coordinated with other soil and geotechnical testing work performed to characterize subsurface conditions as described in Appendix C. Detailed assessment data and preliminary runoff modelling results for karst areas are then compiled into a Karst Site Assessment Report. Suggested content for the Detailed Karst Assessment Report is provided in Appendix E.

[7] https://www.dcr.virginia.gov/natural-heritage/karsthome

### 6.2.2.6 Biological/Ecological Resources

When designing for a site, existing onsite natural resources should be evaluated, considered, and ultimately conserved to the extent possible. Existing plants and animals should be protected to the greatest extent practicable for both long- and short-term impacts. In some instances, the natural resources may be used as design elements. For instance, natural swales can be used for conveying runoff, while forest resources can receive dispersed runoff conveyed via level spreader. Although the Regulation does not specifically address biological/ecological resources, it should be considered best practice to evaluate them during the site design process. Furthermore, be advised that impacts to these resources may be regulated by other federal, state, or local laws. Some resources to consider are given below:

Cultural Resources: Existing information can be obtained from the Virginia Department of Historic Resources. For potential BMP sites within a watershed, conduct background research to characterize the cultural resource potential of the project area. This research will provide a historic context for evaluating any cultural resources potentially located in the project area.

Fish and Wildlife Resources: Existing information on fish and wildlife resources can be obtained from the Virginia Department of Game and Inland Fisheries. This information is often useful when selecting BMPs to protect sensitive areas.

Recreational Areas and Sources of Water Supply: An inventory of recreational areas and water supply sources will facilitate, and in some cases mandate, the management goals of the watershed. This information is often available through locality GIS mapping. There also may be overlay districts associated with certain water supplies established by the local planning and zoning department. Broader data sets including recreational waterbodies are available from the USDA-NRCS and various public domain data sets, including Natural Earth.[8]

The Virginia Department of Health regulates private wells (see 12VAC5-630) and retains records as resources. In general, water withdrawal is regulated by VDEQ; due to stresses on specific aquifers, some locations may be subject to additional requirements under Groundwater Withdrawal Regulations (9VAC25-610-40, restricting groundwater withdrawal within a groundwater management area, except as authorized pursuant to a groundwater withdrawal permit), for example, the northeast parts of Virginia. Mapping these features and selecting the appropriate models to identify sources of pollution, understand the hydrologic and hydraulic characteristics of the watershed, and evaluate alternatives to meet the goals of the watershed and manage water quality is beneficial to the overall design.

Threatened and Endangered Species: Existing information can be obtained from surveys conducted by the VDCR Division of Natural Heritage. For portions of the watershed that have not been previously surveyed, the Division of Natural Heritage’s Element List can be compared to plant community information derived from previous investigations in the watershed, as well as from wetlands identification efforts. The inventory should include the most current state and federal list of potential threatened or endangered species.

Significant Trees and High-Quality Forest Stands: High quality forests provide shade, habitat, and the potential to absorb large volumes of stormwater. Consider procuring a forest stand survey to identify trees or tree stands of special value that could be saved or minimally impacted through smart design. Retaining a certified arborist is a useful step in ensuring the tree and forest resources are well protected. Also check local ordinances, which may have requirements for tree mapping and preservation.

[8] https://www.naturalearthdata.com/

### 6.2.2.7 Soils and Geotechnical Conditions

Although the Regulation does not specifically address existing soils and geotechnical conditions, it is considered best practice to evaluate them during the site design process because they may be considered a constraint or an opportunity during development. Understanding the prevalence and location of various soil types is essential when assessing stormwater impacts and stormwater management needs, as well as building constraints and requirements.

Many aspects of soils influence drainage, stormwater management, and related aspects of stormwater site design. Soil type influences permeability, or how much water can be infiltrated over time. Broadly speaking, coarse soils (i.e., having large particle size, such as sand) have high infiltration rates, while finer soils (e.g., clayey soils) have a low rate of infiltration. The level of compaction can also significantly impact infiltration rates. Soil type also affects PR potential. PR functions vary with soil type as physical processing (filtration), biological processing (various types of microbial action), and chemical processing (cation exchange capacity and other reactions) are all affected by the size and texture of various soils. For these and other reasons, understanding soil characteristics is an essential early step in stormwater site design.

> **Know Your Soil**
> Each soil type has a unique set of properties that impact how that soil will act. The most important properties are soil structure (how soil particles adhere to each other), soil texture (the size of the particles in the soil), bulk density (how tightly those particles are packed together), percentage of organic matter, infiltration rate (the speed by which water enters the soil), permeability rate (the speed by which water moves through the soil), and K factor (the rate of runoff/ erodibility factor).
>
> When dealing with structural practices that rely on infiltration (such as infiltration basins, trenches, and dry wells), the USDA-NRCS's Hydrologic Soil Group (HSG) classification is crucial for determining the appropriate BMP design strategy and for computing flow rates. All of these properties must be evaluated and mapped on a site to ensure that all soils are appropriate for the development.

Soil surveys provided by the USDA-NRCS (2019b) on a county-by-county basis provide a considerable amount of information relating to all relevant aspects of soil characteristics. Although reliance on published soil data is acceptable for most feasibility studies and conceptual planning purposes, detailed planning should be based on field investigations to verify site-specific soil types and characteristics. Note that soil surveys are notoriously unreliable in urban areas, which mainly consist of fill and decades of development and redevelopment. Some city agencies may have records of geotechnical tests performed for other projects or local mapping of areas likely filled based on analysis of historical topographic maps that may be helpful for planning purposes. However, the most accurate data comes from a geotechnical investigation, which often includes borings to determine the soil structure layered deep in the ground. This information is especially crucial when designing earthwork and retaining structures such as dams, embankments, or retaining walls. For additional information on soils and geotechnical investigation methods, see Appendix C.

#### 6.2.2.7.1 Acid Sulfate Soils and Sulfidic Materials

Acid sulfate soils form when sulfide-containing geologic materials are excavated from below the land surface and are exposed to the atmosphere during construction, land drainage, dredge disposal, or other significant land-disturbing activities. Sulfides (e.g., pyrite) are commonly found at depth in certain areas of all geologic regions of Virginia (Orndorff et al. 2004) but have been weathered and removed from oxidized surface soils over geologic time. However, when active cut/fill or dredging processes expose deeper non-weathered materials at the surface, they can rapidly oxidize to produce highly problematic soil and local water quality conditions (see Figures 6-3 and 6-4). These sulfidic materials oxidize to produce sulfuric acid, iron oxides/hydroxides, and a wide array of complex sulfate precipitates. The resulting soil is typically highly acidic (pH < 3.5), and is often associated with acidic, metal-laden stormwater runoff or seepage to groundwater. Depending on the type, concentration, and size of the sulfides present, these reactions and impacts may occur within weeks of exposure or can be time-lagged for several years. Impacts tend to be localized in and around the area of cut/fill disturbance but can extend over hundreds of acres of impact (Fanning et al. 2004) in worse case exposures (Virginia Tech 2020).

Exposure of sulfidic materials can present a number of technical, environmental, and social problems (Virginia Tech 2020):

- Acids degrade metal and concrete building materials, particularly concrete, galvanized steel, and ductile iron infrastructure.
- Weathering of fill material and precipitation of sulfates compromise structural stability via heaving of fills and cracking concrete.
- Highly acidic soils cannot support temporary or permanent vegetation, resulting in increased erosion and acidic stormwater runoff.
- Highly acidic and metal-laden stormwater runoff impairs surface water quality and aquatic life.
- Visible pollution and adverse conditions for aquatic life limit recreational use of impacted surface waters.

***Figure 6-3 Site-Specific Impacts of Acid Sulfate Soil Formation in Construction Fill Materials in Fredericksburg, Virginia***

*Note: Common diagnostic symptoms include soil/water pH < 3.5, dead or dying vegetation, red iron oxide and/or white sulfate stains on concrete, and corrosion and damage to infrastructure. Acid impacts were obvious within three months of fill placement here. Source: Virginia Tech 2020.*

**Figure 6-4 Direct Surface Water Impact to Stormwater Discharge Point**

*Note: Discharge point is < 100 feet below the lot shown on Figure 6-3. Source: Virginia Tech 2020.*

Local water quality impacts can persist for many years following construction and include low pH, high conductivity and elevated aluminum, iron and manganese. Native biota may be absent or impaired for decades. The red iron oxide "floc" seen in figures 6-3 and 6-4 is particularly diagnostic of drainage produced by actively oxidizing sulfidic materials (Virginia Tech 2020).

Acid sulfate soils occur at hundreds of sites in all geologic settings across Virginia, including (Virginia Tech 2020):

- Coastal Plain: Tertiary marine sediments and the Tabb formation.
- Piedmont: Phyllite and slate of the Quantico Formation.
- Blue Ridge: Alum phyllite.
- Valley and Ridge: Devonian black shale including the Marcellus, Millboro, and Chattanooga shale and Needmore Formation.
- Appalachian Plateau: Coal seams and shale including the Wise, Kanawha, Norton, New River, Lee, and Pocahontas Formations.

**Planning for Acid Sulfate Soils and Sulfidic Materials**

1. Screen for the relative risk of encountering acid sulfate soils within the proposed limits of clearing and grading. Screening should be performed by qualified professional with experience in acid sulfate soil recognition and/or acid abatement and remediation in mining sites. Support is also available from Virginia Tech's School of Plant and Environmental Sciences (Virginia Tech 2020).[9]

   The following Google Earth™ map overlay (.kmz) and associated guidance may be used to screen for the potential risk of encountering acid sulfate soils in near-surface excavations. File Link: https://drive.google.com/file/d/16vLAgyhnBcTuRwNbCNPuMljrjYhVBt7K/view.

Users of the Google Earth™ mapping resource should keep the following guidance in mind: This map is based on small-scale (state-wide) geologic mapping and, therefore, provides only a rough guideline for site-specific planning. This map is based on surficial geology, therefore, significant geologic changes may occur with depth (i.e., an area mapped as “no-risk” or “low-risk” may have problematic sulfide-bearing formations occurring within an excavation depth beneath the surficial geologic formation), and a “high-risk” geologic unit which has undergone significant geologic weathering may no longer be acid forming through the depth of weathering. This map is based on the Digital Representation of the Current Digital Geologic Map of Virginia[10] and is best interpreted with an understanding of local geology and landforms for the given area (Virginia Tech 2020).

2. If the relative risk of encountering acid sulfate soils within the proposed limits of clearing and grading is considered to be moderate- to high-risk, the design professional or another qualified professional with experience in acid sulfate soil recognition and remediation should perform a site-specific investigation, including the collection of soil and drainage samples (Virginia Tech 2020).
3. Follow assessment sampling protocols and procedures for site assessments available from Virginia Tech’s School of Plant and Environmental Sciences (Virginia Tech 2020)[11] or via other resources cited herein. However, the full details are beyond the scope of this guidance. The general recommended approach is as follows (Virginia Tech 2020):

Utilize the Google Earth™ based mapping tool and/or other resources available via the USGS (2003) Digital Representation of the Current Digital Geologic Map of Virginia[12] or other guidance from appropriate sources to determine the relative risk of the site’s underlying geologic unit.

If the site is over potentially sulfidic materials, then assume that all near-surface materials that are well-oxidized (soil Munsell color value > 3.5 and chroma > 2.0) are fully oxidized/weathered and not reactive. These materials will generally be brown, yellow, or red in overall color hue.

Extensive gray, bluish gray, or black materials should be sampled from soil or geologic borings and tested for total-Sulfate. Other indicators of risk are the presence of continuous red lateral banding or hardened ironstone pans at the contact between surface weathered soils and underlying gray/blue-green/black sediments.

If total-sulfur values are > 0.2 percent (%), the risk is relatively high, and these materials should be tested for potential acidity via U.S. Environmental Protection Agency (USEPA) standard acid-base-accounting procedures as detailed by Sobek et al. (2004) or the Potential Peroxide Acidity procedure described by Orndorff et al. (2008).

Even relatively minor amounts of reactive sulfides in a given sediment or other geologic materials can require extremely high amounts of reactive liming materials to neutralize. It is not uncommon to encounter sulfidic sediments within 10 feet of the existing soil surface in Virginia that contain 0.5% reactive pyritic-sulfur. Full neutralization of these materials to protect local soil and water quality requires at least 15 to 20 tons of agricultural lime per acre 6 inches in depth (or 15 to 20 tons of lime per thousand dry tons of treated material).

In addition to USEPA methods and local Virginia resources, further detailed and useful guidance on recognition and field/laboratory procedures (e.g., field oxidized pH [pHfox] test, 30% hydrogen peroxide) is available from the Australian Government Initiative’s *National Acid Sulfate Soils Sampling and Identification Methods Manual* (2018).[13]

Identify site acid-sulfate soils and/or sulfidic materials before site disturbance as a key to mitigating potential impacts. Freshly exposed unreacted sulfidic materials usually have a near neutral pH, so the only fully reliable way to identify them before disturbance is appropriate testing and laboratory analyses. However, they will react strongly with 30% hydrogen peroxide as a field screening tool, and this can be subject to “false positive” results due to the presence of manganese oxides or finely divided organic matter (e.g., humus). The potential error can largely be eliminated by a subsequent pH measurement (e.g., the pHfox test) of the reacted slurry, but it is important to note that this form of hydrogen peroxide can only be used with appropriate safety precautions (e.g., goggles, gloves) by professionals and is not publicly available.

Once sulfidic materials react to become active acid sulfate soils, distinctive visual field indicators can include: dead vegetation, red iron staining on concrete and block walls, concrete etching and dissolution, rapid corrosion of iron and galvanized metal, white sulfate salts on surfaces, yellow jarosite mottling, and occasionally strong sulfurous odor from rubbed hand samples (see Figure 6-5).

**Figure 6-5 Active Acid Sulfate Soil Formed in Cut Coastal Plain Sediments in Stafford County**


*Note: Scale is in centimeters.*

Based upon the site-specific conditions and the laboratory results, the design professional or another qualified professional with experience in acid sulfate soil recognition and remediation should develop a site soil reclamation prescription. This prescription should be incorporated into the land-disturbing activity’s Erosion and Sediment Control Plan and geotechnical investigation/report.

*The profile shown on Figure 6-5 was originally solid gray and pH 7.0 to the surface when first exposed to weathering and this photo was taken after 15 years. The surface was remediated via application of lime stabilized biosolids incorporated to 6 inches (Orndorff et al. 2008) The effective liming rate was ~50 tons of agricultural limestone per acre. The yellow mottles in the middle of the profile are jarosite ($KFe^{3+}(OH)_6(SO_4)_2$), an important diagnostic mineral phase that forms when the pH drops below 3.5. The pH of the limed surface here is 6.0, but it drops to < 4.0 within 1 foot (25 centimeters) of the surface.*

*Source: Virginia Tech 2020.*

[9] https://landrehab.org

[10] https://energy.virginia.gov/webmaps/GeologyMineralResources/

[11] https://landrehab.org/home/programs/acid-sulfate-soils-management/

[12] https://mrdata.usgs.gov/geology/state/state.php?state=VA

[13] https://www.waterquality.gov.au/issues/acid-sulfate-soils/sampling-and-identification-methods-manual

#### 6.2.2.8 Environmental Contamination

Although the Regulation does not specifically address sources of environmental contamination, they can significantly impact the stormwater management and erosion control strategy as well as the entire site development plan. Understanding and mapping these sources of contamination is critical to proper siting of stormwater and erosion and sediment control features, as well as understanding the need for and cost of environmental remediation work required create conditions suitable for intended uses. Appendix D provides guidance on evaluating a site for potential contamination. When beginning a site evaluation for potential contaminants, consult the following resources:

Locality-specific GIS Mapping: Locality GIS records often contain historical ownership information for parcels, which can provide insights about the previous onsite land use and may also indicate the types of contaminants the site potentially contains, such as petroleum from gas tanks or chemicals from a dry-cleaning operation. Property tax records zoning records may also be helpful.

Sanborn Map: Sanborn Maps were created for fire insurance companies to assess liability during the 19th and 20th centuries. The maps are now used to provide historical context for urban areas. The information can be used to determine longer-ranging historical land uses and potential contaminants or resources in an area.

Aerial Imagery: Historical aerial imagery can be used to show locations of structures and to identify changes in site use over time. This is especially helpful in determining prior uses of the site which are no longer evident in the field.

Topography Maps: Historical topographic maps can provide information on areas such as cut and fill slopes and changes in drainage patterns from historical trends.

Additional information on standard practices for environmental assessments is provided in ASTM International E1527, *Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process*, and is a good starting point for a screening-level analysis for potential contamination sources.

Stormwater Hotspots: Stormwater hotspots are defined as a land use or activity that monitoring studies have found generate higher concentrations of a particular pollutant(s), such as sediment, hydrocarbons, trace metals, or toxicants, than what are found in typical stormwater runoff (Center for Watershed Protection [CWP] 1997). Stormwater hotspots can include areas with known or suspected soil contamination based on observations of the site and/or historical land uses. Examples of operations considered to be hot spots include sand and salt storage areas typical of road operations and vehicle maintenance shops.

### 6.2.3 Regulatory Factors

It is extremely important to assess the environmental impacts associated with site development and the placement of a stormwater BMP. Local, state, and federal regulations may restrict the disturbance of or encroachment upon any of the following: wetlands, Waters of the United States, stream or wetland buffers, floodplains, conservation easements, and other sensitive resources. Two primary programs that interact with stormwater management and erosion and sediment control are the Virginia Water Protection (VWP) permit program and the National Flood Insurance Program (NFIP).

VWP Permit Program: VDEQ's VWP permit program regulates all activities in Virginia that result in impacts to surface waters, such as land clearing, dredging, filling, excavating, draining, or ditching in open water, streams and wetlands. (See generally § 62.1-44.15:20 of the Code of Virginia and 9VAC25-210.) This can include wetlands, perennial streams, and other aquatic resources. The VWP permit program operates in conjunction with the USACE Federal Permit authorized by the Clean Water Act. Some projects may require one or both permits. The permit typically requires that the developer investigate alternatives to the proposed protected feature impacts. If no alternatives are viable, then possible design modifications may be needed, such as pretreatment of stormwater prior to discharging into wetlands or addressing thermal and dissolved oxygen impacts to the receiving stream. Contact the appropriate state or federal agencies prior to design development to identify permit requirements and confirm site features as applicable.

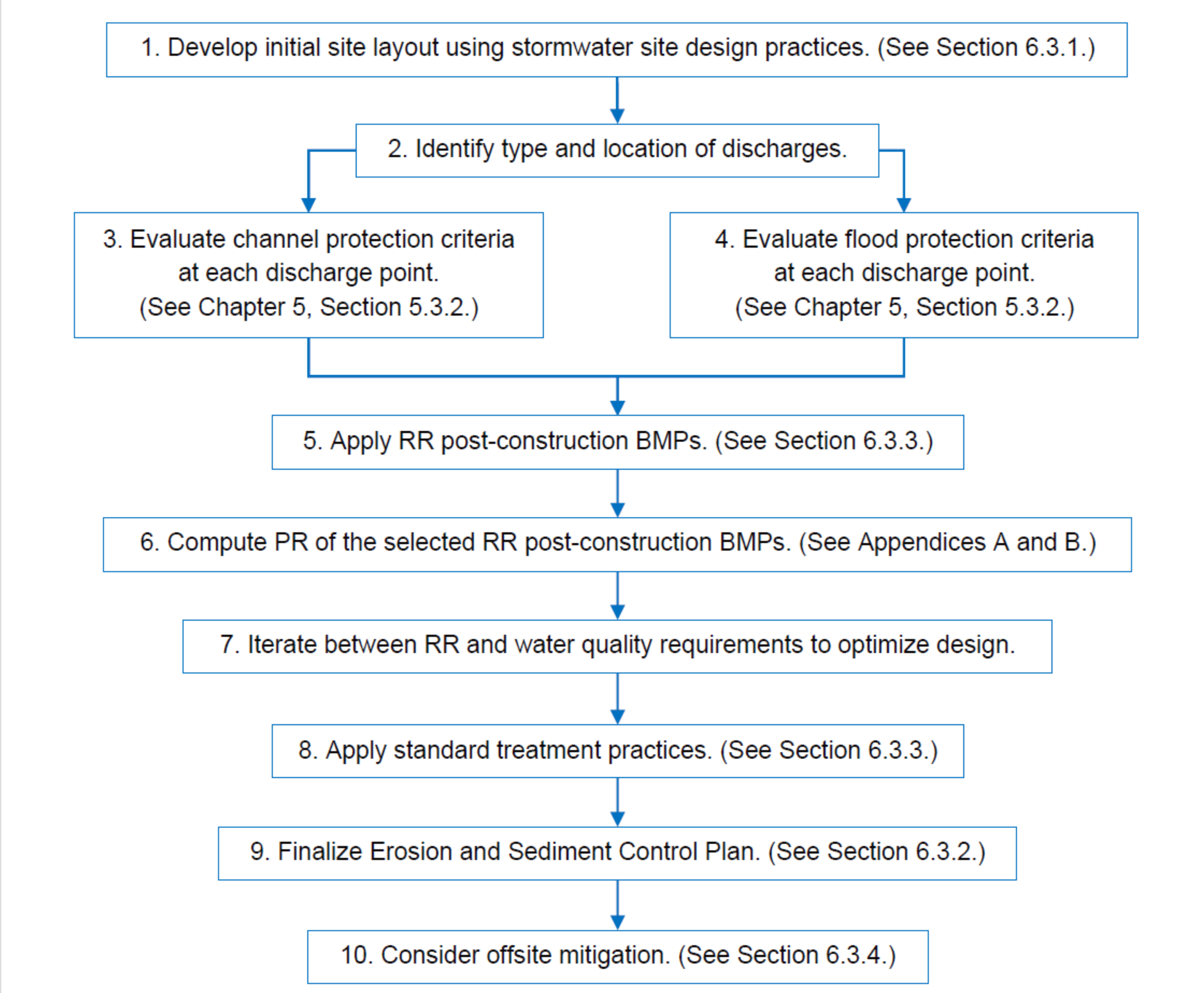
NFIP: VDCR coordinates FEMA floodplain mapping, the NFIP, and regulated dams. Local governments implement local floodplain management ordinances consistent with state and federal statutes, but local governments can also be more stringent. Contact VDCR and the local government prior to design development to identify any mapped 100-year (i.e., 1% annual exceedance probability) floodplains located on the project and determine the specific requirements for proper design.

## 6.3 Multi-Step Design Process

This section introduces a multi-step design process (shown on Figure 6-6) for site layout and design compliance with erosion and sediment control and stormwater management requirements. The process involves evaluating water quantity and water quality requirements early in the process such that a comprehensive approach to stormwater management can be developed. For more information on requirements, see Chapter 5. Review applicable state and local stormwater management requirements before undertaking the stormwater site design.

Follow this 10-step process to develop a comprehensive erosion and sediment control and stormwater management design. This process is typically more iterative than depicted here. After each design step, revisit the site layout to ensure the design still aligns well with the overall goals of the project.

**Figure 6-6 Multi-Step Design Workflow**




The stormwater site design process starts with application of stormwater site design techniques to avoid, minimize, and mitigate impacts. These include preservation of natural site features to mimic existing hydrologic runoff characteristics and minimize the impact of land development on water resources. Then evaluate the potential for RR practices and, subsequently, standard treatment practices to meet water quantity and water quality requirements. Finally, incorporate erosion and sediment controls and consider offsite mitigation to meet any remaining water quality requirements.

1. <u>Develop initial site layout using stormwater site design practices.</u>

This step focuses on stormwater site design practices at the start of the site layout. Design professionals should implement stormwater site design practices during the initial phases of site layout to the maximum extent practicable. The goal is to preserve natural features including, but not limited to, trees, riparian buffers, undisturbed high-quality soils, and drainageways, while avoiding impacts to floodplains, wetlands, karst, and steep slopes. The site inventory and assessment discussed in Section 6.2 provides the groundwork for implementing stormwater site design. Along with avoidance, work to minimize impacts to the site by reducing the clearing and grading effort as well as the amount of impervious area proposed. Also, at this stage, concurrently develop an initial strategy for erosion and sediment control, particularly with respect to limiting areas of disturbance.

2. Identify the type and location of discharges from the site.

   This step compares the post-development impacts on the site to the pre-developed condition. Identify each location in the pre- and post-development where stormwater will leave the site and identify each location as a “study point” or “point of discharge”. The natural drainage divides should be retained to the maximum extent possible to reduce stormwater detention requirements and more closely match the pre-development flow as stormwater leaves the site (see Va. Code § 62.1-44.15:28 A 10). Post-development drainage areas should deviate from the pre-developed condition by no more than plus or minus 10%.

3. Evaluate the channel protection criteria at each point of discharge from the site.

   This step focuses on understanding the water quantity requirements in the Virginia Erosion and Stormwater Management Act (VESMA) and Virginia Erosion and Stormwater Management Regulation (Regulation) to meet channel protection as discussed in Chapter 5, Section 5.3.2. The energy balance equation is applied to each point discharge (or alternative methods as applicable) and all areas of sheet flow must be identified and analyzed. In developing a strategy for meeting this criteria, remember that: (1) all concentrated flows need to be released into a stormwater conveyance system; and (2) sheet flow discharges in proposed conditions (through either disconnected or the use of level spreaders) are only applicable where sheet flow was present in the existing condition.

4. Evaluate the flood protection criteria at each point of discharge from the site.

   This step focuses on understanding the water quantity requirements in the VESMA and Regulation to meet flood protection as discussed in detail in Chapter 5, Section 5.3.2. Study the downstream channels and impacts of the post-development flow on these channels to determine what onsite practices are needed.

5. Apply RR post-construction BMPs.

   This step considers the potential combinations of RR practices on the site. Design professionals should implement RR practices during site layout to the maximum extent practicable. In each case, estimate the area to be treated by each RR practice to incrementally reduce the required treatment volume for the site. Use RR practices in series (i.e., treatment trains) within individual drainage areas (e.g., rooftop disconnection to a grass swale to a bioretention area) to achieve a higher level of RR. Major RR practices are:

   - Grass Chanel (P-CNV-01)
   - Dry Swale (P-CNV-02)
   - Vegetated Roof (P-FIL-02)
   - Rooftop Disconnection (P-FIL-01)
   - Sheet flow to Vegetated Filter/Open Space (P-FIL-07)
   - Bioretention (P-FIL-05)
   - Infiltration (P-FIL-04)
   - Permeable Pavement (P-FIL-03)

- Extended Detention (P-BAS-03)

6. Compute PR of the selected RR post-construction BMPs.

   This step uses the Virginia Runoff Reduction Method (VRRM) spreadsheet (see Appendix A and Appendix B) to determine whether the required phosphorus load reduction has been achieved by the application of RR practices. If the target phosphorous load limit is not achieved, then return to prior steps to explore alternative combinations of stormwater site design and RR practices to achieve compliance.

7. Iterate between RR practices and water quantity requirements to optimize design.

   This step focuses on applying RR practices into stormwater quantity requirements to lower the post-development curve number and peak discharge. This step will optimize the stormwater site design benefits to the overall stormwater management plan and will reduce the remaining post-development storage volume required.

8. Apply Standard Treatment Practices.

   If the target phosphorus load limit is still not reached, then select additional BMPs (also called Pollution Reducing or PR practices) that provide water quality treatment but do not provide RR (e.g., filtering practices, wet ponds, stormwater wetlands) to meet the remaining load reduction requirement. These practices are often also needed to meet stormwater quantity requirements, including the channel protection and flood control requirements. These practices should be implemented to the maximum extent practicable.

9. Finalize the Erosion and Sediment Control design to ensure a comprehensive approach.

   This step focuses on developing the erosion and sediment control plan to determine how the stormwater controls will fit within the design. Often the post-construction BMPs are utilized for sediment trapping devices during construction. Review the location of any post-construction BMP and determine the best approach to protect that facility during construction. The construction sequence is a vital guide for the contractor to construct all facilities and keep them functional throughout the construction process.

10. Offsite mitigation options to achieve phosphorus removal requirements.

    This step focuses on offsite phosphorus nutrient credit purchases, where such options are allowed by the local stormwater management program, to compensate for any load that cannot feasibly be met on a particular site. See 9VAC25-875-610 for more detail on the criteria for use of offsite options. The use of offsite mitigation is also discussed in Section 6.3.4.

## 6.3.1 Stormwater Site Design Practices

Compliance with stormwater management requirements can be achieved through multiple stormwater site design principles and practices—either individually or combined. The site inventory and assessment discussed in Section 6.2 provides the groundwork for implementing stormwater site design. Once site features are mapped, create a layout that incorporates these features into the design to reduce impacts on the watershed.

Each design practice incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required. These stormwater site design principles and practices must be considered at the earliest stages of design to be most effective, and then implemented and sustained as a low-maintenance natural system.

### 6.3.1.1 Stormwater Site Design Principles

Stormwater site design principles allow the designer to mimic natural hydrologic runoff characteristics through avoidance, minimization, and mitigation. When applied together, these principles will optimize the stormwater management design and achieve compliance with regulations.

**Avoidance**

The first principle of stormwater site design is avoidance. This principle strives to preserve natural environmental features to the maximum extent practical while still achieving development goals. The site inventory map from Section 6.2 identifies key features to better understand the site constraints. Some of those key features include, but are not limited to: wetlands, waters, floodplain, bedrock, groundwater, karst, steep slopes, and ecology. Understanding what natural systems apply to the site and making the commitment to work within the limits of these systems whenever and wherever possible provides multiple benefits to the project as described in Section 6.3.1.2.

**Minimization**

Once avoidance principles are established, the next step is to minimize impact. Minimization is the process of reducing the extent of construction and development practices that adversely impact the hydrologic conditions of the site.

Development should be strategically located based on resource areas and physical conditions at a site. This includes limiting the clearing and grading of land to the minimum needed to construct the development and associated infrastructure, as well as avoiding concentration of flows near mapped sinkholes or karst areas to reduce the risk of ground failure. Fixed improvements (e.g., roads, houses or buildings, sanitary and storm sewer utility corridors) should be located on the site to minimize unnecessary grading and/or compaction of the natural soil horizon, clearing of trees, and creating of impervious surfaces (Virginia Low Impact Development Working Group 2005).

When accounting for changes in site condition, the runoff curve number is typically used to reflect the land cover type. Of specific concern is the area of impervious cover as a fraction of the total site area. The impervious cover has a pronounced effect on the hydrologic response of the site. The site's design should mimic the pre-development hydrology and preserve the site's runoff rate and patterns; maintain the pre-development volume, frequency, and duration of runoff; and sustain groundwater recharge, stream baseflow, and stream water quality. Ideally, the post-development drainage patterns and time of concentration should closely resemble those of the pre-development condition. As land cover changes and impervious area is added, all these metrics are more challenging to achieve.

These considerations are rarely thought of as conventional stormwater management practices, yet they result in significant benefits to both stormwater quantity and quality because they essentially work as a RR practice for stormwater management.

**Mitigation**

Mitigation is the final step in stormwater site design and applied when avoidance and minimization principles have been exhausted. From both an environmental and economic perspective, redirecting runoff back into the ground, as close to the point of origin as possible, costs less and helps to maintain natural hydrology. Structural conveyance systems, which consist of inlet structures leading to a network of underground pipes to convey stormwater, increase the challenges of managing stormwater. Such systems increase flow rates and volumes, worsening erosive stormwater forces. Structural collection and conveyance systems are increasingly expensive, both to construct and maintain. An alternative is to avoid concentrating stormwater flows, which can be achieved when stormwater is infiltrated at or near the source, rather than conveyed long distances.

Mitigation begins with maximizing the disconnection of impervious cover. This practice allows stormwater to infiltrate into the ground and/or increase the time to reach the receiving channel. Both factors lower the post-development peak flow and provide more relief at discharge points from the site. Following the disconnection effort, mitigation continues by using post-construction BMPs (discussed in Section 6.3.3) to comply with regulations. The combination of avoidance, minimization and mitigation provides a comprehensive approach to stormwater site design.

#### 6.3.1.2 Stormwater Site Design Benefits

Prioritizing stormwater site design can benefit the developer and the public, as well as the environment. Environmentally conscious sites lead to lower construction costs because the increased amount of open space leads to smaller limits of clearing and grading and decreased impervious cover. There will also be fewer erosion and sediment controls required during construction. These more condensed sites also contain smaller roads and utility footprints, further decreasing the construction costs. Additionally, sites with more open space are more aesthetically pleasing and provide increased opportunities for recreation.

#### 6.3.1.3 Stormwater Site Design Process

Once the site assessment map is completed (see Section 6.2), stormwater site design principles can be implemented using stormwater site design practices (see Section 6.3.1.4).

**Avoiding Impacts**

The best way to avoid impacts is to dedicate areas with key environmental features to remain undisturbed during the construction process. This is primarily achieved through:

- Conserving natural areas (SD-1);
- Reserving stream, wetland, and shoreline buffers; and
- Minimizing disturbance of permeable soils.

Setting aside areas for preservation, often in areas that are protected already such as wetlands and stream buffers, is a straightforward way to reduce onsite impacts. Increases in open space can be claimed on the VRRM spreadsheet to reduce the phosphorus loadings associated with the site's runoff. Additionally, protecting permeable soils reduces the runoff value a site is assigned. These combine to provide both water quantity and water quality benefits.

**Minimizing Impacts**

In areas that cannot be fully avoided, minimizing onsite impacts can be achieved through:

- Maintaining natural flow paths
- Providing a building footprint and layout which limits clearing and grading
- Reducing unnecessary impervious cover

Protecting the natural flow paths to the maximum extent practicable and aligning the building in a way that reduces the required clearing and the impervious area will reduce the impacts and provide benefits in the same way, just to a smaller extent, as the practices above.

**Mitigating Impacts**

Finally, when the other two principles cannot be applied, mitigation can be used to reduce the impact of the developed areas. The primary method for mitigation is to:

- Maximize disconnection of impervious cover.

This practice promotes infiltration of runoff from the development to reduce runoff volumes and improve water quality.

#### 6.3.1.4 Stormwater Site Design Techniques and Practices

As discussed above, stormwater site design is the first step in the multi-step design process and is an important part of how VDEQ expects developers to address erosion and sediment control and stormwater management requirements. Stormwater site design strategies are implicitly connected to early discussions on site layout, arrangement, and programming and should be conducted concurrently with these early activities and built into early cost estimates used to secure project financing. If the development is part of a larger development zone or program, such as a campus or large redevelopment area, stormwater site design practices need to be considered prior to the design of specific development projects, i.e., during master planning.

The following subsections provide detailed guidance on the seven stormwater site design techniques and practices recommended by VDEQ.

##### 6.3.1.4.1 Conserve Natural Areas (SD-1)

| Table 6-1 Conserve Natural Areas (SD-1) – Key Benefits and Practice Use | |
|---|---|
| **Key Benefits** | **Using This Practice** |
| • Overall stormwater RR<br>• Overall PR in stormwater runoff<br>• Preservation of site's existing hydrology<br>• Soil erosion prevention<br>• Promotion of infiltration | • Delineate natural areas before performing site layout and design using survey, GIS, and site analysis reports.<br>• Ensure that areas to be conserved are left in an undisturbed state throughout construction and occupancy. |

Conserving natural areas on a development site helps to maintain the original hydrology of the area, aids in reducing the generation of additional stormwater runoff and pollutants and provides natural areas that can be used strategically to manage sheet flow (Figure 6-7 shows one example). Additionally:

- Undisturbed vegetated areas promote soil stabilization and provide filtering, infiltration, and evapotranspiration of runoff.
- Forested areas intercept rainfall in their canopy, reducing the amount of rain that reaches the ground, thereby reducing the likelihood of raindrop erosion.
- Vegetation pumps soil water back into the atmosphere via evapotranspiration during the growing season, which increases the storage available in the soil for the next rainfall event. Native vegetation further prevents erosion by stabilizing soil, filtering sediment and pollutants from runoff, and absorbing nutrients from the groundwater.

Natural areas are not limited to forested and grassed plots of land. Wetlands, estuaries, and coastal marshes are other natural features that provide many benefits. Amongst these are habitats for fish and wildlife, natural water quality improvement, flood storage, shoreline erosion protection, and opportunities for recreation and aesthetic appreciation. Wetlands in particular help improve water quality, including that of drinking water, by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water. In many instances, these features are regulated at the local, state, and/or federal level. Existing natural areas work to protect shallow groundwater systems, and it is important that individual development projects in particular prioritize their maintenance not only for the benefit of the site, but everyone downstream as well.

Preserving areas where threatened or endangered species exist is also a wise decision and is typically required by law. There are scientific reasons to preserve the habitat of these species. For example, species extinctions can disrupt the interactions and feedback mechanisms of natural ecosystems that have developed over time to be relatively stable and resistant to pests and diseases.

The conservation of natural areas requires limiting the extent of land-disturbing activities. Natural conservation areas are typically identified through a site analysis using survey, maps and aerial/satellite photography, GIS, or by conducting a site visit (see also Section 6.2). These areas should be delineated before any stormwater site design, clearing, or construction begins. When delineated before the concept plan is created, the planned conservation areas can be used to guide the layout of the development.

After identifying areas that remain in a natural state, prepare a concept plan that provides for the conservation and protection of natural features. The following items are important to consider:

**Figure 6-7 Subdivision with Conserved Natural Areas**

- Limit clearing and grading of native vegetation to the minimum needed to build on lots, allow access, and provide fire protection.
- Incorporate conservation areas into site plans and clearly mark all construction and grading plans to ensure that equipment is kept out of these areas and that native vegetation is not disturbed.
- Utilize open space as an effective stormwater site design technique for preserving natural areas at residential sites without losing developable lots.
- Maintain a natural buffer between adjacent properties as a way to screen and provide privacy for residential areas; this can often be accommodated if planned from the design's inception.
- Consider utilizing naturally preserved space to create an amenity, for example, providing a pervious walking path throughout a developed site.
- Connect onsite conservation areas with similar offsite areas to maximize overall natural areas and ecological function. Natural grassland areas should be five acres or larger and forested areas should be in the range of 20 to 40 acres. However, smaller areas will still yield water quality and other environmental benefits.
- Map the boundaries of each area during conceptual planning to illustrate the limits of land-disturbing activities. Once established, protect natural conservation areas during construction and ensure they are managed after occupancy by a responsible party who is able to maintain the areas in a natural state in perpetuity. Typically, conservation areas are protected by legally enforceable deed

restrictions, conservation easements, and maintenance agreements. Buildings and roads should be located around the natural topography and drainage to avoid unnecessary land disturbance.

#### 6.3.1.4.2 Preserve Stream, Wetland, and Shoreline Buffers (SD-2)

**Table 6-2 Preserving Stream, Wetland and Shoreline Buffers (SD-2) – Key Benefits and Practice Use**

| Key Benefits | Using This Practice |
|---|---|
| • Buffers can be used for nonstructural stormwater filtering and infiltration.<br>• Buffer zones provide a right-of-way for large flood events. Keeping development outside buffer zones prevents structures from being in the floodplain.<br>• Buffers preserve existing ecosystems and habitats. | • Delineate naturally vegetated buffers.<br>• Ensure that buffers and native vegetation are protected throughout construction and occupancy.<br>• Consult local plan review authority for applicable buffer requirements and recommended or minimum widths. |

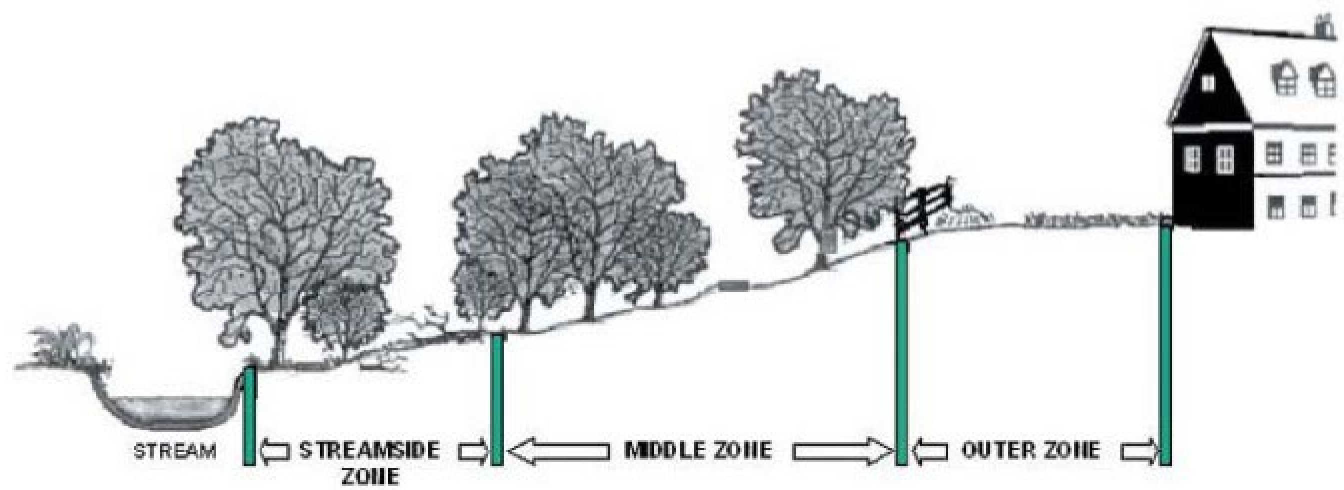
Buffers are vegetated systems protecting targeted soil and water resources, and are most commonly found along streams, rivers, lakes, wetlands, and shorelines. The primary function of buffers is to protect and physically separate a stream, lake or wetland from future disturbance or encroachment. Given the importance of riparian forests in the ecology of headwater streams, characteristics such as width, target vegetation and allowable uses within the buffer should be managed to ensure that the goals designated for the buffer are achieved. If properly designed or maintained, a buffer can stabilize soils, provide stormwater management functions, provide a right-of-way during floods, and sustain the integrity of stream ecosystems, wildlife corridors and habitats.

Buffers can provide many different ecosystem services and economic benefits, including:

- Reduced small drainage problems and complaints;
- Reduced risk of flood damage;
- Reduced stream bank erosion;
- Enhanced PR;
- Location for greenways and trails;
- Sustained integrity of stream ecosystems and habitat;
- Protection of wetlands associated with the stream corridor;
- Prevention of disturbance of steep slopes;
- Mitigation of stream warming; and
- Protection of important stream corridor habitat for wildlife.

A riparian buffer can be of fixed or variable width but should be continuous and not interrupted by impervious areas that allow stormwater to concentrate and flow into the stream without first flowing through the buffer. Local jurisdictions may designate required minimum buffer requirements for streams, wetlands, and shorelines that should be adhered to. Ideally, riparian buffers should be sized to include the 100-year (i.e., 1% annual exceedance probability) floodplain as well as steep banks and freshwater wetlands. For proper performance, buffer depth will depend on the size of the stream and the surrounding conditions; but a minimum 25- to 35-foot undisturbed vegetative buffer is needed for even the smallest perennial streams and a 50-foot or larger undisturbed buffer is ideal. Even with a 25- to 35-foot undisturbed buffer, additional zones can be added to extend the total buffer to at least 100 feet from the edge of the stream. Figure 6-8 shows the three-zone stream buffer system.

***Figure 6-8 Three-Zone Stream Buffer System***




*Source: CWP 1998*

The buffer is often viewed as simply a line drawn on a map that is virtually invisible to contractors and landowners. In order to increase awareness of the buffer and the need for its protection, local governments may require boundaries to be marked with appropriate signage.

Generally, buffers should remain in their natural state. Development within a buffer should be limited only to those structures and facilities that are necessary. The following recommendations are provided to minimize the risk of buffer encroachment and damage:

- Avoid utility crossings unless there is no feasible alternative.
- Ensure buffers appear on site plans and are clearly labeled.
- Do not place structures in buffers unless absolutely necessary.
- Ensure buffers also appear on clearing and grading plans.
- Identify buffers and discuss buffer protection measures during the pre-construction meeting.
- Ensure construction inspectors ensure that buffer integrity is not violated.
- Disclose the presence and location of buffers, with notes regarding limitations of use, on recorded plat maps.
- For planting guidance, see VDEQ’s Riparian Buffer Modification and Mitigation Guidance Manual 784 (2023b).[14]

Allowable activities should be specifically identified in any codes or ordinances enabling the buffers. When construction activities do occur within the riparian corridor, specific mitigation measures should be required, such as larger buffer widths or riparian buffer improvements. The function, vegetative target, and allowable uses vary by zone, as described in Table 6-3. These recommendations are minimum criteria that should apply to most streams. Some streams and watersheds may require additional measures to achieve protection. In some areas, specific laws and regulations (e.g., the Bay Act) or local ordinances (e.g., drinking water reservoir protection) may require stricter buffers than those described here. The recommended buffer widths discussed herein are not intended to modify or supersede deeper or more restrictive buffer requirements that are already in place.

**Table 6-3 Recommended Buffer Management Zones**

| Criteria | Streamside Zone | Middle Zone | Outer Zone |
|---|---|---|---|
| **Width** | Minimum 25 feet plus wetland and critical habitat (35 feet is better for both forest and wildlife habitat); protect the physical integrity of the stream ecosystem. | Variable, depending on stream order, slope, and extent of 100-year floodplain (minimum 25 feet, but generally 50 to 75 feet); provides a buffer between upland development and the streamside zone. | 25-foot minimum setback from structures; prevent encroachment and filter backyard runoff. |
| **Vegetative Cover** | Undisturbed mature forest. Reforest, if grass. | Managed forest, with some clearing allowed. | Forest encouraged, but usually turfgrass. |
| **Allowable Uses** | **Very Restricted** e.g., flood control, utility easements, rights-of-way, footpaths, limited water access, trimming for sight lines. | **Restricted** e.g., some passive recreational uses, some stormwater controls, pedestrian and bike paths, tree removal by permit. | **Unrestricted** e.g., residential uses including lawn, garden, compost, yard wastes, and most stormwater controls. |

Source: Minnesota Pollution Control Agency 2006.

In addition to runoff protection, the streamside zone provides bank stabilization as well as shading and protection for the stream. This zone should also include wetlands and any critical habitats, and its width should be adjusted accordingly. The middle zone provides a transition between upland development and the inner zone and should consist of managed woodland that allows for infiltration and filtration of runoff. An outer zone allows more clearing and acts as a further setback from impervious surfaces. It also functions to prevent encroachment and filter runoff.

Buffers naturally provide stormwater treatment. It is recommended that stormwater management facilities discharge to available buffers or naturalized areas prior to entering a surface water system (see also SD-7 below). To optimize stormwater treatment, the outer boundary of the buffer should be designed with a stormwater depression area and a grass filter strip. Runoff captured within the stormwater depression is spread across a grass filter designed for sheet flow conditions, and discharges to a wider forest or shrub buffer in the middle or streamside zones that can fully infiltrate and/or further treat storm flow. It is important that discharge be converted to sheet flow and dissipate energy prior to entering the outer buffer zone, as high velocity concentrated flow will cause erosion of the natural soils and subsequent conveyance into the surface water system. Sheet flow also maximizes the ground contact with the runoff to promote natural infiltration and treatment.

When establishing or enhancing riparian buffers on a development site, it is important to manage the buffer in a way that reduces the risk of catastrophic wildfire. Increasingly, development is occurring near wildland environments where wildfire is a major element of the native plant community. Development is expanding into the wildland/urban interface where structures are located next to large areas of natural vegetation. Designing defensible space around structures protects property from wildfire damage. Design that takes into consideration reduction and management of fuels on the site reduces risks to local ecosystems, property, and lives.

The Fire Hazard Rating System and National Wildland/Urban Interface Fire Protection Program provide recommendations for target vegetation around structures. If a community has a high potential risk for wildfire, there are different recommendations and requirements to reduce this risk. These hazards and their solutions should be evaluated and addressed throughout stormwater site design. Additional guidance on these topics is available through FEMA and the National Fire Protection Association.

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14 https://townhall.virginia.gov/L/GetFile.cfm?File=C:\TownHall\docroot\GuidanceDocs\440\GDoc_DEQ_5415_v1.pdf

#### 6.3.1.4.3 Minimize Disturbance of Permeable Soils (SD-3)

| Table 6-4 Minimize Disturbance of Permeable Soils (SD-3) – Key Benefits and Practice Use | |
|---|---|
| **Key Benefits** | **Using This Practice** |
| • Natural PR<br>• Reduction in stormwater runoff quantity | • Conduct in-situ soils testing to find and identify the qualities of permeable soil.<br>• Include permeable soil into the stormwater management train to further reduce runoff quantity and pollutant loadings. |

Soils are highly complex systems that provide essential environmental benefits including biofiltration of pollutants, nutrients for plant growth, and the storage and slow release of storm flows. The ability of soil to effectively store and slowly release water is dependent on its properties—texture, structure, organic matter content, and biota—as well as depth. Soil properties are the principal factor controlling the fate of water in the hydrologic system (North Carolina Department of Environmental Quality [NCDEQ] 2017).

When permeable soils are disturbed, the natural infiltration ability of the soil to reduce overall runoff quantity and provide PR prior to runoff entering downstream surface water systems is reduced or entirely removed. Retaining permeable soils can also help to meet stormwater requirements. For instance, depending on location, leaving permeable soils in place and discharging stormwater control measures to these undisturbed areas can further reduce runoff and be part of the overall energy balance design.

The first step in preserving permeable soils is determining where they exist (see also Section 6.2). Focus on identifying soils with high infiltration rates and a separation from the seasonal high water table elevation of at least 3 feet. Preliminarily utilize USDA-NRCS Soil Surveys (2019b) to obtain a general idea of the soil types existing within the project site. Next, in-situ soil testing should be performed to determine infiltration rates and the elevation of the seasonal high water table. All soil test pits, soil borings, soil permeability tests, and associated documentation should be conducted under the direct supervision of an appropriately licensed Virginia design professional § 54.1-2205. During all subsurface investigations and soil test procedures, adequate measures should be taken to ensure personnel safety and prohibit unauthorized access to the excavations at all times. Entering a soil pit excavated below the water table can be extremely dangerous and should be avoided (NCDEQ 2017). Placement of the test pits should be such that it provides adequate characterization of the infiltration area. The total number of required soil profile pits should be placed equidistant from each other to provide adequate characterization of the infiltration area. The recommended number of soil test pits for BMPs utilizing infiltration are shown in Table 65 (NCDEQ 2017).

| Table 6-5 Recommended Number of Soil Test Pits | | |
|---|---|---|
| **Number of Soil Profiles and Infiltration Tests per BMP** | | |
| **BMP Footprint** | **Number of Soil Profile Explorations** | **Number of Infiltration Tests** |
| Up to 2,500 square feet (ft2) | 1 | 1 |
| 2,500 ft2 to 10,000 ft2 | 2 | 2 |
| Greater than 10,000 ft2 | Add 1 soil profile and 1 infiltration test for each additional 10,000 ft2 of practice. | |
| Note: Linear practices should add 1 additional soil profile and infiltration test for each 100 linear feet of practice. | | |

One of the most widely accepted methods for in-situ soil infiltration testing is ASTM International Standard D 3385, *Standard Test Method for Infiltration Rate in Field Soils Using Double-Ring Infiltrometer*. A double-ring infiltrometer consists of two concentric metal rings driven into the soil and filled with water. The outer ring helps prevent divergent flow within the soil. The drop in water level or volume within the inner ring is used to calculate an infiltration rate. The infiltration rate is the depth of water per surface area over time. The diameter of the inner ring should be approximately 50% to 70% of the diameter of the outer ring, with a minimum inner ring size of 4 inches. Double-ring infiltrometer testing equipment designed specifically for that purpose may be purchased. Other constant head permeability tests, such as the Constant Head Permeameter, that utilize in-situ conditions and accompanied by an independent published source reference can be used for establishing permeability rates (NCDEP 2017). Where soil or groundwater properties vary significantly between soil explorations, additional soil profile pits should be conducted as necessary to resolve such differences and accurately characterize the subsurface conditions below permeable pavement. Use the median infiltration rate determined from the in-situ soil testing for design purposes. For more information on soil and geotechnical analysis, see Appendix C.

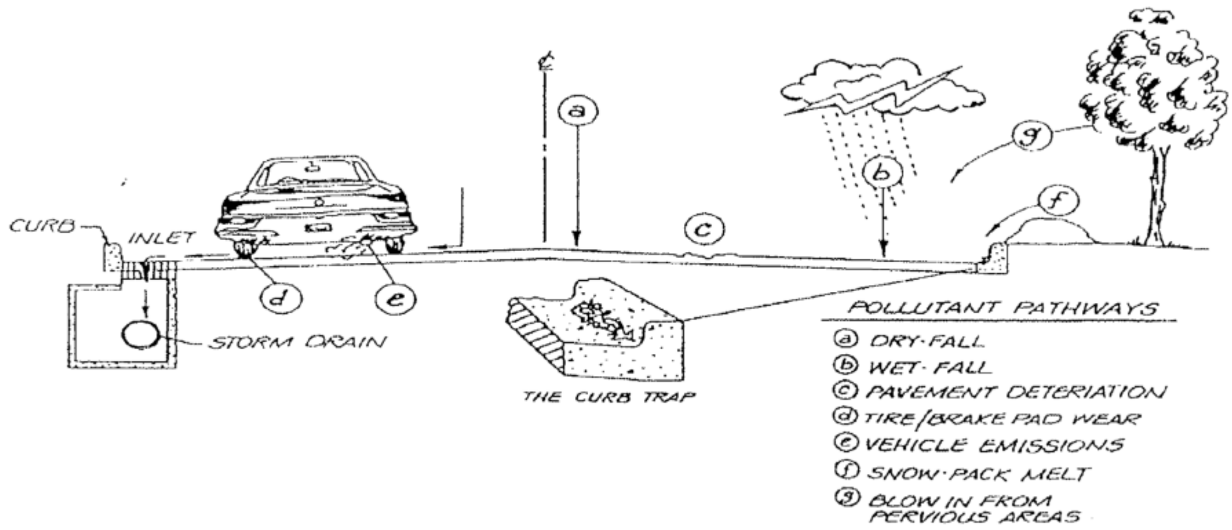
#### 6.3.1.4.4 Maintain Natural Flow Paths (SD-4)

| Table 6-6 Maintain Natural Flow Paths (SD-4) – Key Benefits and Practice Use | |
|---|---|
| **Key Benefits** | **Using This Practice** |
| • Use of natural drainageways reduces the cost of constructing storm sewers or other conveyances, such as roadway curbs and gutters, and may reduce the need for land disturbance and grading.<br>• Natural drainage paths are less hydraulically efficient than man-made conveyances, resulting in longer travel times and lower peak discharges.<br>• Natural flow paths reduce the cost of road and storm sewer construction.<br>• Natural flow paths maintain the site's natural hydrology. | • Preserve natural flow paths in the site design.<br>• Direct runoff to natural drainageways, ensuring that peak flows and velocities will not cause channel erosion.<br>• Use vegetated open channels (enhanced wet or dry swales or grass channels) in place of curb and gutter to convey and treat stormwater runoff. |

Where topography, soils, and slopes allow, it is preferable to use the natural drainageways of a site, or properly designed and constructed vegetated channels and swales (see the discussion of conveyance BMPs in Section 6.3.3.3.3) to convey and treat stormwater runoff instead of constructing underground storm sewers, concrete open channels, or roadway curb and gutter structures. Streets and connected sewers contribute some of the highest loads of pollutants to urban stormwater systems (see Figure 6-9). For example:

- Atmospheric pollutants settle or are washed onto the street during rain events.
- Pavement fragments contribute to stormwater pollution.
- Vehicles contribute emissions and tire and brake system particles and residues.
- Snow collected at the street edge melts and contributes salts.
- Leaves and pollen from trees are blown into the street.
- Curb and gutter systems channel polluted stormwater directly into streams.

**Figure 6-9 Street Related Pollutant Pathways**




*Source: Schueler, 1995*

While structural drainage systems are hydraulically efficient in removing stormwater from a site, they ultimately increase peak runoff discharges, increase flow velocities, and convey pollutants downstream. Velocities and erosive forces of stormwater are worsened by such systems.

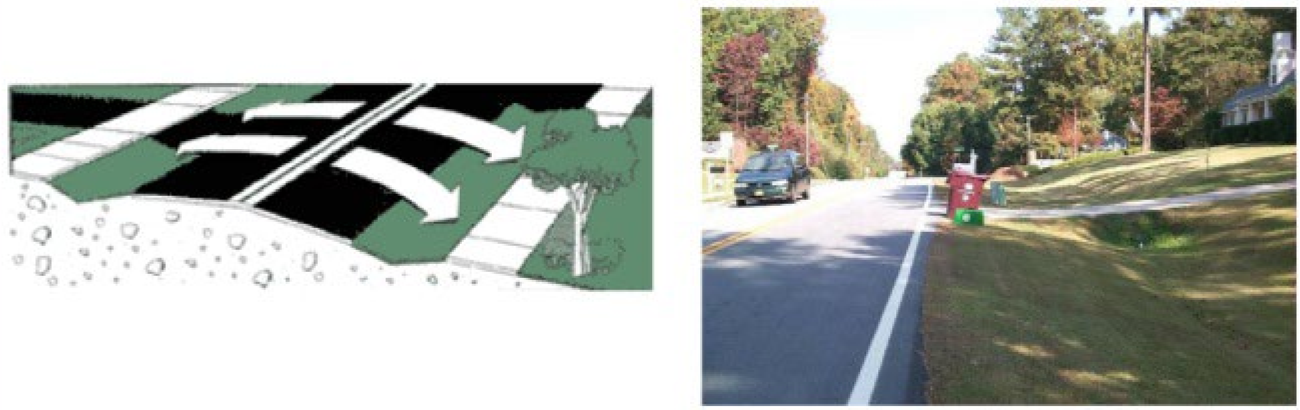
Objective #1 - Reduced Flow Rates: Simple conveyance in a vegetated channel causes a decrease in the velocity of the flow. As the water passes over and through the vegetation, it encounters resistance. This resistance translates into increased times of concentration (slowing the flow) within the watershed, more temporary storage of onsite stormwater during the storm and reduced peak discharge rates. Some of the flow will also infiltrate, depending on the design of the swale and the residence time.

Objective #2 - Improved Water Quality: Passing stormwater runoff through vegetation can reduce pollutant loadings before their conveyance downstream. In a typical piped or concrete channel, pollutants are washed into the system and transported to surface waters without treatment. Early consideration of how to implement vegetated swales and other naturalized drainageways will yield a more cost efficient, well-designed development (see Figure 6-10). Designers should consider:

- Design roads without curb and gutter to allow runoff to flow directly into a natural drainage path. Where curb and gutter are required, consider periodically spaced curb cuts in lieu of drainage inlets to provide the same relief to the roadway without utilizing a piped conveyance network.
- Install culverts at driveway crossings to create a chain of vegetated conveyance channels.
- For developments that require planting strips, evaluate whether the planting strips can double as a natural drainage pathway to reduce the size of the downstream stormwater control measure and treatment system.
- Consider roadway medians as locations for placing vegetated conveyance paths.

These strategies can help meet both quantity and quality requirements, meaning a reduced need for post- construction BMPs.

**_Figure 6-10 Using Vegetated Swales Instead of Curb and Gutter_**



*Source: Atlanta Regional Commission 2001*

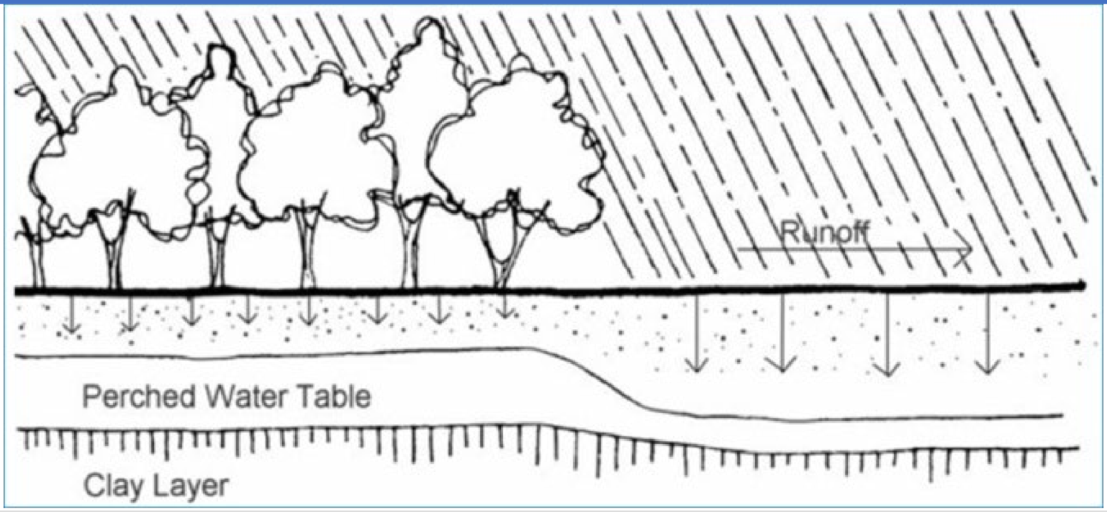
### 6.3.1.4.5 Build Footprints and Site Layout to Reduce Grading (SD-5)

**Table 6-7 Build Footprints and Site Layout to Reduce Grading (SD-5) – Key Benefits and Practice Use**

| Key Benefits | Using This Practice |
| --- | --- |
| • Preserves undisturbed natural areas on the site. | • Establish limits of disturbance for all development activities. |
| • Reduces the area of exposed soil and potential for erosion. | • Plan roads to follow natural topography where possible to minimize limits of disturbance. |
| • Erosion control costs are lessened. | • Step building footprints as necessary to follow natural slope of terrain as much as possible to limit disturbance area. |
| • More natural topography and drainage features are maintained. | |

Clearing and grading is one of the early construction activities on most projects, and one that disturbs the land the most. Unnecessary removal of natural vegetation and disturbance of the soil leaves the land at risk of erosion and sedimentation (see Figure 6-11). Vegetation plays an enormous role in regulating stream flow and maintaining water quality. Areas that contain high-quality, stable, or unique vegetation should be identified and preserved. Erosion control measures that can be implemented during clearing and grading activities are discussed in Section 6.3.2.3. Although there are actions that can be taken after land has been cleared and graded to prevent this, the first step is limiting the extents of disturbance during conceptual plan development.

**Figure 6-11 Decreased Infiltration and Baseflow and Increased Runoff Resulting from Cleared Site Vegetation**




*Source: Day and Crofton 1978*

Clearing and grading of the site should be limited to the minimum amount needed for the development function, road access, and the necessary infrastructure (e.g., utilities, wastewater disposal, and stormwater management).

Minimum disturbance methods include the following:

- Avoid mass grading and establish physically marked limits of disturbance based on the development plan. These limits should accommodate reasonable construction techniques and equipment needs together with additional space requirements due to physical site limitations (e.g., steep slopes, soils, trenching). Limits of disturbance distances will be unique to each development.
- Fit the stormwater site design to the terrain. Designers should take note of existing high points, valleys, and ridgelines prior to establishing a detailed grading plan for the site. Roads should be designed to follow natural topography to the greatest possible extent. Buildings can be clustered or stepped to reduce the need for retaining walls and overall limits of disturbance. Fitting the design to the terrain will assist with overall earthwork balancing for the development. Careful layout of roadways and driveways to align with the topography, rather that cut through it, can dramatically reduce grading of both cut and fill slopes.
- If used, place ponds (see Section 6.3.3) at the lowest elevation of the development and maintain adequate separation from natural features and buffers to allow for adequate space for construction activities with the limits of disturbance.
- Use stormwater site designs that incorporate open space or cluster developments. Cluster developments group residential properties to maximize the open space for conservation.
- Take care not to make tie in slopes steeper than necessary. Generally, a tie in slope should be no steeper than 3:1, with 4:1 or flatter being utilized on slopes of shorter length to reduce runoff velocity and prevent sediment transport.
- Phase construction and earth disturbance.

#### 6.3.1.4.6 Reduce Unnecessary Impervious Cover (SD-6)

## Table 6-8 Reduce Unnecessary Impervious Cover (SD-6) – Key Benefits and Practice Use

| Key Benefits | Using This Practice |
|---|---|
| • Reduced overall volume of stormwater<br>• Reduced pollutant generation and conveyance<br>• Associated cost savings due to reduction in infrastructure for conveyance, treatment, and control | • Reduce unnecessary lengths of road, sidewalks, and other pavements.<br>• Utilize cluster developments.<br>• Use structurally reinforced turf for emergency access for buildings.<br>• Use permeable pavers, grass pavers, or green roofs. |

***Figure 6-12 Permeable Pavers Replace Concrete or Asphalt for Residential Driveways***

*Source: Creative Commons*

The amount of impervious area—i.e., rooftops, parking lots, roadways, sidewalks, and other surfaces that do not allow for rainfall infiltration into the soil (see Figure 6-8)—is an essential factor when designing a site and its stormwater management. In all cases (site by site, watershed by watershed), increased impervious area means increased stormwater generation, and increased stormwater discharge rates. Further, stormwater running over impervious area collects and carries contaminants to downstream waterbodies. Reducing imperviousness also helps to reduce the urban heat island effect (see Figure 6-13).

There are cost savings associated with stormwater infrastructure that can be reaped by reducing onsite impervious area. First, the reduction in impervious area will reduce the overall volume of stormwater and volume of contributing pollutants. This can lead to a reduction in the size and cost of necessary infrastructure for drainage, conveyance, treatment, and control.

Some suggestions for reducing impervious pavement on a development include:

**_Figure 6-13 Green Roofs Reduce Impervious Surface on a Building Rooftop_**

*Source: Flickr*

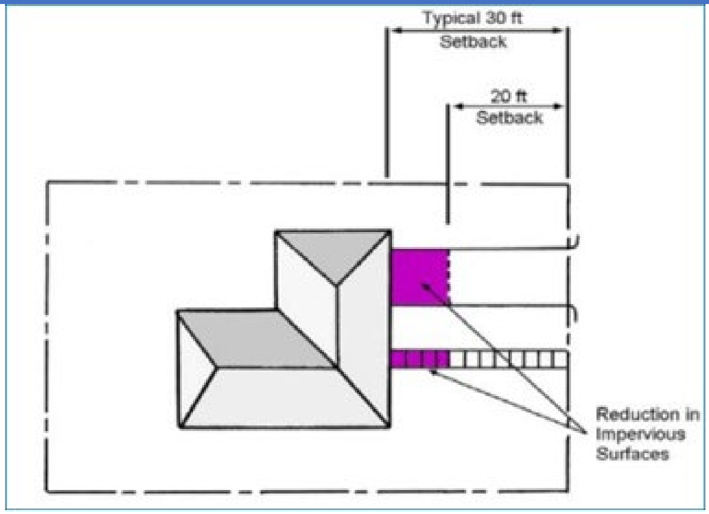
- Plan sites so that there are no unnecessary lengths of roadway, sidewalks, and other pavements. Cluster developments may be useful in achieving shorter roads and sidewalks without sacrificing lot density. Try analyzing different site and roadway layouts to see if they can reduce overall street length. Efficient roadway layouts will further reduce infrastructure costs since the reduction in road length will likely correspond to a similar reduction in conveyance needs.
- Reduce roadway width where feasible. Roadways should be able to support the proposed levels of traffic and provide safety for motorists and pedestrians. However, many communities propose roadway widths that are higher than necessary. Check the requirements of the local jurisdiction.
- Use pervious materials for driveways, walkways, and patios such as pea gravel, gravel, crushed shells, and mulch. See Section 6.3.3 and Chapter 8 for guidance on using post-construction BMPs.
- Use permeable or grass pavers. Construction costs for permeable pavement materials are generally higher than for conventional pavements. However, cost savings due to reduced curb and gutter and reduced stormwater management requirements can offset this initial cost difference. Similarly, reduced storm sewer and stormwater management facility maintenance requirements may offset the generally greater maintenance requirements associated with permeable pavement. See Section 6.3.3 and Chapter 8 for guidance on using post-construction BMPs.
- Use structurally reinforced turf for emergency access to buildings instead of extending roads or providing paved hammerhead turnarounds.
- Install green roofs on buildings. See Section 6.3.3 and Chapter 8 for guidance on using post-construction BMPs.
- Design shared parking spaces for daytime-only users and nighttime-only users.
- Provide parallel parking to meet parking requirements. Since parallel parking is already adjacent to the road, it does not require a drive aisle or other drive aisle extensions that may be required depending on the parking lot configuration.
- Allow for shared impervious spaces whenever possible, including dumpsters, sidewalks, driveways, and roads.
- Reduce building footprints.

**Residential Driveways**

Driveways are linked very much to the configuration of a development. Most local codes contain front yard setback requirements that dictate driveway length; however, as residential lots have grown larger, minimum setback criteria have often been exceeded. Adhering to minimum setback standards will reduce residential driveways to the minimum necessary for parking and access to the garage, while maximizing backyard space. Shorter driveways help reduce infrastructure costs for developers since they reduce the amount of paving or concrete needed.

Another option, where applicable, is the elimination of the driveway altogether, with garages opening onto alleyways. Where driveways are necessary, consider the use of alternative driveway surfaces like permeable or grass pavers. See Figure 6-14.

***Figure 6-14 Reduced Impervious Area with Shorter/Minimum Setbacks***




*Source: MPCA 1989*

**Parking Lots and Parking Footprints**

The size of a parking lot is driven by stall geometry, lot layout, and parking ratios. Overall imperviousness associated with parking lots can be reduced by eliminating unneeded spaces, providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, maximizing the use of parallel parking on adjacent roadways, using multi-storied parking decks, and using permeable pavers or pavement surfaces in overflow parking areas to reduce and treat stormwater runoff.

Parking and stormwater issues link to larger macro planning issues. For example, low density development sprawling into the countryside, such as widely scattered subdivisions, office parks and shopping centers along major roadways and at expressway interchanges, typically forces maximum reliance on the automobile for transportation, meaning there is a need for more parking accommodations.

The following suggestions can be studied when developing a concept site plan to reduce parking impervious area:

- Minimize standard stall dimensions for regular spaces.
- Provide compact car spaces.
- Use pervious pavement (e.g., asphalt, concrete, blocks, sand amendments) for overflow parking.
- Incorporate efficient parking lanes, such as one-way drive isles.
- Evaluate the potential for shared parking to lower the overall parking requirement.
- Create stormwater "islands" in traffic islands or landscaping areas to treat runoff using bioretention, filter strips, or other practices.
- Use structured parking.

**Parking Lot Dimensions**

Effective use of the minimum parking space and aisle dimensions as permitted in the jurisdictional zoning code allows the number of parking spaces to remain the same, while adding valuable green space to the parking lot. Ultimately, smaller parking lots can reduce impervious cover and provide more effective treatment of stormwater pollutants. Further, smaller parking lots reduce both up front construction costs and long-term operation and maintenance costs, as well as the size and cost of stormwater practices.

A parking space is composed of four impervious components:

- Overhang at the edge of the stall (beyond the car);
- Curb stop or curb;
- Parking stall; and
- Parking aisle allowing for access to the stall.

In many communities, parking lots are oversized and under-designed. Where able, vehicles can overhang into pervious landscape beds in lieu of adding extra length on the parking stall. Internal traffic patterns can be optimized to eliminate unnecessary drive aisles. For example, two-way traffic aisles require greater widths than one-way aisles. One-way aisles used in conjunction with angled parking stalls can significantly reduce the overall size of the parking lot.

Parking lot landscaping makes the lot more attractive and comfortable for users and promotes safety for both vehicles and pedestrians. Trees and other landscaping helps screen adjacent land uses, shade people and cars, reduce summertime temperatures, and improve air quality and bird habitat.

**Parking Ratios**

The common practice of a jurisdiction is to set parking ratios to accommodate the highest hourly parking needed during the peak season. The trend in recent years has been to increase these ratios, perhaps reflective of the general increase in land development and traffic and congestion and the concern on the part of most localities to err on the conservative side. Municipalities typically establish minimum parking ratios, but rarely establish maximum parking ratios, resulting in parking lot designs with far more spaces than are actually required. Conversation with the municipality early in the process can help moderate inflated parking ratios.

It may be valuable to study similar nearby sites to evaluate the parking capacity at peak hours of the day to help determine what the minimum working parking ratio is for the proposed site.

**Structured Parking**

Structured parking decks are one method to significantly reduce the overall impervious area footprint. Often the type of parking facility constructed in a given area is a reflection of the cost of land and construction expenses. In suburban and rural areas, where land is relatively inexpensive, surface parking costs much less than a parking garage. However, in highly urban areas with higher land costs, multi-deck garages may be more economical per car space than open lots.

Some local jurisdictions may offer incentives (e.g., tax credits, stormwater waivers, or density, floor area, or height bonuses) to encourage the construction of multi-level, underground, and under-the-building parking structures. In this manner, developers can reduce the land cost chargeable to parking.

**Shared Parking Spaces**

Depending on site conditions (i.e., proximity to mass transit or a mix of land uses), it is possible to reduce the number of parking spaces needed. Parking can be shared in mixed-use areas by creatively pairing uses wherever possible, especially when the adjoining parking demands occur at different times during the day or week. Table 6-9 shows land uses with typically different operating times.

| Table 6-9 Land Uses with Different Peak Daily Operating Times | |
|---|---|
| **Land Uses with Daytime Peak Hours** | **Land Uses with Evening Peak Hours** |
| Banks | Bowling Alleys |
| Business Offices | Hotels (without conference facilities) |
| Professional Offices | Theaters |
| Medical/Dental Clinics | Restaurants Bars |
| Service Stores | Night Clubs |
| Retail Stores | Auditoriums |
| Manufacturer/Wholesale | Meeting Halls |
| Grade Schools/High Schools | |

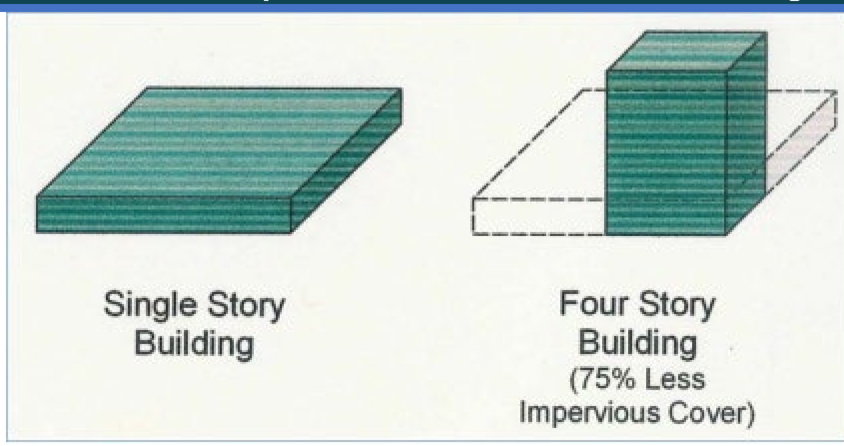
*Source: CWP 1998a.*

Developers often do not attempt such sharing because of the perception that officials would reject the concept. Municipalities can incorporate such sharing concepts into their requirements. Localities could even consider providing incentives for developers to use sharing options.

**Building Footprints**

The impervious footprint of commercial buildings and residences can be reduced by using alternate or taller buildings while maintaining the same floor to area ratio. Figure 6-15 shows the reduction in impervious footprint by using a taller building design.

***Figure 6-15 Taller Buildings with Smaller Footprints Reduce the Overall Impervious Surface Area of a Building***




### 6.3.1.4.7 Maximize Disconnection of Impervious Cover (SD-7)

| Table 6-10 Maximize Disconnection of Impervious Cover (SD-7) – Key Benefits and Practice Use | |
|---|---|
| **Key Benefits** | **Using This Practice** |
| • Sending runoff to pervious vegetated areas increases overland flow time and reduces peak flows.<br>• Vegetated areas can infiltrate and filter stormwater runoff.<br>• Helps to recharge groundwater.<br>• Reusing captured runoff for irrigation can reduce owner costs for potable water. | • Minimize directly connected impervious areas and drain runoff as sheet flow to cisterns or pervious vegetated areas. |

Where possible, direct runoff from impervious areas (e.g., rooftops, roadways, and parking lots) to cisterns for onsite reuse or to pervious areas such as yards, open channels or vegetated areas and avoid routing runoff directly to the roadway or structural stormwater conveyance system (see Figures 6-16 through 6-20). In this way, the runoff is "disconnected" from a hydraulically efficient structural conveyance such as a curb and gutter or storm drain system. Often, it is easy to connect all impervious surfaces and send stormwater directly to the conveyance system; however, with intentional design in the concept site planning stage, designers can achieve this low-cost benefit.

Discharging to vegetated areas prior to conveyance to other downstream stormwater control measures increases overland flow time and allows for a portion of the water to naturally infiltrate into the soil (reducing peak flows) and provides treatment. Accounting for infiltration, early treatment, and overland runoff time in early stormwater site design can result in cost savings in downstream conveyance, control, and treatment systems.

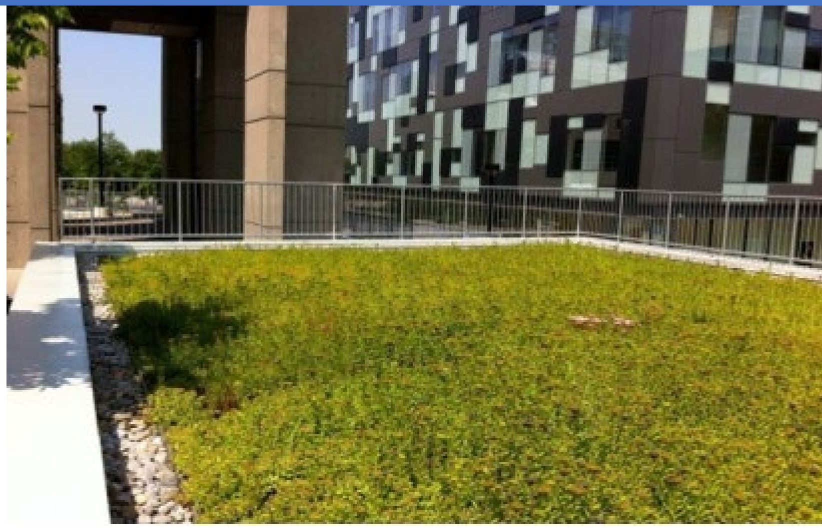
***Figure 6-16 Rain Barrel***

*Source: Flickr*

Some of the methods for disconnecting impervious areas include:

- Design roof drains to flow to infiltration trenches or landscaped areas.
- Direct flow from paved areas such as driveways and parking lots to stabilized vegetated areas.
- Break up flow directions from large, paved surfaces.
- Use permeable paving surfaces where site conditions are appropriate.
- Capture roof runoff in cisterns or rain tanks for reuse.
- Vegetated roofs reduce runoff by providing water storage in the soil prior to runoff.
- Connect roof drains or other impervious area flows to a dry well for direct discharge into the ground.

**Figure 6-17 Vegetated Roof**



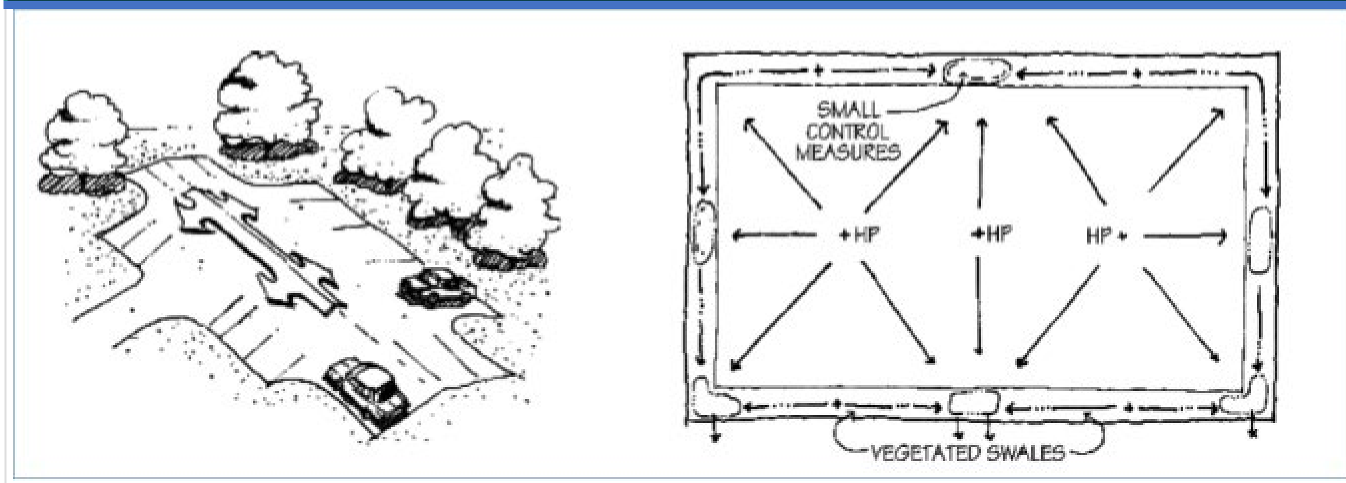
Source: Creative Commons

**Figure 6-18 Parking Lot Runoff Connected to a Gravel Filter Strip and Grassed Area**

Source: Creative Commons

**Figure 6-19 Dry Wells Infiltrate Water Into the Ground Instead of Connecting to a Conveyance System**

**Figure 6-20 Using Vegetated Swales Instead of Curb and Gutter**




*Source: NC DENR 1998*

To successfully employ infiltration practices, the site must contain soils with moderate to high infiltration capacities and must contain adequate depth to groundwater and underlying geology (see also Appendix C). Poor soils will inhibit or even preclude aggressive infiltration. However, site soils can be amended with compost and other appropriate materials to improve the infiltration capacity. Infiltration on sites developed in karst areas should be limited to micro- and small-scale infiltration practices. Large-scale infiltration practices will likely increase the risk of sinkhole formation.

For more specific information about using rainwater harvesting, vegetated roofs, infiltration devices, soil amendments, or permeable paving surfaces, see the specifications in Chapter 8.

### 6.3.1.5 Stormwater Site Design for Special Site and Climatic Conditions

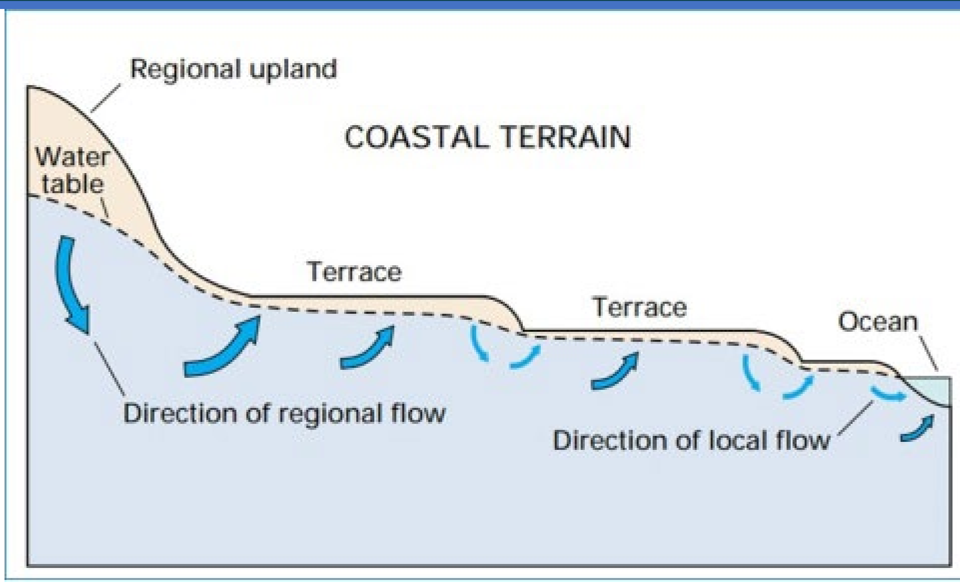
Certain kinds of site or climatic conditions create unique challenges when considering stormwater site design. The significance of these conditions and how to approach each is discussed in the sections below. Guidance for selecting erosion and sediment control BMPs is discussed in Section 6.3.2.4, and post-construction stormwater BMPs in Section 6.3.3.4.

#### 6.3.1.5.1 Coastal Plain

#### 6.3.1.5.1 Coastal Plain

Since most stormwater practices were originally developed for the Piedmont physiographic region, they may need amending for application in a coastal region. The Virginia Coastal Plain is characterized by higher groundwater tables, flat terrain, tidal inundation, poorly draining soils, and an increase in wetland density (see Figure 6-21). Coastal waters are sensitive to pollutants like nitrogen, bacteria, and metals, which degrade water quality and impact aquatic resources like tidal wetlands, beaches, and habitats. Differences between the Coastal Plain and Piedmont are described below.

***Figure 6-21 Surface Water and Groundwater Interactions at Terraces and Scarps***




*Source: Winter et al. 1998*

Flat Terrain: Unlike in the Piedmont where elevation change is commonly present, flat terrain reduces the available hydraulic head available to treat the quality of stormwater or move floodwaters through the watershed during high- intensity tropical storms or hurricanes for which this region is especially prone.

Interaction Between Groundwater and Surface Water: The flat terrain of the Coastal Plain terrain increases surface water and groundwater interactions due to local and regional flow systems. Small local groundwater flow cells associated with terraces and scarps, formed when sea levels were historically higher, overlie more regional groundwater flow systems. In tidal zones, saline and brackish surface water mixes with fresh groundwater from the local and regional flow systems (Winter et al. 1998).

High Water Table: Due to proximity to tidally influenced waterbodies, it is common for the groundwater table to exist within a few feet of the surface. This increases the movement of pollutants into sensitive environments along the coastline, and diminishes the feasibility or performance of many stormwater control practices. Further, a high groundwater table discourages plants from developing deep root systems, thereby preventing them from transpiring surface water at the maximum rate. The result is potential for ponding and higher levels of evapotranspiration.

Highly Altered Drainage: The headwater stream network in many Coastal Plain watersheds no longer exists as a natural system. It has largely been replaced by ditches, canals, and roadway drainage systems.

Soil Variability: Portions of the Coastal Plain contain poorly draining soils, which prevents infiltration and results in a greater density of wetlands than other regions in the country. Alternatively, there are areas in the Coastal Plain that contain highly permeable sandy soils, particularly along nearest the coastline. This is a particular design concern because of the stronger risk of pollutants entering into the groundwater system and the reliance in the region on groundwater for the drinking water supply.

Drinking Water Wells and Septic Systems: As noted above, the reliance on public or private wells for drinking water is a notable characteristic of the coastal region. It is imperative to consider groundwater protection a first priority when considering stormwater treatment and disposal. At the same time, development in the Coastal Plain relies heavily on septic systems or land application to treat and dispose of domestic wastewater.

Pollutants of Concern: The key pollutants of concern in Coastal Plain watersheds are nitrogen, bacteria, and metals. These pollutants degrade the quality of unique Coastal Plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat, and tidal wetlands.

Shoreline Buffers and Critical Areas: CBPAs in Virginia include special shoreline buffer and stormwater PR requirements that strongly influence how stormwater practices are designed and located. In addition, the predominance of shoreline development often means that stormwater must be provided on small land parcels a few hundred feet from tidal waters. Consequently, many development projects within CBPAs must rely on stormwater micro-practices to comply with applicable requirements.

The Highway as the Receiving System: The stormwater conveyance system for much of the Coastal Plain is frequently tied to the highway ditch system, which is often the low point in the Coastal Plain drainage network. New upland developments often must receive approvals from highway authorities to discharge to their drainage system, which may already be at or over capacity with respect to handling additional stormwater runoff from larger events. The requirement for developers to obtain both a local government and highway agency approval for their project can result in conflicting design requirements.

Sea Level Rise: Sea level is forecast to rise at least 1 foot over the next 30 to 50 years as a result of subsidence and climate change (VDCR 2021). This large change in average and storm elevations in the transition zone between tidal waters and the shoreline development a few feet above it has design implications for stormwater site design.

Hurricanes and Flooding: Due to their location, coastal communities are subject to rainfall intensities that are 10% to 20% greater for the same design storm event compared to sites further inland (VDCR 2021). The flat terrain lacks enough hydraulic head to quickly move water out of the conveyance system (which may be further complicated by the backwater effects of tidal surges). Additionally, large tidal surges may cause significant flooding with no precipitation present.

Use these stormwater site design principles to guide developments in the Coastal Plain:

- Take maximum advantage of disconnections, given the prevalence of highly permeable soils.
- Take steps to identify lands that may be subject to flooding in the future and consider reserving these lands as natural areas.

- Take a linear design approach to spread treatment along the entire length of the drainage path, from the rooftop to tidal waters, maximizing the use of swales and ditches for conveyance and treatment.
- Design disconnections to riparian buffers and natural lands to maximize nitrogen removal.
- Consider the effect of sea level rise on future elevations of infrastructure. In some cases, it may make more sense to use stormwater site design to "raise the bridge" by increasing the vertical elevation of building pads at Coastal Plain development sites.

### 6.3.1.5.2 Solar Panel Arrays

Solar farms consisting of large arrays of ground-mounted photovoltaic systems are becoming increasingly common in Virginia. Responsible development of solar farms must balance the growth of this valuable industry with the need to protect our natural resources, including addressing issues related to erosion and sediment control (ESC), stormwater runoff management and collective local water quality impacts. Solar farms that use traditional elevated solar panels are unique due to the impervious surface (elevated solar panel) that often is surrounded by a pervious surface (vegetated ground cover) underneath the panel.

However, site development practices such as grading (cut/fill), trenching, access road construction and installation operations can expose bare soils for extended periods of time, leading to reduced soil infiltration rates and decreases subsoil permeability (Ksat) if not properly mitigated. Larger Utility Scale Solar (USS) developments often lead to extensive progressive exposure of bare (denuded) soils during the land clearing and site development phase that pose a high short-term risk of sediment loss during storm events. Unless properly mitigated following site development, soil compaction limits revegetation success and enhances runoff. The impervious panel arrays concentrate storm event rain and snowmelt into drip lines that can accentuate local concentration of sheetflow and enhance interrill erosion, particularly during vegetation establishment periods. Therefore, maintenance of a sufficiently stabilized surface ($\geq$ 75% intact mulch or temporary vegetation) on slopes (> 5%) during the site clearing and development phase is important and should be followed by rapid establishment of a permanent perennial stand of vegetation sufficient to meet assumptions for unconnected surface water flow following storm events as enhanced by the panel arrays and drip lines.

Several key factors must be considered during the design of a solar site. These include but are not limited to 1) runoff computations, including unconnected (disconnected) impervious area computations, 2) solar cell orientation/inclination, and 3) soil compaction and plant selection/establishment.

### 6.3.1.5.3 Solar Stormwater Runoff Computations

Stormwater runoff flowing from an impervious area as sheet flow over an intervening pervious area prior to entering the receiving stormwater conveyance system is considered unconnected impervious flow. On March 29, 2022, VDEQ issued a technical memorandum that implemented stronger post-development stormwater management policy for solar projects subject to VSMP requirements. The memo stated that ground-mounted solar panels would be considered unconnected impervious cover as defined in Chapter 9, Part 630 of the NRCS National Engineering Handbook. The runoff curve numbers published in Chapter 9, Part 630, of the NRCS National Engineering Handbook (and NRCS Technical Release 55), however, were developed assuming that all impervious areas were directly connected to the stormwater conveyance system. In addition, current VDEQ guidance requires designers of any site to adjust post-development curve numbers by one HSG to account for compaction during construction (see A.3.7.2 Post-Development Curve Number Selection). Both items must be considered when performing final stormwater runoff computations. To determine the runoff CN when all or part of the impervious area is not directly connected to the stormwater conveyance system, the design professional should use one of the CN adjustment methods as reproduced below and provided in A.3.7.4.2 Curve Number Adjustment by NRCS Method.

A. The following equation should be used to compute the composite runoff curve number (CNc) when all or part of the impervious area is not directly connected to the stormwater conveyance system **AND** the total impervious area is less than 30% of the total drainage area:

$$CN_c = CN_p - (P_{imp} / 100)(98 - CN_p)(1 - 0.5R)$$

where:

$CN_c$ = composite runoff curve number,

$CN_p$ = pervious runoff curve number,

$P_{imp}$ = percent impervious, and

R = ratio of unconnected impervious area to total impervious area

B. The following equation should be used to compute the composite runoff curve number (CNc) when all or part of the impervious area (including the solar panels) is not directly connected to the stormwater conveyance system **AND** the total impervious area is greater than or equal to 30% of the total drainage area:

$$CN_c = CN_p + (P_{imp} /100)(98 - CN_p)$$

where the variables are defined as shown in the preceding equation.

***Limited Exception to Applicability of Unconnected Impervious Analysis Requirement:***

As noted above, a VDEQ issues memorandum dated March 29, 2022 required solar installations to be considered as unconnected impervious cover. A subsequent memorandum, dated April 14, 2022, recognized that, for those solar projects in advanced stages of design or implementation, several fiscal, contractual, and other obligations need to be considered in the implementation timing of the previous memorandum. Specifically, the April memorandum stated:

*"… any solar project that does not obtain an interconnection approval by a regional transmission organization or electric utility by December 31, 2024, must comply with the requirements detailed in the Department's March 29, 2022, memorandum, which will be further clarified in an agency guidance document. Any owner or operator with a previously VDEQ-approved solar project that does not obtain an interconnection approval by a regional transmission organization or electric utility on or before December 31, 2024, may submit a revised stormwater management plan to VDEQ for a fast-tracked (expedited) review to verify compliance with this section. No additional plan review fee(s) will be assessed by VDEQ for solar projects falling within this category."*

To provide further guidance, "Interconnection Approval" can be demonstrated by the issuance of the System Impact Study as defined in PJM Manual 14a: New Services Request Process, Section 4.3 or equivalent study that results from the PJM Reform Process. "Interconnection Approval" can also be demonstrated by the issuance of a Small Generator Interconnection Agreement for projects subject to the state interconnection process.

Additionally, if an owner or operator wants to confirm whether the stronger post-development stormwater requirements will apply to a particular project, "Interconnection Approval" may also be demonstrated by PJM approval of a new service request on or before April 14, 2022. In all cases, an owner or operator should indicate on the plan cover sheet which demonstration is being selected and provide appropriate documentation of acceptance of this new service request by the applicable entity of the cover sheet.

Finally, in accordance with the April 14, 2022 memorandum, any owner or operator with a previously VDEQ-approved solar project that does not obtain an interconnection approval, as further demonstrated by the documentation previously described, may submit a revised stormwater management plan to VDEQ for a fast-tracked (expedited) review to verify compliance with Chapter 9, Part 630 of the NRCS National Engineering Handbook.

### 6.3.1.5.4 Solar Cell Orientation/Inclination

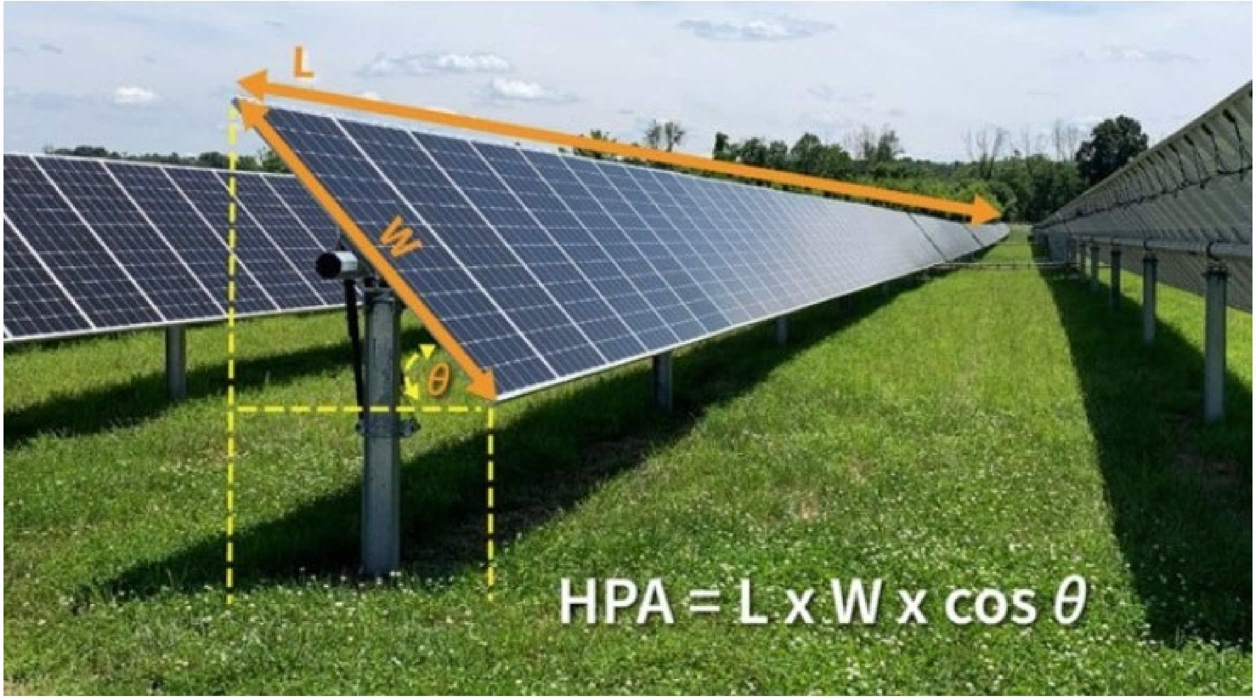
The orientation and inclination of solar cells directly affects the computation of unconnected impervious areas for a solar project. Some solar installations include motorized tracking systems used to track the sun during production and stow the cells in a near-vertical state during rainfall which can greatly impact the unconnected impervious area used in runoff calculations. Unless directly connected to the stormwater conveyance system, the horizontal projected areas (HPAs) of all solar panels should be considered unconnected impervious area when performing runoff computations for erosion and sediment controls (e.g., temporary sediment traps, temporary sediment basins) and when performing post-development water quantity and water quality design computations. As shown in Figure 6-22 below, this represents the worst-case scenario for erosion and sediment control design and implementation (i.e., drainage areas consisting of unconnected impervious cover constructed over newly graded, compacted bare earth conditions).

**Figure 6-22 Utility Scale Solar facility in the southern Piedmont of Virginia**

Source: Appalachian Power

The following equation should be used to determine a solar panel's HPA when performing erosion and sediment control, water quantity, and water quality design computations:

**Figure 6-23 Example of Solar Power Array and HPA Calculation Formula**




$$HPA = L \times W \times \cos\theta$$

where:

HPA = horizontal projected area (square ft),
L = solar panel run length (ft)
W = solar panel width (ft)
$\theta$ = solar panel minimum operating angle from horizontal (degrees) for normal operations without a rain sensor, or the maximum angle from horizontal (degrees) when a rain sensor is deployed

***Panels with Integrated Rain Stow Technology***

Should a project owner elect to implement rain-sensing technology such that the solar panels rotate to a completely vertical position during storm events, the horizontal projected area may be assumed to be zero. If the rain sensing technology results in a less than vertical position, the HPA equation, above, should be used to reflect that as the operating angle. In either instance, the acreage of the solar panel support posts, columns, beams, etc. that are not underneath a solar panel's horizontal projected area (HPA) should be considered impervious area when performing erosion and sediment control, water quantity, and water quality design computations.

The rain sensor should be programmed to rotate the solar panels to their rain position (aka "Rain Stow") after the immediately preceding 24 hours of rainfall's cumulative volume (in watershed inches) exceeds the initial abstraction (Ia, inches), as calculated by the NRCS Curve Number (CN) method, for the panel's underlying soil and cover type, as calculated after the panels have rotated to their design rain stow angle. At least one rain sensing device used for panel stow logic will be located on site. The panels can redeploy to the desired angle based on the sun's position once the rainfall rate drops to less than 0.02 inch per hour for more than 1 hour. For storms occurring through the night, to reduce mechanical stress, it is suggested that panels not rotate back in place until near production hours (dawn) in case rainfall is intermittent over an extended period. Documentation as to the design standards for the selected rain-sensing technology should be provided on the Cover Sheet of the plan.

### 6.3.1.5.5 Solar Installation Soil Compaction and Plant Selection/Establishment

Without careful consideration, the installation of solar panels can reduce soil permeability and increase the potential for concentrated runoff and raindrop erosion. All solar site areas will conform with the overall standards and definitions for overall erosion and sediment control in 9VAC-25-840.40, including that "Stabilized" means land that has been treated to withstand normal exposure to natural forces without incurring erosion damage. Thus, this stabilization should occur progressively as the site is developed and not delayed until the entire site is completed. Consider the following when planning stormwater site design features for solar sites:

a) Avoid compaction of subsoil. Excessive compaction of cut or filled subsoil materials (B and C horizons) should be minimized during and after installation of solar arrays to maximize post-development surface infiltration and internal soil permeability/drainage. If compaction occurs during construction, the subsoil (B and C horizons) and topsoil (if salvaged) should be decompacted to > 6 to 12 inches via tillage to approach pre-construction bulk density (in grams per cubic centimeter [g/cm3]) depending on the intended rooting depth of the species mix employed. A second round of compaction may occur to some extent with topsoil return and regrading and should be mitigated via tillage to include the upper 1 to 2 inches of the underlying subsoil to ensure drainage. In general, the root-limiting dry bulk density of sands is 1.85 $g/cm^3$; sandy loams is 1.65; silt loams is 1.55; and for massive non-aggregated clays, 1.45 $g/cm^3$ (Weil and Brady 2017). Compost amendment (P-FIL-03) is recommended for the upper 4 to 6 inches of the final revegetation surface (NCDEQ 2018).

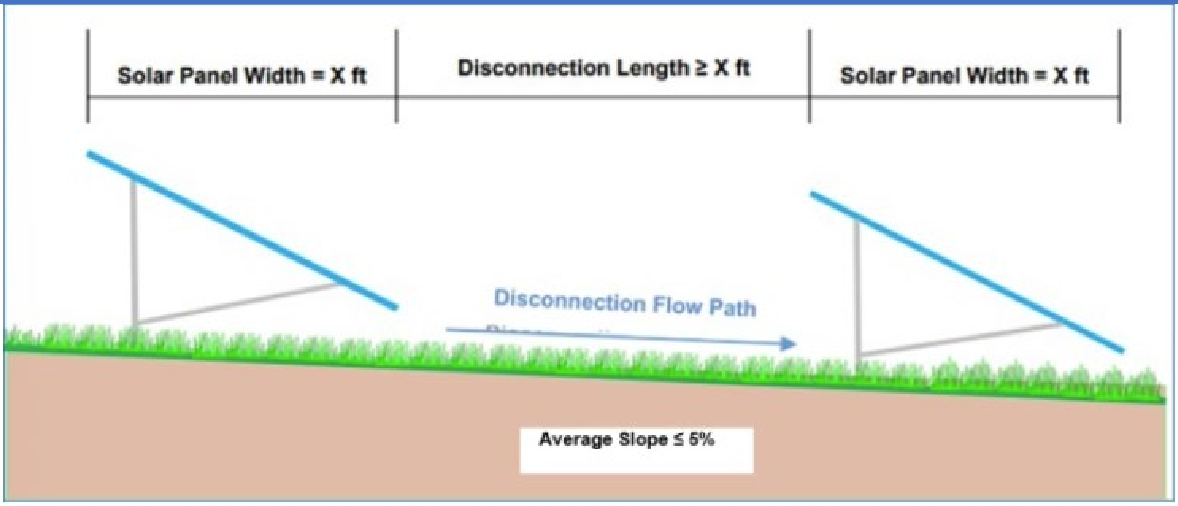
b) When possible, complete soil reconstruction and initial revegetation before panel installation. Remedial tillage to alleviate soil compaction and to incorporate soil amendments (compost, lime, and fertilizer) is best and most efficiently accomplished before panel installation. Rapid establishment of temporary or permanent vegetation ahead of panel installation will decrease short-term erosion risk, reduce stormwater peak flows, and enhance soil moisture removal during the growing season (NCDEQ 2018).

c) Use diverse revegetation species seed mixes. Solar sites pose a much more complex environment for establishment of both temporary and permanent vegetation due to the irregular pattern of soil disturbance (e.g., cut, fill, trenches, roads) that intersects with regular linear patterns of shading vs. direct sun exposure. Permanent seedings should contain at least 3 to 4 species with a wide range of adaptation to local soil and climatic conditions. Legume species (> 25% of stand) should be established unless routine N fertilization of the permanent stand during the operational phase is planned. Where compatible with short- and long-term erosion and sediment control needs, native and pollinator species should be included in permanent seed mixes and/or introduced and established after short-term erosion and sediment control goals are met; refer to the VDCR Virginia Pollinator-Smart Program.

d) Disconnect (un-connect) runoff from solar panel arrays. Solar arrays should be designed and installed to allow establishment and management of permanent/perennial vegetation under and between the solar panel arrays. For erosion and sediment control, at least 75% uniform living ground cover should be established and maintained. Rows of panels should be installed with sufficient distance between rows to allow for capture of rainfall from at least 1.0 inch of rain (see Figure 6-24) within 24 hours. Where installed on slopes greater than 5%, consider options for maintaining sheet flow and dissipating energy at the drip edge of panel rows.

   In general, the minimum disconnection length between two rows of solar panels is equal to the width of each row, as shown on Figure 6-24. However, some panel layouts include horizontal gaps between individual modules that allow stormwater to drip off the panels at intervals much smaller than the width of each row. In these instances, the solar farm can be designed with a smaller disconnection length, if they will not cause concentration of stormwater runoff. The disconnection length should not be less than 80% of the total solar panel width (NCDEQ 2018).

**Figure 6-24 Disconnection of Flow Path Between Solar Panels when Average Slope is Less Than 5%**




Source: NCDEQ, 2018

a) Avoid concentration of stormwater. Panels should be positioned to allow stormwater to run off their surfaces; however, collection and concentration of stormwater flow is to be avoided. Arrays should be installed on a uniform plane such that stormwater will sheet flow off the panels and remain unconcentrated. When considering a potential build site, consider the slope of the land in the areas of the site where the solar arrays are most likely to be installed. Areas with steep slopes may not be suitable or may require considerable grading (NCDEQ 2018).

b) Minimize use of herbicides and fertilizers. Weed control and vegetation management are particularly important for ground-mounted solar systems. Overuse of herbicides and fertilizers can contribute to degraded water quality. Limit the use of fertilizers to that necessary to maintain vegetation. Use mowing for vegetation control instead of herbicides (NCDEQ 2018). The Virginia Solar Site Native Plant Finder (https://www.dcr.virginia.gov/natural-heritage/solar-site-native-plants-finder) assists designers in identifying native plant species appropriate for use at solar facilities.

c) Limit vertical clearance to less than or equal to 10 feet. Stormwater runoff falling from solar panels can cause scouring and erosion at the driplines. Limiting the lowest vertical clearance to no greater than 10 feet will help prevent erosion and scouring along the dripline (NCDEQ 2018).

d) Avoid disturbance of acid sulfate soil materials. Follow protocols below to avoid exposure of acid sulfate soils and sulfidic materials. For USS sites, this risk is particularly enhanced for permanent stormwater pond excavations in lower landscape positions in the Coastal Plain and certain rock units in the northeastern Piedmont.

#### 6.3.1.5.6 Karst

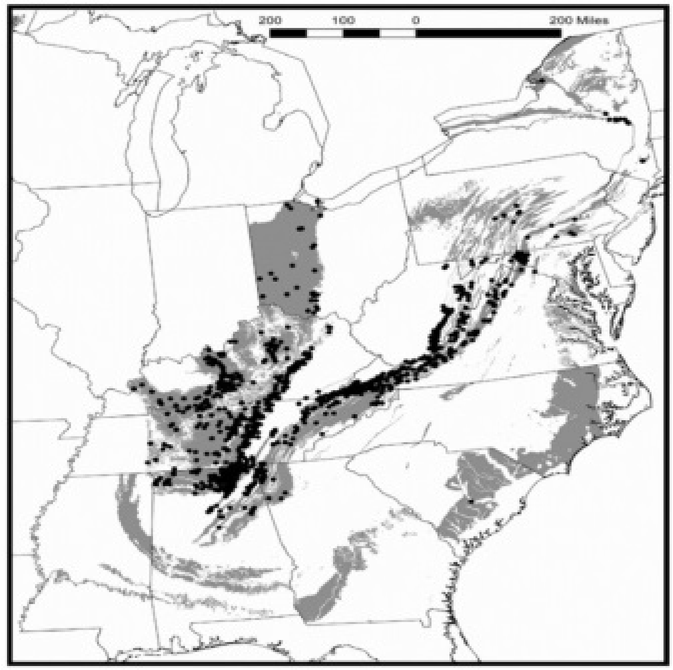
"Karst" is a term that describes terrain formed by the dissolution of carbonate rock and is characterized by closed depressions, sinkholes, disappearing streams, springs, caves, and an absence of surface streams and lakes. These features result from the dissolution of carbonate rock. In common practice, karst is used to describe a type of terrain and geology. Two of Virginia's major tributaries, the Potomac and the James Rivers, flow through karst country. This band of karst terrain runs through the Chesapeake Bay watershed, and encompasses portions of Maryland, Pennsylvania, Virginia, and West Virginia (see Figure 6-24A). Karst in Virginia creates a dynamic landscape characterized by sinkholes, springs, caves, and a pinnacled, highly irregular soil-rock interface that is a consequence of the presence of underlying carbonate rocks such as limestone, dolomite, and marble (Denton 2008).

Karst is often referred to as a dissolving landscape. However, bedrock can dissolve over geologic time to result in hidden voids in the subsurface, susceptible to soil cover collapse into these voids. So, when building in a karst environment, the watchword is to live lightly on the land.

The presence of karst within the Ridge and Valley Province (and select portions of the Piedmont Province) complicates the land development process and requires a unique approach to stormwater design. Significant cut and fill can aggravate karst issues. Some important considerations include:

- Post-development runoff rates that are greatly increased;
- Highly variable subsurface conditions;
- Surface/subsurface drainage patterns that are poorly understood;
- Lower stream density and more karst swales;
- Rural development patterns and growth pressures;
- Groundwater contamination risks;
- Increased sinkhole formation; and
- Endangered species.

***Figure 6-24A Karst Distribution in the Bay States***




*Notes: grey = karst; black = caves. Source: Weary 2005*

West of the Blue Ridge mountains, limestone and dolomite valleys are separated by narrow ridges largely composed of sandstone and shale. Both of these terrains can exhibit extreme karst topography, with first and second order streams that can abruptly lose drainage to the cavernous subsurface, temporal streams with drainage areas, “blind valleys” (i.e., large linear sinkholes that are often mistaken for adequate drainageways), and estavelles or hydrologically-active sinkholes that normally receive drainage from surrounding areas, but also discharge water in floods (Jennings 1985). These features comprise an interconnected karst hydrological system that is easily contaminated and able to transmit large volumes of water over long distances in a short period of time, frequently passing beneath surface watershed boundaries (Veni et al. 2001; Zokaites 1997) and exit to an unknown outfall, which could be miles downstream. Obviously, karst areas present problems to those attempting to work with conventional stormwater design concepts.

Consider these general principles for site layout in karst regions (for additional guidance please see Appendix E):

- Perform preliminary and detailed site investigations prior to site and stormwater design to fully understand subsurface conditions, assess karst vulnerability, and define the actual drainage pattern present at the site. Any existing sinkholes should be surveyed and permanently recorded on the property deed. In addition, an easement, buffer, or reserve area should be identified on the development plats for the project so that all future landowners are aware of the presence of active karst on their property.
- Minimize site disturbance and changes to soil profile, including cuts, fills, excavation, and drainage alteration, near karst features.

- Maintain natural conditions to the maximum extent practicable through maintaining existing drainage patterns and features on the site. This involves maintaining and creating appropriate water quality buffering adjacent to karst drainageways, limiting construction access to these areas, protecting the water quality of springs and seeps, and avoiding impacts to existing site sinkholes that capture runoff from offsite areas. Natural hydrologic conditions should be replicated as much as possible when designing.
- Increase setbacks from buildings and other infrastructure.
- Minimize impervious surfaces to minimize the volume of surface runoff generated.
- Take advantage of subsurface conditions when locating building pads and place foundations on sound bedrock. To ensure this, take soil borings at key locations near buildings, roads, conveyances, and at centralized stormwater management facilities. The number and depth of borings depends on the karst feature plans and local requirements.
- Prioritize the preservation of the maximum length of natural karst swales present on the site as feasible to increase infiltration and accommodate flows from extreme storms.
- If sinkholes occur during construction, the site superintendent should report the occurrence to the local plan approving authority within 24 hours of discovery, halt construction activities in the immediate area of the sinkhole until it is stabilized, and direct the surface water away from the sinkhole area to a suitable storm drainage system if possible.

#### 6.3.1.5.7 Acid Sulphate Soils

Acid sulphate soils are those soils in which sulfuric acid will either be produced, is being produced, or has been produced in amounts containing a lasting effect on the main soil characteristics. A complete discussion of acid suphate soils is found in Section 6.2.2.7.1.

When planning for acid sulphate soils during site development:

- Conduct a thorough site investigation to identify the presence and extent of acid sulfate soils (see the acid sulfate soils discussion in Section 6.2.2.7.1).
- Plan and design the site so that there is minimal disturbance to the acid sulfate soils.
- Consider using raised platforms or buildings on piles to avoid excavation and soil disturbance.
- Use appropriate materials for site stabilization and drainage, such as gravel or coarse sand.
- Avoid the use of lime-based materials that can increase the acidity of the soil.
- Ensure adequate management and treatment of stormwater runoff to prevent the mobilization of acid sulfate soils.
- Provide adequate monitoring and management of the site to prevent the leaching of metals and sulfates from the soil.

## 6.3.2 Construction BMPs

Once onsite conservation areas are identified and site design practices have been selected, the next step is to conduct a preliminary assessment of how erosion and sediment control practices will be implemented throughout construction. To select BMPs that will be most effective, consider how erosion can occur on a site and what contributing factors may increase the likelihood of erosion taking place. An overview of erosion is provided below.

**Erosion Basics**

Soil erosion is the process by which land surface is worn away by the action of wind, water, ice, and gravity. Although erosion is naturally occurring, major problems can occur when large amounts of sediment enter waterways. Accelerated erosion is most often caused by surface mining, poorly managed croplands, construction sites, urban and suburban stream banks, and logging roads. Water-generated erosion is one of the most severe types of erosion, particularly in developing areas or construction sites where soil is unnaturally exposed; it is, therefore, the problem which is primarily addressed in this section. Water-generated erosion can be categorized into the following types:

Raindrop Erosion:

This is the first impact of a rainstorm on soil. Raindrops dislodge soil particles and splash them into the air. When they resettle, these particles are vulnerable to additional types of erosion. Raindrop erosion can lead to the building of soil deposits and the subsequent development of irregular surface contours. Water concentration in irregular surface contours leads to rill erosion (see Figure 6-25).

**Figure 6-25 Raindrop Erosion Dislodges Soil Particles**


*Source: EOS Data Analytics 2021*

Sheet Erosion: This is erosion caused by shallow runoff occurring when the soil's infiltration ability is less than the intensity of the storm event. While these shallow sheets of water seldom cause the detachment of fine soil particles, they collect and convey detached soil particles to waterbodies.

Rill Erosion: Rill erosion is what develops when water has concentrated in the low spots of irregular surface contours and forms faster-flowing channels of water. The concentrated water flow has greater depth, velocity, and turbulence than sheet flow, and this increased energy is able to detach and transport larger soil particles and materials. This leads to the water cutting additional small channels of its own, called rills, which are small but well-defined channels with a depth of a few inches (see Figure 26).

**_Figure 6-26 Rill Erosion_**

*Source: USDA-NRCS 2019b*

Gully Erosion: As the water flowing in rills joins and forms a single flow path with even greater energy, the soil will further erode to form a gully. Larger soil particles are able to be detached and conveyed from their origin point. The major difference between gully and rill erosion is a matter of magnitude. Gullies are too large to be repaired with conventional tillage equipment and usually require heavy equipment and special techniques for stabilization.

Channel Erosion: Channel erosion occurs when the volume and velocity of a channelized flow causes movement of the materials making up a stream bed or stream bank. Flows contain considerably higher energy and velocity, and the water quality is often poor due to loosened sediment particles ranging in size.

The principal effect of land development activities on the natural or geologic erosion process is the exposure of disturbed soils to precipitation and runoff. **Excessive quantities of sediment cause costly damage to waters and to private and public lands. Obstruction of stream channels and navigable rivers by masses of deposited sediment reduces their hydraulic capacity which, in turn, causes an increase in subsequent flood crests and a consequent increase in the frequency of damaging storm events.**

The erosion potential for any area is determined by the following four principal factors: soil characteristics, vegetative cover, topography, and climate. These factors must be evaluated together to create a comprehensive control plan.

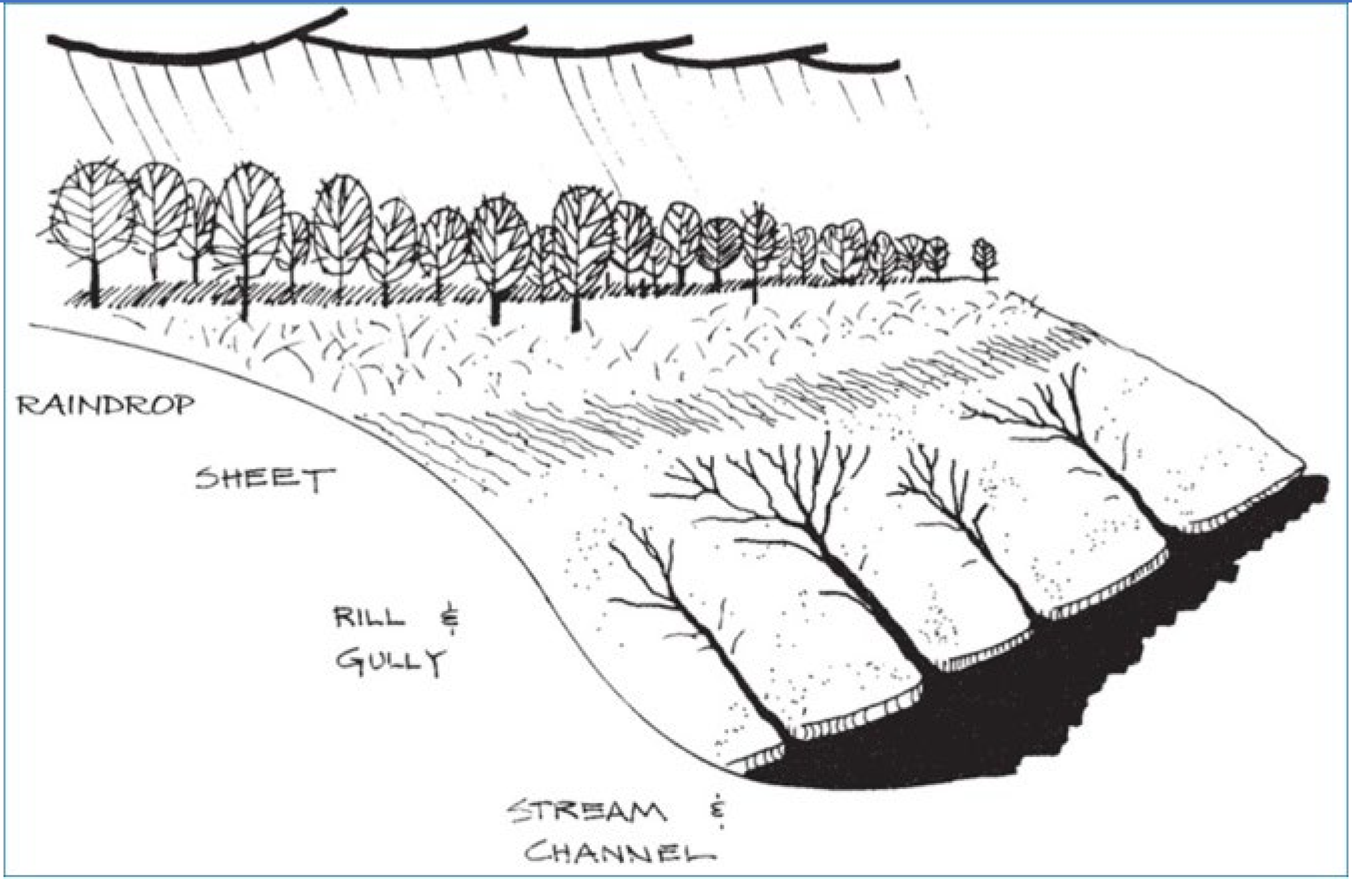
1. Soil Characteristics: Infiltration of rainfall into the soil reduces runoff and potential for erosion. Changes to the soil affecting its infiltration capacity and those which reduce the soil resistance to

detachment will increase the likelihood of carrying away sediment and erosion. Soil erodibility is primarily influenced by soil texture (particle size and gradation), organic content percentage, structure, and permeability.

Soils containing many fine sands and silt are normally the most erodible. As the clay and organic matter content of these soils increases, the erodibility decreases. Soils high in organic matter contain a more stable structure, which improves their permeability. Such soils resist raindrop detachment and infiltrate more rainwater. Clear, well-drained and well-graded gravel and gravel-sand mixtures are usually the least erodible soils.

2. Vegetative Cover: Vegetation provides an important role in controlling erosion. Because land-disturbance activities often remove vegetative cover, designers should be aware of the soil's increased exposure to erodibility. Vegetation shields soil from raindrop impact. Root systems from the established plants hold soil particles in place. The soil's capacity to absorb water, which helps prevent increased runoff, is enhanced by vegetation. Runoff is slowed because the vegetation obstructs the flow path, increases friction, and reduces the water energy and velocity. Finally, the plants remove subsurface waters between rainfalls via evapotranspiration (see Figure 6-27).
3. Topography: The size, shape, and slope characteristics of a watershed influence the amount and rate of runoff. As both slope length and gradient increase, the rate of runoff increases and the potential for erosion is magnified. Slope orientation can also be a factor in determining erosion potential. For example, a slope that faces south and contains droughty soils may have such poor growing conditions that vegetative cover will be difficult to re-establish (see Figure 6-27).
4. Climate: The frequency, intensity, and duration of rainfall are fundamental factors in determining the amounts of runoff produced. As the volume and velocity of runoff increases, the capacity of runoff to detach and transport soil particles also increases. Where storms are frequent, intense, or of long duration, erosion risks are higher. Seasonal changes in temperature, as well as variations in rainfall, help to define the high erosion risk period of the year. For instance, when precipitation falls as snow, no immediate erosion will take place. However, when the temperature rises, melting snow adds to runoff and erosion hazards increase. Because the ground is still partially frozen, its absorptive capacity is reduced. While frozen soils are relatively erosion-resistant, soils with a high moisture content are subject to uplift by freezing action and are often easily eroded upon thawing.

Figure 6-27 Soil Erosion on an Exposed Slope




*Source: NCDEQ 2013*

### 6.3.2.1 Erosion and Sediment Control Design Principles and Strategies

It is critical that those bearing the responsibility for their site's erosion and sediment control implement measures to reduce the conveyance of sediment offsite and adversely impacting downstream properties, populations, and waterbodies. **When correctly implemented, erosion and sediment control measures can control soil movement so there is only minimal conveyance of sediment offsite and no appreciable damage to offsite receiving channels. Erosion and sediment control mandated for many developments by the Virginia Erosion and Stormwater Management Regulation (see Chapter 5 for specific regulatory thresholds and minimum standards).**

Effective erosion and sedimentation control requires first that the soil surface be protected from the erosive forces of wind, rain, and runoff, and second that eroded soil be captured onsite. For an erosion or sediment control program to be effective, provisions for sediment control must be made in the design stages. The principles and strategies discussed below should be integrated into a site-specific system of control measures and management techniques to mitigate sediment and erosion.

**Minimize extent and duration of exposed areas.**

Depending on the size and duration of a development project, phase the project construction to minimize the amount of the site that is exposed and reduce the duration of exposure. Topographic changes and the removal of natural vegetation will lead to increased soil erosion. Plan the development stages so that only areas of active development are exposed. If working on a larger plan of development, implement in stages to limit the amount of disturbance. If larger areas need to be exposed to balance earthwork or for any other reason, keep exposure time to a minimum. Utilize temporary or permanent surface stabilization measures as soon as possible when ground disturbing activities like grading or utility installation are occurring. Special consideration should be given to maintenance of existing vegetative cover as long as possible on and surrounding areas planned for exposure.

**Mark sensitive areas.**

Scheduling can be as effective means of reducing the hazards of erosion. Minimize grading of large or critical areas during seasons with maximum erosion potential–the spring thaw in February and March, and the thunderstorm season from May to September. Track short-term weather forecasts when land-disturbing activities are planned. Ensure that construction notes and pre-construction communications emphasize the need to be prepared to react to sudden storms and immediately secure any unstabilized areas.

**Erosion and Sediment Control To-Dos**

Sequence construction so that grading operations can begin and end as quickly as possible.

Install sediment trapping measures as a first step in grading. Seed and mulch these immediately following installation.

Stabilize graded areas immediately with temporary seeding or other stabilization.
Cordon off areas that are not to be disturbed using flags, signs, fencing, etc.

Know who is responsible. The responsible land disturber listed on the permit is responsible for the installation and maintenance of all construction BMPs.

After achieving stabilization in accordance with requirements, clean up and remove temporary construction BMPs. Clean out sediment basins and convert them, if required, to permanent stormwater management facilities.
When working in a live waterway or wetland, conduct all work in the dry whenever possible.

When working in a live waterway, sequence the work to be conducted from upstream to downstream to minimize sedimentation and disturbance.

**Avoid land-disturbing activities during unsuitable weather or seasons.**

Scheduling can be an effective means of reducing the hazards of erosion. Minimize grading of large or critical areas during seasons with maximum erosion potential—the spring thaw in February and March, and the thunderstorm season from May to September. Track short-term weather forecasts when land-disturbing activities are planned. Ensure that construction communications emphasize the need to be prepared to react to sudden storms and immediately secure any unstabilized areas.

When planning the construction schedule, designers should also be aware of other seasonal restrictions on earthmoving and related activities, including avoiding in-stream work during the wet season or during times of year when restrictions from Virginia Department of Wildlife Resources apply to the site (e.g., fish breeding seasons). Winter months may also pose restrictions; for example, soil amendments should not be applied to frozen ground.

**Apply erosion control and surface stabilization practices.**

The core of any erosion and sediment control plan is to control erosion on a site to prevent excessive sediment from being produced or conveyed outside the property limits. This starts with keeping soil covered as much as possible with temporary or permanent vegetation, stabilization blankets, or other surface stabilization measures. Then, utilize erosion control measures to prevent sediment laden runoff from exiting the property and entering downstream waterways. Planning ahead and creating multiple phases of erosion control will allow for site sediment control practices to evolve with construction stages. The needs of the site during the clearing and earthwork stage will be different from a site with installed pavement and an installed stormwater collection system. Stabilize the ground immediately following attaining final grade.

**Figure 6-28 Silt Fence Perimeter Control Practice**


*Source: Creative Commons*

**Apply perimeter control practices.**

Perimeter control practices are the site's last defense before sediment is conveyed to neighboring properties and waterbodies. Perimeter control practices isolate the development site from surrounding properties.

**Keep runoff velocities low and retain runoff onsite.**

The removal of existing vegetative cover, changing of soil characteristics, and likely increase in impermeable surface area during development will increase both the volume and velocity of runoff. Increases should be accounted for during construction as well as post-construction. Keep slope lengths short and gradients low. Safely convey runoff to a stable outlet using diversions, stormwater infrastructure, and riprapped channels. Place stormwater control measures in low locations where emergency spillways and open outfalls will discharge to an energy-dissipating device. Design conveyance systems to withstand velocities of projected peak discharges and provide freeboard where it can be reasonably accommodated between structure rim elevations and hydraulic grade line elevations.

**Maintain sediment onsite.**

Some erosion will be unavoidable, and the resulting sediment should be trapped onsite. Plan the location where sediment deposition will occur and maintain access for cleanout. Protect low points below disturbed areas by building barriers to reduce sediment loss. Direct offsite flow away from disturbed areas to reduce erosive potential onsite. Whenever possible, plan and construct sediment traps, basins, and other erosion control measures before other land-disturbing activities (NCDEQ 2013).

**Implement a thorough maintenance and follow-up program.**

If not properly maintained, some BMPs may cause more damage than they prevent. When considering which control practice to use, evaluate the consequences of a measure failing and the practicality of the contractor or responsible party maintaining the measure. Thorough, periodic inspections of the erosion and sediment control practices should occur to ensure their effectiveness. Routine end-of-day checks of site conditions and installed BMPs should be performed to ensure that all control practices are working properly. If a BMP is not functioning, then have a backup plan to remediate the situation.

**Develop a detailed construction sequence.**

A well thought out construction sequence is critical to limiting erosion and sedimentation during construction. Some tips for developing effective sequences include:

- Thinking through the logic of construction, especially for drainage and stormwater structures.

- Anticipating the site conditions that will exist as construction proceeds. Interim conditions may occur that require a different approach to erosion and sediment control than the finished condition.
- Consider staging of equipment within the sequence such that work can be completed without delay.
- Emphasize the need for stabilization at the end of every work day.

Read more about construction sequencing in Chapter 9.

### 6.3.2.2 Erosion and Sediment Control Benefits

The rise in impervious cover associated with new development affects local water resources by reducing the infiltration of rainfall and increasing the volumes of stormwater runoff that eventually enter local waterbodies. Many Virginia communities are currently struggling with the issue of balancing economic growth with protection of their natural resources and water quality. The application of environmental design principles to reduce runoff volumes and pollutants can help developers and local governments recognize increased economic and environmental benefits through:

- Improving stream health for habitat and recreational use by preventing sedimentation of habitats and the introduction pollutants commonly associated with sediment;
- Enhancing public safety by reducing the amount of sediment on streets and sidewalks;
- Lowering maintenance costs by keeping sediment out of storm pipes, ditches, and street gutters, air quality from reduced airborne dust, etc.;
- Reducing damage to neighboring property and associated civil liability; and
- Avoiding sedimentation of post-construction stormwater management BMPs, which can, in turn, undermine the performance of these BMPs.

### 6.3.2.3 Construction Techniques and Practices

The following sections detail the categories and summary overviews of the construction practices recommended for use in Virginia. Complete standards and specifications for these practices can be found in Chapter 7.

#### 6.3.2.3.1 Surface Stabilization Measures

Implement surface stabilization measures when exposed soil needs to be settled or stabilized to prevent the erosive influences of rain, snow, and wind and other erosive activities (see Table 6-11). Note that where plantings are being implemented, native species should be used to the greatest extent practicable and invasives should be avoided. See Appendix G. for more information on plantings.

| Table 6-11 Surface Stabilization Measures | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| C-SSM-01 | Tree Preservation and Protection | Protecting existing trees and their root zones from mechanical and other injury during land-disturbing and construction activity to ensure the survival of trees where they will be effective for erosion and sediment control and provide other environmental and aesthetic benefits. |
| C-SSM-02 | Topsoiling | Preserving and using topsoil to provide a suitable growth medium for vegetation used to stabilize disturbed areas. Applicable where preservation or importation of topsoil is most cost-effective method of providing a suitable growth medium; not recommended for slopes steeper than 2:1 unless additional measures are taken to prevent sloughing and erosion. |
| C-SSM-03 | Surface Roughening | Grading practices such as stair-stepping or grooving slopes or leaving slopes in a roughened condition by not fine-grading them. Reduces runoff velocity, provides sediment trapping, and increases infiltration, all of which facilitate establishment of vegetation on exposed slopes. Applicable to all steep slopes that have received final grading but will not be stabilized immediately. Also recommended for other exposed slopes with flatter grades. |
| C-SSM-04 | Compost Blanket | A layer of loosely applied composted material placed on the soil in disturbed areas to reduce runoff. |
| C-SSM-05 | Soil Stabilization Blankets and Matting | The installation of a protective blanket or a soil stabilization mat on a prepared planting of a steep slope, channel, or shoreline. |
| C-SSM-06 | Sodding | Stabilizing fine-graded areas by establishing permanent grass stands with sod. Provides immediate protection against erosion and is especially effective in grassed swales and waterways or in areas where an immediate aesthetic effect is desirable. |
| C-SSM-07 | Bermuda and Zoysiagrass Establishment | Establishment of vegetative cover with hybrid bermudagrass or zoysiagrass by planting sprigs, stolons, or plugs to stabilize fine-graded areas where establishment by sod is not preferred. |

| Table 6-11 Surface Stabilization Measures | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| C-SSM-08 | Trees, Shrubs, Vines, and Ground Cover | Stabilizing disturbed areas by planting trees, shrubs, vines, and ground covers where sod is not preferred. These plant materials also provide food and shelter for wildlife as well as many other environmental benefits. Especially effective where ornamental plants are desirable and turf maintenance is difficult. |
| C-SSM-09 | Temporary Seeding | Establishment of temporary vegetative cover on disturbed areas that will not be brought to final grade for periods of 30 days to one year by seeding with appropriate rapidly growing plants. |
| C-SSM-10 | Permanent Seeding | Establishment of perennial vegetative cover by planting seed on rough-graded areas that will not be brought to final grade for a year or more or where permanent, long- lived vegetative cover is needed on fine-graded areas. |
| C-SSM-11 | Mulching | Application of plant residues or other suitable materials to disturbed surfaces to prevent erosion and reduce overland flow velocities. Fosters plant growth by increasing available moisture and providing insulation against extreme heat or cold. Should be applied to all seeding operations, other plant materials which do not provide adequate soil protection by themselves, and bare areas which cannot be seeded due to the season, but which still need protection to prevent soil loss. |

#### 6.3.2.3.2 Erosion Control Measures

Erosion control measures occur on or in advance of exposed slopes to dissipate the energy of concentrated water flow. Erosion control measures should be implemented when land-disturbing activities commence and should be maintained until land has been permanently stabilized (see Table 6-12).

| Table 6-12 Erosion Control Measures | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| C-ECM-01 | Straw Wattles | Agricultural straw wrapped in a biodegradable tubular plastic or similar encasing material used to break up the continuous length of a slope and prevent the development of concentrated flows. Straw wattles reduce velocity, filter runoff, and retain sediment. |
| C-ECM-02 | Impermeable Diversion Fence | A barrier of impermeable sheeting over a chain link fence located in such a manner as to direct water to a desired location. |
| C-ECM-03 | Slope Interruption Device | A three-dimensional tubular device used to provide filtration and reduce velocity and slope length of runoff on slopes. Soil erosion is reduced by dissipating the energy of overland sheet flow runoff. |
| C-ECM-04 | Temporary Diversion Dike | A ridge of compacted soil constructed at the top or base of a sloping disturbed area which diverts offsite runoff away from unprotected slopes and to a stabilized outlet, or to divert sediment laden runoff to a sediment trapping source. |
| C-ECM-05 | Diversion | A channel constructed across a slope with a supporting earthen ridge on the lower side. Used to intercept and divert stormwater runoff to stabilized outlets at non- erosive velocities. |
| C-ECM-06 | Temporary Fill Diversion | A channel with a supporting ridge on the lower side, constructed along the top of an active earth fill constructed in order to divert runoff away from the unprotected fill slope to a stabilized outlet or sediment trapping structure; applicable where the area at the top of the fill drains toward the exposed slope and continuous fill operations make the use of a Temporary Diversion Dike infeasible. |
| C-ECM-07 | Temporary Right-of-Way Diversion | A ridge of compacted soil or loose gravel constructed across a disturbed right-of-way or similar sloping area to shorten the flow length within the disturbed strip and divert the runoff to a stabilized outlet. Earthen diversions are applicable where there will be little or no construction traffic within the right-of-way, and gravel structures are applicable where vehicular traffic must be accommodated. |

| Table 6-12 Erosion Control Measures | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| C-ECM-09 | Stormwater Conveyance Channel | A permanent channel designed to carry concentrated flows without erosion. Applicable to man-made channels, including roadside ditches, and natural channels that are modified to accommodate increased flows generated by land development; not generally applicable to major, continuous-flowing natural streams. |
| C-ECM-10 | Subsurface Drain | A perforated conduit installed beneath the ground to intercept and convey groundwater. Prevents sloping soils from becoming excessively wet and subject to sloughing and improves the quality of the vegetative growth medium in excessively wet areas by lowering the water table. Can also be used to drain detention structures. |
| C-ECM-11 | Paved Flume | A concrete-lined channel constructed to conduct concentrated runoff from the top to the bottom of a slope without causing erosion on or below the slope. |
| C-ECM-12 | Temporary Slope Drain | A flexible tubing or conduit, used before permanent drainage structures are installed, intended to conduct concentrated runoff safely from the top to the bottom of a disturbed slope without causing erosion on or below the slope. |
| C-ECM-13 | Riprap | An erosion-resistant ground cover of large, loose, angular stone installed wherever soil conditions, water turbulence and velocity, expected vegetative cover, etc., are such that soil may erode under design flow conditions. |
| C-ECM-14 | Level Spreader | An outlet for dikes and diversions consisting of an excavated depression constructed at zero grade across a slope to convert concentrated, sediment-free runoff to sheet flow and release it onto areas of undisturbed soil which is stabilized by existing vegetation. |
| C-ECM-15 | Outlet Protection | The installation of riprap channel sections and/or stilling basins below storm drain outlets to reduce erosion and under-cutting from scouring at outlets and to reduce flow velocities before stormwater enters receiving channels below these outlets. |
| C-ECM-16 | Flexible Transition Mat | A flexible scour-protection system that is a synthetic alternative to riprap. |

#### 6.3.2.3.3 Sediment Control Measures

Sediment control measures are those that collect and prevent sediment from entering infrastructure and waterways. They should be installed at exits to the development site, at openings to channels, grates, inlets, or pipes, and anywhere that sediment-laden runoff can exit the project (see Table 6-13). Sediment control measures may require implementation or removal in phases as construction proceeds. Consider construction sequencing, the installation timeline of piped conveyance systems and ground stabilization (installation of impervious area) and generate phased erosion control plans as needed.

**Table 6-13 Sediment Control Measures**

| Spec Number | Practice | Definition |
|---|---|---|
| C-SCM-01 | Dust Control | Reducing surface and air movement of dust during land disturbance, demolition, or construction activities in areas subject to dust problems in order to prevent soil loss and reduce the presence of potentially harmful airborne substances. |
| C-SCM-02 | Construction Road Stabilizations | Temporary stabilization of access roads, subdivision streets, parking areas and other traffic areas immediately after grading to reduce erosion caused by vehicles during wet weather, and to prevent having to regrade permanent roadbeds between initial grading and final stabilization. |
| C-SCM-03 | Temporary Stone Construction Entrance | A stone pad, located at points of vehicular ingress and egress on a construction site, to reduce the soil transported onto public roads and other paved areas. |
| C-SCM-04 | Storm Drain Inlet Protection | The installation of various kinds of sediment trapping measures around drop inlets or curb inlet structures prior to permanent stabilization of the disturbed area. Not intended to control large, concentrated flows. |
| C-SCM-05 | Culvert Inlet Protection | A sediment filter located at the inlet to storm sewer culverts which prevents sediment from entering, accumulating in, and being transferred by the culvert. |
| C-SCM-06 | Woodchip Filter Berm | A berm constructed of mounded wood chips placed perpendicular to sheet flow to collect sediment from laden runoff. |
| C-SCM-07 | Rock Check Dams | An erosion-resistant ground cover of large, loose, angular stone with filter fabric or granular underlining. |
| C-SCM-08 | Rock Filter Outlet | A berm constructed of riprap and stone aggregate installed where unanticipated concentrated flow to a perimeter control (e.g., silt fence or straw bale barrier) has caused the perimeter control to collapse. |
| C-SCM-09 | Turbidity Curtain | A floating geotextile material which minimizes sediment transport from a disturbed area adjacent to or within a body of water. It provides sedimentation protection for a watercourse from upslope land disturbance or from dredging or filling within the watercourse. |

| Table 6-13 Sediment Control Measures | | |
|---|---|---|
| **Spec Number** | **Practice** | **Definition** |
| C-SCM-10 | Dewatering Structure | A settling and filtering device for water which is discharged from dewatering activities to remove sediment prior to discharging water offsite. |
| C-SCM-11 | Temporary Sediment Trap | A small ponding area, formed by constructing an earthen embankment with a stone outlet across a drainage swale, to detain sediment-laden runoff from small, disturbed areas for enough time to allow most of the suspended solids to settle out. |
| C-SCM-12 | Temporary Sediment Basin | A temporary barrier or dam with a controlled stormwater release structure which is formed by constructing an embankment of compacted soil across a drainageway. It is used to detain sediment-laden runoff from drainage areas for enough time to allow most of the suspended solids to settle out. It can be constructed only where there is sufficient space and appropriate topography. |
| C-SCM-13 | Concrete Washout Pit | A temporary excavated or aboveground lined constructed pit or a prefabricated or fabricated container where concrete truck mixers and equipment can be washed after their loads have been discharged, to prevent highly alkaline runoff from entering storm drainage systems or leaching into soil. |

#### 6.3.2.3.4 Perimeter Control Measures

Perimeter control measures serve to protect disturbed areas from offsite runoff and to prevent sedimentation conveyance and damage to areas downstream of the development site. Install perimeter control measures prior to commencing land-disturbing activities and ensure their maintenance throughout construction (see Table 6-14).

| Table 6-14 Perimeter Control Measures | | |
|---|---|---|
| **Spec Number** | **Practice** | **Definition** |
| C-PCM-01 | Safety Fence | A protective barrier installed to prohibit undesirable use of an erosion control measure. |
| C-PCM-02 | Straw Bale Barrier | A temporary sediment barrier composed of straw bales placed across or at the toe of a slope to intercept and detain sediment and decrease flow velocities from drainage areas of limited size; applicable where sheet and rill erosion may be a problem. |

| Table 6-14 Perimeter Control Measures | | |
|---|---|---|
| **Spec Number** | **Practice** | **Definition** |
| C-PCM-03 | Brush Barrier | A temporary sediment barrier composed of limbs, weeds, vines, root mat, rock, and other cleared materials pushed together to form a berm; located across or at the toe of a slope to intercept and detain sediment and decrease flow velocities. |
| C-PCM-04 | Silt Fence | A temporary sediment barrier constructed of posts, filter fabric and, in some cases, a wire support fence, placed across or at the toe of a slope or in a minor drainageway to intercept and detain sediment and decrease flow velocities from drainage areas of limited size; applicable where sheet and rill erosion or small concentrated flows may be a problem. Maximum effective life of 6 months. |
| C-PCM-05 | Compost Filter Sock | Compost filter sock, also called a filter log, consists of a biodegradable or photodegradable mesh tube filled with a coarse compost media to filter sediment and other pollutants. |

#### 6.3.2.3.5 Environmentally Sensitive Area Protection

Environmentally sensitive areas like wetlands, streams, channels, springs, sinkholes, cave openings, or losing streams may require additional or modified erosion and sediment control measures in order to disturb the area to the least extent possible and protect the existing ecosystem. Great care should be taken to reduce the disturbance footprint within these areas. The practices shown in Table 6-15 have been modified or developed with this in mind. Additionally, where plantings are utilized, native species should be used to the greatest extent practicable and invasives should be avoided. See Appendix G for more information.

| Table 6-15 Environmentally Sensitive Area Protection | | |
|---|---|---|
| **Spec Number** | **Practice** | **Definition** |
| C-ENV-01 | Vegetative Streambank Stabilization | The establishment of appropriate vegetation on streambanks to protect the banks from erosion. |
| C-ENV-02 | Structural Streambank Stabilization | Stabilizing the banks of live streams with permanent structural measures to protect them from erosion. Particularly applicable to watercourses which must pass increased flows due to upstream development; not applicable to tidal streams. |
| C-ENV-03 | Temporary Vehicular Stream Crossing | A temporary structural span across a live stream to provide vehicular access to construction activity on either side of the stream while keeping sediment out of the stream and preventing damage to the channel bed and banks. |

| Table 6-15 Environmentally Sensitive Area Protection | | |
|---|---|---|
| **Spec Number** | **Practice** | **Definition** |
| C-ENV-04 | Utility Stream Crossing | A strategy for crossing small waterways when in-stream utility construction is involved. The strategy helps to prevent sediment from entering the affected watercourse and minimizes the amount of disturbance within the stream itself. |
| C-ENV-05 | Cofferdam Crossing | A cofferdam is a temporary structure within a waterway or body of water designed to provide a dry work area for temporary construction activities and to contain disturbed soil and/or suspended sediments. |
| C-ENV-06 | Stable Wetland Crossing | A stable wetland crossing is a method or temporary structure used to cross a wetland with vehicles and/or equipment and/or strategy for crossing wetlands when in- wetland utility construction is involved. |
| C-ENV-07 | Gabions/Gabion Deflectors | Gabions are rectangular baskets fabricated from a hexagonal mesh of heavily galvanized steel wire filled with rock material. Gabions are used to slow the velocity of concentrated runoff or to stabilize slopes with seepage problems and/or non-cohesive soils |
| C-ENV-08 | Pump Around Diversion/Bypass Pipe Flume/Pumped Bypass | The pump-around-diversion is a dewatering practice used for temporarily pumping flow around segments of a stream channel during construction; the practice involves installing a temporary pump-around system and instream barriers to divert flow around sections or reaches of the stream. |
| C-ENV-09 | Overnight Channel Protection | Overnight channel protection is the temporary stabilization of a stream channel bed using secured filter fabric while in-stream work activities are not actively taking place. This practice is used during stream restoration projects when there is active disturbance to an existing natural stream channel bed. |
| C-ENV-10 | Trenchless Silt Fence | Trenchless silt fence is a temporary sediment barrier consisting of a synthetic filter fabric stretched across and attached to supporting posts with no trench. |
| C-ENV-11 | Wetland Berm | A wetland berm is an earthen berm structure used in the creation, restoration, and enhancement of wetlands through the collection and retention of water that flows by gravity or other means to the bermed area. |
| C-ENV-12 | Wetland Weir Outlet | A wetland weir outlet is an overflow water control structure that regulates the volume of water impounded in the created, restored, or enhanced wetland. |

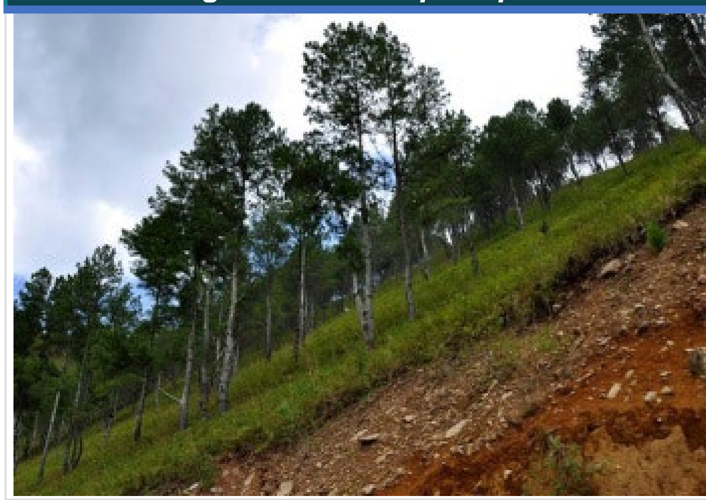
| Table 6-15 Environmentally Sensitive Area Protection | | |
|---|---|---|
| Spec Number | Practice | Definition |
| C-ENV-13 | Wetland Cell Sediment Trap | Wetland mitigation bank projects create and restore wetlands through the construction of wetland cells that are large, flat areas that can be used as giant sediment traps where applicable during construction. |
| C-ENV-14 | Modified Turbidity Curtain for Streams | A floating or staked barrier installed within across stream flow that may also be referred to as a floating boom, silt barrier or silt curtain. |
| C-ENV-15 | Seeding, Mulching, and Soil Stabilization for Wetlands and Streams | Establishment of perennial vegetative cover on disturbed areas by planting seed; applying a protective blanket of mulch to the soil surface during the establishment of seeding, and planting of forb, shrubs, and/or trees in stream and/or wetland areas during restoration. |

#### 6.3.2.4 Construction BMPs for Special Site and Climatic Conditions

Although intentional planning can help reduce erosion control from construction activities, there will inevitably be site and climatic conditions that require special treatment. Obstacles such as exceptionally steep slopes, winter weather, and offsite runoff entering the property call for a dedicated approach to ensure that the potential for additional erosion and sedimentation is mitigated.

**Exceptionally Steep Slopes**

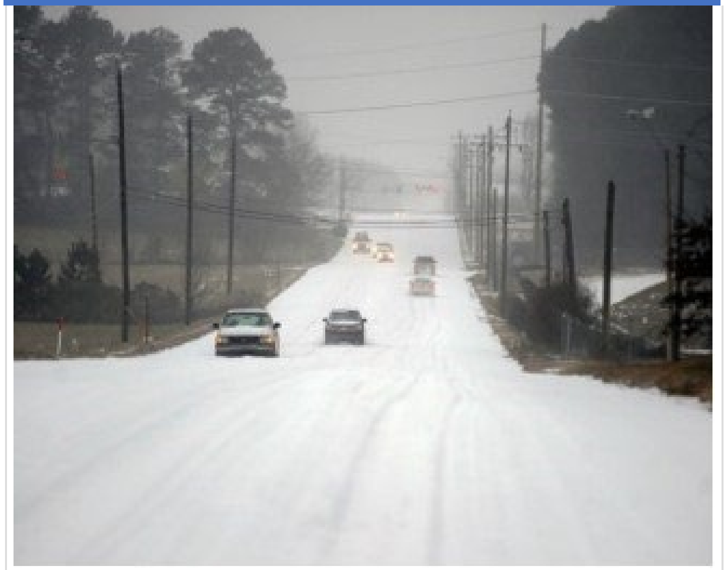
*Figure 6-29 Steep Slopes*



Sites with exceptionally steep slopes (e.g., Figure 6-29) require diligence in implementing, inspecting, and maintaining erosion control measures. Steep slopes are at risk for increased erosion, and topsoil that has washed away can take years to naturally rebuild. The site engineer should consider implementing diversions, erosion control blankets, permanent and temporary seeding if steep slopes are being disturbed during construction activities. If slopes are not being disturbed but may be subject to sheet or concentrated flow from upstream, construct a diversion to concentrate and direct water, and stabilize the low side of the diversion with additional erosion control blankets. Inspection and maintenance should occur regularly in addition to after significant rainfall events.

**Winter Weather**

Figure 6-30 Winter Weather



Source: Vickie D. King, Mississippi Today

While controlling erosion and sedimentation is a year- round effort, the snow and ice that comes with winter will pose an extra challenge for installed erosion control measures the following spring. Erosion control blankets, mulching, and seeding with a winter mix, and other surface stabilization measures are critical for keeping soil in place. When the snow melts, it will take loose sediment with it and clog perimeter control measures.

The optimum time to conduct frost seeding is in late winter to early spring after snow is gone but the ground is still frozen. Identify problem areas where snow melt or winter rains will become concentrated flow (e.g., Figure 6-3) and prepare in advance using sediment control measures. Winter preparations should be in place prior to slowing down a job site for winter weather (Marion County Soil and Water Conservation District 2019).

**Controlling Offsite Runoff**

Developments are not only responsible for runoff generated on their site, but also responsible for collecting and conveying any runoff entering their site from a neighbor (see 9VAC25-875-560 19 for more information on these requirements). Evaluate the topography of neighboring properties in addition to the site location to determine where water may enter the construction area. The construction of a diversion, flume, or temporary culvert to collect offsite runoff and convey away or around the site to the natural discharge location will prevent water contamination from active construction. Further, proactively identifying and conveying offsite flows will prevent surprise flooding of the construction area during significant rainfall events.

**Karst Topography**

Karst topography is landscape where the dissolving of bedrock has created sinkholes, caves, sunken streams, and other ground features. Be aware that the design of sediment and erosion control measures will require modification to fit the karst conditions of the site to prevent or remediate the formation of sinkholes, impacts to groundwater and springs from sediment discharge to sinkholes, and backflooding of existing sinkholes, which can result in slope destabilization and erosion from overflow. Appendix E provides additional guidance for minimizing erosion and sedimentation within karst environments. These considerations include limiting excavated conveyance channels and piping, lining sediment traps and basins, and backfilling utility trenches with lower-permeability materials.

**Linear Development**

Linear development projects pose unique challenges related to erosion and sediment control. Roads within several watersheds may be subject to different regulations. The linear nature of the work may prevent the use of land-intensive measures. Designers are tasked with implementation of BMPs that are suitable given limited right-of-way and geographic constraints. Projects may be located adjacent to environmentally sensitive areas (see Section 6.3.2.3.5). It is important to be knowledgeable about the regulations governing the linear project, and to plan erosion and sediment control measures throughout the project scope to account for changing topographic and regulatory conditions and requirements.

### 6.3.3 Post-Construction Stormwater BMPs

Post-construction stormwater control measures, also known as BMPs, are used in Virginia to manage stormwater runoff. The BMPs included here have been selected based on their ability to:

- Capture and treat the full treatment volume.
- Reduce the volume of stormwater runoff.
- Remove total phosphorus (TP) from site runoff (a regulatory compliance criteria).
- Remove total nitrogen (TN) from site runoff.
- Remove total suspended solids (TSS) from runoff .
- Remove other pollutants (e.g., hydrocarbons, bacteria, metals).
- Address stormwater quantity criteria (e.g., channel protection criteria, and flood protection).

The BMPs discussed below are well studied and recognized as being effective in reducing runoff, phosphorus, and nitrogen.

**Filtration and Infiltration**

Filtration and infiltration practices both reduce runoff volumes by capturing and treating stormwater runoff and sending it back into the ground. Filtration captures stormwater runoff and passes it through an engineered filter media, collecting the filtered water in an underdrain, and returning it back to the storm drainage system. Infiltration practices typically allow stormwater to penetrate the underlying soil, enabling vegetation to absorb and remove pollutants. Filtration utilizes physical processes, whereas infiltration utilizes chemical and biological processes.

Filtration practices do not receive credit for reducing runoff because the system is typically used to clean water before directing it back into the storm system. Filtering systems do, however, have high efficiencies for both nitrogen and phosphorus removal. Infiltration practices have very high RR efficiencies because their primary purpose is to penetrate runoff into the ground. As the water infiltrates through the BMP, vegetation works to absorb and remove nutrients, and to a lesser extent, other contaminants.

**Conveyance**

Conveyance practices use channels that are designed to convey stormwater runoff at a manageable flow rate, while using filtration and infiltration to decrease runoff and pollutant loads. These practices are commonly used as pretreatment practices because they can carry runoff to other treatment facilities. These channels are commonly found along roadways and are typically used to manage runoff from small drainage areas. Conveyance practices can help to reduce the size of other required onsite stormwater management facilities. These systems can be enhanced by adding compost amendments to the soil beneath the channel, thereby improving the infiltration capacity.

Conveyance practices achieve different things depending on the specific practice used. Some practices apply infiltration throughout the length of the conveyance to reduce runoff amounts, while others only provide PR. However, all conveyances help to reduce the immediate load on storm sewer systems, which lowers associated costs. Additionally, these systems can provide visually interesting landscape features. Vegetated areas also provide habitats and pollination sources.

**Basins**

Basins are wet or dry ponds designed to manage the volume and velocity of stormwater runoff caused by development on a site. The basin is designed with enough temporary water storage volume during a storm event to prevent flooding and release stormwater at a controlled discharge rate to prevent channel erosion. Basins do not reduce runoff volumes, but they control stormwater by storing and releasing it at rates that will not impact downstream properties. Release rates should also keep flows below a critical velocity that would cause erosion to the downstream receiving channel. Basins receive PR credit through physical means such as the settling of sediment with adsorbed nutrients.

**Manufactured Treatment Devices**

Manufactured Treatment Devices (MTDs) are prefabricated stormwater treatment structures that use settling, filtration, absorptive and adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to remove pollutants from stormwater runoff. MTDs can provide a wide range of benefits depending on the type of device used. Some are used to physically remove pollutants such as trash and debris, while others mimic natural processes to remove nutrients from water. The benefits are dependent on each unique device.

MTDs are typically proprietary, meaning that they are products that are specifically owned and sold under a brand name by a private company. Each different type typically utilizes different techniques to achieve RR and PR. To use MTDs in Virginia, the MTD must first either be on an approved list, which is created and updated by VDEQ, or an exception must be granted. See 9VAC25-875-170 B and 9VAC25-875-590.

### 6.3.3.1 Post-Construction Stormwater Design Principles

Post-construction stormwater design is part art and part science. Incorporate these fundamental design principles to achieve the most out of the stormwater site design, reduce costs, and meet site requirements.

- Use stormwater site design. Stormwater site design techniques can really make a difference in lowering the need for expensive BMPs. Before using post-construction BMPs, take another look at the site layout to see if there is more than can be done to reduce the creation of impervious surfaces.
- Think quantity and quality. Aim to meet both water quantity and water quality requirements when selecting and installing BMPs. This is often an iterative process, but worth it in terms of taking advantage of BMPs that provide both functions.
- Design with maintenance in mind. Smart stormwater design provides opportunities to make BMPs easier to maintain over time and lowers operating costs, which can be put into other property upkeep activities. See also Chapter 10, which provides detailed recommendation for designing BMPs to reduce maintenance.
- Consider phasing. When using phased developments, ensure the stormwater management plan will work efficiently for all phases, not just the initial build out.
- Pretreat. Pretreatment is particularly important if the post-development condition will generate high debris loading, such as locations with industrial activities, stockpiled materials, or overhanging trees. Pretreatment support components (P-SUP-01 to 06) are addressed in Chapter 8.
- Recognize the erosion and sediment control BMP connection. Many designers like to use future post-construction BMPs for sedimentation basins during construction. However, these choices can result in poor conditions that are unsuitable for processes like infiltration or plant growth. Take this consideration into account when planning through the interim and final conditions. Tight construction sequencing is required and expected among most reviewers.
- Combine and optimize BMPs. Use a combination of BMPs to optimize BMP design.
- Choose optimal BMPs. Stormwater regulations apply to an enormous variety of sites ranging from linear developments to solar farms, to ultra-urban in-fill, big box retail, warehousing, and suburban residential. Additionally, Virginia is a diverse state with distinct geography, physiography, and regulatory requirements. Picking the right set of BMPs is critical. Take maximum advantage of the BMP selection guidance provided in Section 6.3.3.3, Section 6.3.3.4, and Chapter 8.

### 6.3.3.2 Post-Construction Stormwater Benefits

Although VDEQ prefers the use of non-structural stormwater site design strategies, post-construction BMPs are also an important part of design strategies for meeting stormwater requirements. BMPs assist in meeting both water quantity and water quality goals. Beyond meeting the stormwater requirements for water quantity and water quality, post-construction stormwater BMPs can help meet a variety of goals and provide a variety of benefits, particularly if using nature based, vegetative BMPs.

Early in the design process is the best time for design teams to discuss ways to incorporate vegetative BMPs into the site layout.

Benefits of nature based and vegetative BMPs include:

- Aesthetics/Beautification – The use of vegetated BMPs such as infiltration basins, bioretention, and constructed wetlands can all add aesthetic appeal to a variety of development types. Consider weaving these features throughout the landscape to accentuate and add landscape features or add a central or focal point. Research has shown the benefits of adding natural landscapes in terms of enhancing retail sales and increasing property values.
- Recreation – The benefits of natural areas for wellbeing, both physical and mental, are well known. Incorporating BMPs as natural areas creates obvious opportunities for natural environments that incorporate benches, trails, and other amenities.
- Flood Mitigation – The economic and public health impacts of flooding are increasing as the climate continues to change. Oversizing BMPs is a low-cost way to protect properties from the effects of flooding.
- Habitat Creation – Vegetated BMPs can attract wildlife such as song birds, butterflies and other wildlife that can enhance the everyday experience for customers, workers, and residents. Consider adding bird boxes or other features to maximize these benefits.
- Energy Savings – BMPs like green roofs contain insulative and cooling benefits that can save on energy spending and help to extend the roof service life.
- Water Harvesting – Treating stormwater as a resource can provide a low-cost source of potable water to meet irrigation, watering, or non-potable water needs (e.g., make up water for chillers and boilers, process water for industrial uses, cool down water for turf fields).
- Cost Reduction – Developers are commonly focused on controlling costs. Smart use of BMPs that reduce the use of piping and structure can reduce the cost of compliance, helping to lower overall development costs.

### 6.3.3.3 Post-Construction Stormwater Design Techniques and Practices

This section focuses on introducing the types of post-construction stormwater BMPs approved for use in Virginia. Designers should exhaust the range of stormwater site design techniques before considering post-construction stormwater BMPs. See Chapter 8 for design specifications for individual post-construction BMPs.

#### 6.3.3.3.1 Pollution Prevention BMPs

By far the most effective control of urban stormwater pollution is to prevent its release. This is especially true for stormwater hotspots, which are zones where stormwater can come into direct contact with concentrated occurrences of contaminants. There are three families of runoff pollution prevention:

- Impervious surface reductions: reducing the total area of surfaces that limit or prohibit stormwater infiltration (see the SD-6 discussion in Section 6.3.1.4.6).
- Housekeeping techniques: basic clean-up and management practices.

- Construction practices: techniques to prevent exposed soils from eroding, methods to reduce opportunities for sediment release into stormwater, and methods to catch sediment already suspended in stormwater (see Section 6.3.2 and Chapter 9).

Stormwater-related considerations related to hotspots are discussed further in Section 6.3.3.5 and Appendix D. Briefly, the keys to managing and treating runoff at hotspot sites are as follows:

- Prevent contact of rainfall or stormwater runoff with pollutants and make this an important element of the post-construction stormwater plan. It is most important to design manage and store toxic materials on the site in a way that prevents opportunities for the pollutants to be exposed to rain and be washed into runoff.
- Provide pretreatment devices between the source material and any stormwater control measures used to control general runoff from the site, especially if they involve infiltration.
- Inspect and correctly maintain all pollution prevention or treatment elements at the site on a routine basis. Because of the extremely toxic nature of hotspot pollutants, it is extremely important that the stormwater control measures at hotspot sites be kept in good working order.
- Train personnel at the affected area to ensure that industrial and municipal managers and employees understand and implement the correct stormwater pollution prevention practices needed for their site or operation.

### 6.3.3.3.2 Filtration and Infiltration BMPs

| Table 6-16 Filtration and Infiltration BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-FIL-01 | Rooftop Impervious Surface Disconnection | Impervious areas that immediately drain to a stormwater conveyance system or other impervious surface are “connected impervious” areas and produce stormwater that flows untreated to surface waterbodies. Disconnection occurs when impervious surfaces are redirected and dispersed into sheet flow across an expanse of turf grass or natural vegetation. Disconnecting direct rooftop or impervious surface runoff and redirecting flows to designated pervious areas will increase infiltration, resulting in a direct reduce runoff and corresponding storage volume requirements. |
| P-FIL-02 | Vegetated Roof | Vegetated roofs are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing medium that is designed to support low-growing plant growth. Vegetated roofs capture and temporarily store stormwater runoff in the growing medium before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads otherwise generated by rooftops. Vegetated roofs are typically not designed to retain stormwater from larger storms. |
| P-FIL-03 | Permeable Pavement | Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated.<br>Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. |
| P-FIL-04 | Infiltration Practices | Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Infiltration practices are suitable for use in residential and other urban areas where measured soil permeability rates exceed ½ inch per hour. |

| Table 6-16 Filtration and Infiltration BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-FIL-05 | Bioretention | Bioretention can also be designed to infiltrate runoff into native soils. This can be done at sites with permeable soils, a low groundwater table, and a low risk of groundwater contamination. This design features the use of a partial exfiltration system that promotes greater groundwater recharge. Underdrains are only installed beneath a portion of the filter bed, above a stone sump layer, or eliminated altogether, thereby increasing stormwater infiltration. |
| P-FIL-06 | Filtering Practices | Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. Stormwater filters can be applied to most types of urban land especially for hotspot runoff treatment, small high-traffic parking lots, and ultra-urban areas. |
| P-FIL-07 | Sheet Flow to Vegetative Filter Strip/Open Space | Filter strips are vegetated areas that treat sheet flow delivered from adjacent managed turf and impervious areas by slowing runoff velocities and allowing sediment and attached pollutants to settle and/or be filtered by the vegetation. Stormwater must enter the vegetated filter strip or conserved open space as sheet flow. If the inflow to the filter strip is from a pipe or channel, a level spreader must be designed to convert the concentrated flow to sheet flow. See also the SD-7 discussion in Section 6.3.1.4.7. |
| P-FIL-08 | Soil Compost Amendment | Soil restoration and compost amendment is the technique of enhancing compacted soils to improve their porosity and nutrient retention. The soil amendments can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the RR performance of areas that receive runoff, such as downspout disconnections, grass channels, and filter strips. |

| Table 6-16 Filtration and Infiltration BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-FIL-09 | Tree Planting | Trees can be planted as a PR practice on developed land. Trees that are planted to replace others that have been removed as part of the development cannot be counted as a new tree BMP. Tree plantings can be street trees, residential tree plantings, or other small-scale community tree plantings. The planting of new trees not only provides water quantity and quality improvements but also can help mitigate the urban heat island effect in highly developed settings, provide habitat for wildlife, trap air pollution, and provide other benefits. |

#### 6.3.3.3.3 Conveyance BMPs

| Table 6-17 Conveyance BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-CNV-01 | Grass Channels | A grass channel is a broad and shallow open channel vegetated with grass sides used for water quality treatment, water quantity control, and can be a component of pretreatment for some BMPs. Grass channels can be implemented on suitable development sites where development density, topography, and soils are suitable. The linear nature of grass channels makes them well-suited to treat highway runoff, low- and medium-density residential road and yard runoff, and small commercial parking areas or driveways. |
| P-CNV-02 | Dry Swales | Dry swales are shallow channels with a series of check dams that provide temporary storage to allow infiltration of the treatment volume. Dry swales use an engineered soil media as the channel bed with an under drain. Dry swales are vegetated with turf or other surface material (including large cobbles and ornamental plants). Dry swales are a linear biofiltration practice with the goal of providing proper residence time in the swale to filter the stormwater through the soil media and discharge the treated water downstream to a receiving conveyance system. |

| Table 6-17 Conveyance BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-CNV-03 | Wet Swales | Wet swales are a cross between a wetland and a swale that can provide runoff filtering and treatment within a stormwater conveyance system. Linear on-line or off-line wetland cells are formed within the channel to intercept shallow groundwater or retain runoff to create saturated soil or shallow standing water conditions to maintain a wetland plant community. Wet swales are ideal for placement where the water table is located close to the ground surface, or where water does not positively drain out of the swale. Designers should note that a wet swale does not provide a runoff volume reduction credit and is therefore typically the final element in the roof-to-stream PR sequence. |
| P-CNV-04 | Regenerative Stormwater Conveyance | Regenerative stormwater conveyance (RSC) provides treatment, and conveyance through the combination of sand, wood chips, native vegetation, riffles, and shallow pools. RSCs are designed to convey water while minimizing the effects of erosion. RSCs are well-suited for new construction projects and roadway designs with small drainage areas and a high percentage of impervious area. |

#### 6.3.3.3.4 Basin BMPs

| Table 6-18 Basin BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-BAS-01 | Constructed Wetlands | Constructed wetlands, sometimes called stormwater wetlands, are shallow basins that mimic the functions of natural wetlands and use physical, chemical, and biological processes to treat stormwater. Constructed wetlands should be considered only if there is remaining PR or protection volume to manage after all other upland runoff options have been considered and properly credited. |
| P-BAS-02 | Wet Pond | Wet ponds consist of a permanent pool of water that promotes a better environment for gravitational settling, biological uptake, and microbial activity. Wet ponds should be considered only if there is remaining PR or protection volume to manage after all other upland runoff options have been considered and properly credited. |

| Table 6-18 Basin BMPs | | |
|---|---|---|
| **Specification Number** | **Practice** | **Definition** |
| P-BAS-03 | Extended Detention Pond | An extended detention pond is an earthen structure constructed by either excavation of existing soil or the impoundment of a natural depression. The use of extended detention alone generally results in the lowest overall PR rate of any single stormwater treatment option. Alternatively, an extended detention component is combined with wet ponds and constructed wetlands to help maximize PR rates of those practices. |
| P-BAS-04 | Rainwater Harvesting | Rainwater harvesting systems intercept, divert, store and release rainfall for future use. Rainwater that falls on a rooftop is collected and conveyed into an aboveground or belowground storage tank where it can be used for non-potable water uses and onsite stormwater disposal/infiltration. |

### 6.3.3.4 Post-Construction Stormwater BMP Selection

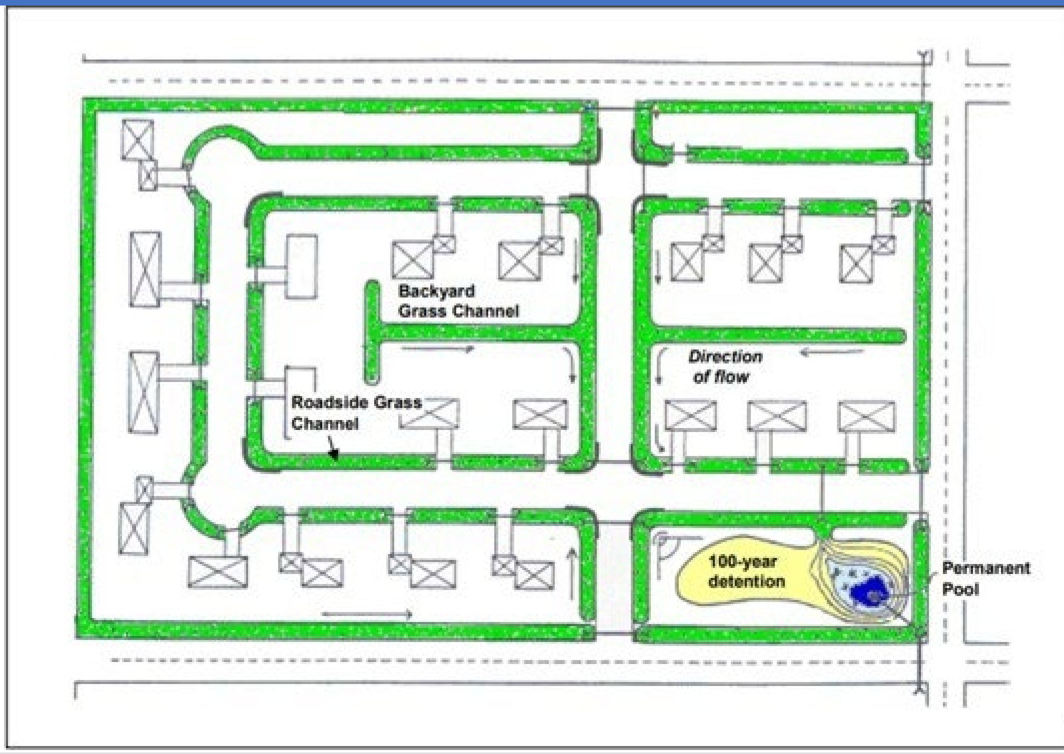
Selection of post-construction stormwater BMPs requires a detailed understanding of the residual water quantity and water quality requirements following the application of stormwater site design techniques, and a nuanced understanding of the site's topography, soils, slopes, subsurface conditions, and natural features. Incorporate post-construction BMPs into the development in creative ways that provide aesthetic and amenity benefits. As described in Section 6.3, VDEQ outlines a comprehensive design process that first uses BMPs that address RR. When these options have been exhausted, then use non-RR BMPs to meet water quantity and water quality requirements.

**Treatment Train Approach**

Central to the selection and arrangement of BMPs within the development site is the concept of a treatment train, which is a connected web of storage and conveyance systems that maximizes stormwater management functions. Where possible, BMPs suitable to meet channel protection and flood protection requirements should not be used by themselves to also address water quality requirements; instead, BMPs should be combined in a "treatment train" of one or more BMPs to meet water quality requirements.

An effective treatment train utilizes pretreatment practices prior to introducing stormwater into BMPs. Pretreatment BMPs are designed to improve water quality and enhance the effective design life of practices by consolidating sedimentation location, but they also cannot meet water quality requirements by themselves. If pretreatment practices are used, they must be combined with other water quality BMPs to meet water quality criteria. It is important that the various BMPs employed in a treatment train use different treatment mechanisms in order to maximize PR (e.g., rooftop disconnection to a grass channel to biofilters and bioretention to a constructed wetland, as depicted on Figure 6-31).

*Figure 6-31 Treatment Schematic*




*Source: Atlanta Regional Commission 2016*

**BMP Applicability**

There are a range of BMPs that can be used to meet water quantity and/or water quality requirements on most sites. That said, some BMPs are particularly well suited for use in certain conditions, while being less suitable or even unsuitable in other conditions. The following section provides a series of BMP applicability tables and matrices that provide the basis of BMP selection for most sites. The tables can be used to identify the most appropriate group of BMPs for site conditions and identify suitable locations for each selected BMPs based on micro-scale site conditions. Be sure to review the design specifications for BMPs that are being considered, as these design specifications may further restrict appropriate siting beyond the guidance offered in this section.

**Land Use**

Land uses associated with proposed development projects can vary from ultra-urban infill projects to linear roadway projects traversing rural landscapes to everything in between. In this step, make an initial screening to select practices that are best suited to a particular land use. Consider these primary land use factors when selecting BMPs:

- Rural: Most BMPs are well suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre) with few neighborhoods and relatively large amounts of open space. Stormwater control measures with larger area demands may be easier to locate with appropriate buffers in rural areas. Additionally, typical stormwater pollutants from rural areas include sediments and nutrients, which can be effectively managed by most stormwater control measures.
- Residential: Residential developments typically contain limited space and higher property values compared to rural undeveloped land. Also, stormwater control measures in residential areas are likely to be located in close proximity to residences. Public safety and nuisance insects are common concerns related to control measures in residential areas. BMPs with large land requirements or

open pools of water may be less desirable in these areas. In some situations, stormwater ponds or other open water practices may be incorporated into the landscape as amenities to provide for habitat, recreation, and aesthetic value.

- Roads and Highways: Major roadway and highway systems typically generate high stormwater pollutant loads due to vehicle traffic and winter deicing activities. Sediments, metals, chlorides, and hydrocarbons are the primary pollutants associated with roads and highways. Nitrogen from vehicle exhausts and bacteria are also commonly present in road and highway runoff. As a result, most treatment practices provide some treatment benefit but do not adequately address all of the water quality impacts associated with this land use. In addition, open water and deep pools can also be a safety issue near roads and highways.
- Commercial/Industrial Development: Commercial and industrial development often contain more intensive traffic, increased risk of spills, and exposure of materials to precipitation. Pollutants associated with these land uses can vary significantly, depending on the nature of activities at each site, although traffic-related pollutants such as sediments, metals, and hydrocarbons are commonly present in runoff from most commercial and industrial sites. These developments may also contain more available space for locating stormwater control measures.
- Hotspot Land Uses: Some BMPs that can accommodate hotspot runoff may contain design restrictions and are noted in the matrix. These BMPs will typically require some level of modification to deal with elevated pollutant loads.
- Ultra-Urban Sites: In ultra-urban environments, population is dense, land area and space are limited, stormwater infrastructure is already in place, a wide range of potential pollutants are present, and original soils have been disturbed. Ultra-urban sites are the most restrictive in terms of BMP selection. Stormwater control measures appropriate for ultra-urban sites are also frequently used at redevelopment and infill sites and to retrofit existing urban development.

**Physical Feasibility**

The are a host of physical constraints at a site that may restrict or preclude the use of a particular BMP (see Table 6--19). In this step, screen the various BMP design criteria to determine whether the soils, water table, drainage area, slope, or head conditions present at a particular development site might limit the use of a BMP. More detailed testing protocols are often needed to confirm physical conditions at the site.

The following are the primary physical feasibility factors:

- Soil Infiltration Rate: Infiltration rate is one of the key physical feasibility factors, given the reliance of many BMPs on infiltration processes. The key evaluation factors are based on an initial investigation of the USDA-NRCS HSGs (2019b) at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors. Knowledge of all soil groups present on the site is needed for runoff calculations, but the presence of HSG-A or HSG-D soils are most likely to constrain the choice of certain BMPs. See Appendix C for infiltration testing requirements.
- Water Table Separation: The minimum depth to the seasonally high water table from the bottom elevation, or floor, of a BMP may limit the choice of certain BMPs. Specifically, infiltration-based BMPs function better in high water table environments.
- Shallow Soils/Depth to Bedrock: The minimum depth to bedrock from the bottom elevation, or floor, of a BMP can constrain the use of many BMPs. In more extreme cases, a reliance on elevated or roof top systems may be needed. Shallow system configurations can also be used.
- Contributing Drainage Area: Contributing drainage areas vary widely from site to site. BMPs differ in terms of the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a

practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits and may be increased or decreased depending on water availability (base flow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

- Slope: Slopes can be highly variable within and among development sites. BMPs typically are associated with a range of slopes within which they are most effective. Slopes outside of this range may make the BMP less effective and may require choosing an alternate BMP or implementing design modifications.
- Hydraulic Head: Hydraulic head refers to the energy gradient present within the BMP due to elevation difference. BMPs can differ in the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

**Table 6-19 Physical Feasibility Criteria for Post-Construction BMPs**

| BMP Category | Specific BMP | Soils1 | Water Table Separation (feet) | Minimum Depth to Bedrock/ Shallow Soils (feet) | Contributing Drainage Area (acres) | Effective Longitudinal Site Slope (%) | Minimum Hydraulic Head (feet) |
|---|---|---|---|---|---|---|---|
| Conveyance | Regenerative Stormwater Conveyance | No soil restrictions | 2 | No depth restrictions | Less than 50; typically 10-30 | Less than 10% | 2 to 3 |
| | Dry Swales | Underdrain required for C-D soils | 2 | 2 | 5 maximum | 4% | 3 to 5 |
| | Grass Channels | Minimum residence time 10 minutes if C-D soils | 2 | 2 | 5 maximum | 2-4% | 2 to 3 |
| | Wet Swales | Best for C-D soils | Below water table | 2 from swale bottom | 5 maximum | 2% swale profile | 2 |
| Filtration & Infiltration | Vegetated Roof | NA | NA | NA | NA | NA | 1 to 2 |
| | Rooftop Disconnection | Need additional RR practice for C-D | 2 | 2 | Maximum 1,000 square feet to each roof discharge point | 1-2% | 1 |
| | Soil Compost Amendment | B-D | 1.5 | 1.5 | Should not exceed impervious area draining directly to practice | 10% | 1 |
| | Filtering Practices | NA | 2 | 2 | 5 maximum; 0.5 to 2 recommended | NA | 2 to 10 |
| | Sheet Flow to Vegetative Filter Strip/Open Space | All soils ok, except fill. Recommend using compost amendments for C-D | 2 | 2 | 3 maximum | 6-8% | 1 to 2 |
| | Tree Planting | All soils ok. Recommend using compost amendments for C-D for greater RR | 5 | 5 | NA | NA | NA |
| | Bioretention Level 1 (with underdrain) | See P-FIL-05 | 2 | 2 | 5 maximum; 0.5 to 2 recommended | 1-5% | 4 to 5 |
| | Bioretention Level 2 (without underdrain) | See P-FIL-05 | 3 | 2 | 5 maximum; 0.5 to 2 recommended | 1-5% | 4 to 5 |

| Table 6-19 Physical Feasibility Criteria for Post-Construction BMPs | | | | | | | |
|---|---|---|---|---|---|---|---|
| **BMP Category** | **Specific BMP** | **Soils1** | **Water Table Separation (feet)** | **Minimum Depth to Bedrock/ Shallow Soils (feet)** | **Contributing Drainage Area (acres)** | **Effective Longitudinal Site Slope (%)** | **Minimum Hydraulic Head (feet)** |
| | Infiltration Practices | Minimum measured hydraulic conductivity of 0.5 inch/hour | 2 | 2 | < 2 and 100% impervious | 0-5% | 2 to 4 |
| | Permeable Pavement | Minimum measured hydraulic conductivity of 0.5 inch/hour | 2 | 2 | Ratio to impervious area to permeable pavement cannot exceed 2:1 | 1-3% | 2 to 4 |
| Basins | Extended Detention Pond Level [1] | A-B may require liner | 2 | 2 | < 10 | NA | 6 to 10 |
| | Extended Detention Pond Level [2] | A-B may require liner | | | > 10 | | |
| | Wet Pond | A-B may require liner | Below water table if no hotspot; otherwise, 2-foot separation | 2 from pond bottom | 25 minimum[5] | NA | 6 to 8 |
| | Constructed Wetlands | A-B may require liner | | 2 from wetland bottom | 25 minimum[6] | NA | 2 to 4 |
| | Rainwater Harvesting | NA | Below grade tanks to be above water table | Below grade tanks to be above bedrock | Rooftop only draining to tank | NA | Varies with design |
| Manufactured Treatment Devices | Hydrodynamic Devices | NA | varies with device; must have clearance below bottom of device | Varies with device; must have clearance below bottom of device | Varies based on manufacturer specification for device used | NA | Varies based on manufacturer specification for device used |
| | Filtering Devices | NA | | | | | |
| | Biofilter Devices | NA | | | | | |

**Notes:**

NA = Not Applicable

1. USDA-NRCS HSGs (2019b)
2. Refers to post-construction slope across the location of the practice.
3. Denotes a required limit, other elements as planning level guidance and may vary somewhat, depending on site conditions.
4. Drainage area can be larger in some instances.
5. Ten acres may be feasible if groundwater is intercepted and/or if water balance calculations indicate a wet pool can be sustained, and anti-clogging device is required.
6. If detention is used, then an impermeable liner must be placed at the bottom of the basin and geotechnical tests should be conducted to determine the maximum allowable depth.

### Utilities, Roads, and Structures

Careful BMP siting is required when BMPs are located in the proximity of utilities, roads, and structures such as buildings and walls. Appropriate setbacks are required, particularly when using infiltrating practices. Infiltration of stormwater can cause infiltration and inflow into sewer lines or basements or cause structural issues. Although some setbacks are standardized, in most cases setbacks will require coordination with local review authorities.

#### Utilities

Utilities include gas, electric, fiber optic and communications, water, and sewer lines. Each utility may have its own requirements for setbacks or specific design requirements for systems that meet setback requirements. Setbacks may apply to the asset itself, or to easements. Check with each local review authority to understand these requirements and ensure that appropriate coordination takes place and approval are secured.

- Coordinate as needed with local review authorities.

- Contact Virginia 811 (formerly “Miss Utility”) to locate existing utilities prior to design.
- Note the location of proposed utilities to serve development.
- Avoid placement of BMPs within utility easements or rights-of-way for public or private utilities.
- If a BMP is needed in or partially in an easement, consult with the utilities in question to determine lateral and vertical offsets from the existing utilities.

**Roads**

Roadways present unique challenges for BMP siting. As with utilities, BMPs typically require setbacks from roadways and/or roadway easements. Consult the local transportation authority, local department of public works, or subdivision ordinance/regulations for setback requirements from local roads and streets. Designs must coordinate with the Virginia Department of Transportation (VDOT) for setbacks from state-maintained roads. Also, approval must be obtained for any stormwater discharges to a local or state-owned storm drain or conveyance channel.

**Structures**

Structures can include buildings, bridges, and retaining walls. Check with local review authorities to understand setback requirements for structures. Jurisdictions may vary in terms of what constitutes a structure. In some cases, features such as fences, sheds, tents, pavilions, and gazebos may be considered structures and may require adherence to a setback requirement or other design requirement.

Table 6--20 provides specific guidance for each BMP with respect to setbacks. Setbacks often vary by jurisdiction, so due diligences with local authorities is essential for compliance.

**Table 6-20 Setbacks for Various Post-Construction BMPs**

| BMP Category | Specific BMP | Setback Recommendations |
|---|---|---|
| Conveyance | Grass Channels | Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. Grass channels should offset from the 1H:1V bearing zone, 10 feet from building foundations, 35 feet from septic system fields, and 50 feet from private wells. For Dry Swales, refer to P-CNV-02 for specific setback recommendations. |
| | Regenerative Stormwater Conveyance | Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. Generally, RSC should offset 25 feet from building foundations, 50 feet from septic system fields and private wells, and 10’ from property lines. For RSC, refer to P-CNV-04 for specific setback recommendations. |
| | Dry Swales | Local subdivision and zoning ordinances, design criteria, and utility requirements should be consulted to determine minimum setbacks. |
| | Wet Swales | NA |
| Filtration & Infiltration | Vegetated Roof | ANSI/SPRI VF-1 External Fire Design Standard for minimum criteria for fire breaks and setback dimensions for all roof penetrations, such as mechanical sheds, penthouses, ducts, pipes, and skylights & mechanical systems |
| | Rooftop Disconnection | Local subdivision and zoning ordinances, design criteria, and |

| Table 6-20 Setbacks for Various Post-Construction BMPs | | |
|---|---|---|
| **BMP Category** | **Specific BMP** | **Setback Recommendations** |
| | Soil Compost Amendment | utility requirements should be consulted to determine minimum setbacks. |
| | Filtering Practices | |
| | Sheet Flow to Veg. Filter Strip/Open Space | Local subdivision and zoning ordinances, design criteria, and utility requirements should be consulted, but filter strip recommended setback from building foundations is 10 feet. |
| | Tree Planting | Local subdivision and zoning ordinances and design criteria and utility requirements should be consulted to determine minimum setbacks. |
| | Bioretention Level 1 | Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. Bioretention recommends a setback of 10 feet on downgradient property, except when a liner is used and therefore no setback is recommended. |
| | Bioretention Level 2 | |
| | Infiltration Practices | Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. Bioretention and infiltration practices recommend offset from the 1H:1V bearing zone, 10 feet from residential structures, 35 feet from septic system fields, and 50 feet from private wells. |
| | Permeable Pavement | 250 to 1,000 square feet of permeable pavement = 5 feet if down- gradient from building & 25 feet if up-gradient;<br>1,000 to 10,000 square feet of permeable pavement = 10 feet if down-gradient from building; 50 feet if up-gradient;<br>> 10,000 square feet of permeable pavement = 25 feet if down-gradient from building; 100 feet if up-gradient. |
| Basins | Extended Detention Pond | Local subdivision and zoning ordinances and design criteria and utility requirements should be consulted to determine minimum setbacks. |
| | Constructed Wetlands | |
| | Wet Pond | Local subdivision and zoning ordinances and design criteria and utility requirements should be consulted to determine minimum setbacks. Recommended setbacks for wet pond setbacks include 20 feet from property lines, 25 feet from building foundations, 100 feet from septic system fields, and 100 feet from private wells. |
| | Rainwater Harvesting | Local subdivision and zoning ordinances, design criteria, and utility requirements should be consulted, but underground tanks recommend a setback of 10 feet from building foundations. |
| Manufactured Treatment Devices | Hydrodynamic Devices | Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. |
| | Filtering Devices | |
| | Biofilter Devices | |

**Critical Water Resources**

Consider what watershed protection goals need to be met for a site's water resources. The design and implementation of BMPs is strongly influenced by the nature and sensitivity of the receiving waters. In some cases higher PR, more recharge, or other environmental performance is warranted to fully protect the resource quality and human health and/or safety. Critical resource areas include: groundwater and source water areas, high value trout streams, other freshwater streams, freshwater lakes and ponds, drinking water reservoirs, freshwater wetlands, and coastal waters (including tidal wetlands).

The following design and siting suggestions are offered to enhance the protection of various types of critical water resources:

**Groundwater Source Water Areas, Water Wells, and Septic Systems**

- Provide adequate setbacks from wells and septic systems, including wellhead protection zones.
- For water wells, a 100-foot setback for infiltration practices and 50-foot setback for other BMPs is recommended.
- For septic systems, a minimum 50-foot setback from a drain field edge is recommended for BMP location.
- Consult the Virginia Department of Health, the local health department, and the local water utility to confirm setbacks and other requirements.
- There should be no infiltration of confirmed hotspot runoff; runoff from potential hotspot runoff should be restricted and be pretreated.
- For infiltrating practices, pretreat runoff in limestone regions.
- Restricted if site is used for Pumped-Storage Hydropower; may need injection well.
- Ensure rainwater harvesting does not adversely impact groundwater recharge rates.

**100-Year (i.e., 1% annual exceedance probability) Floodplain**

- Grading and fill for BMP construction is strongly discouraged within the effective 100-year (i.e., 1% annual exceedance probability) floodplain, as delineated on FEMA flood insurance rate maps, FEMA flood boundary and floodway maps, or more stringent local maps.
- Coordinate with the VDCR Division of Dam Safety and Floodplain Management regarding applicable local floodplain management ordinances and stormwater review authority.
- Floodway fill may not raise the 100-year (i.e., 1% annual exceedance probability) water surface elevation by more than 0.5 foot; (local regulations may be more stringent).
- Only use Bioretention Level 2, infiltration practices, and porous pavements with an impermeable liner and underdrains.

**Cold Water Fisheries and Other Sensitive Receiving Waters**

Cold and cool water streams in Virginia contain enhanced habitats which can support trout and other sensitive aquatic organisms. These streams are classified under Virginia Law as Class V and Class VI and contain stricter criteria for water temperature and dissolved oxygen than other waters in the state (9VAC25-260-60 and 9VAC25-260-70). Part IX of 9VAC25-260 provides a map of Virginia divided into regions and lists each named stream segment within each region, identifying for each the stream class and critical criteria that apply. All this information becomes important when selecting BMPs that will be most successful in protecting these sensitive habitats. Temperature changes can be stressful, and even lethal, to many cold-water organisms. For reasons like this, it is imperative to utilize a unique stormwater site design plan with appropriate BMPs to minimize site impacts on cold-water fisheries. The design objective for cold water (trout) streams is to maintain habitat quality by preventing stream warming, maintaining dissolved oxygen and biological oxygen demand levels, maintaining natural recharge, preventing pollution, preventing bank and channel erosion, and preserving the natural riparian corridor (VDEQ 1999, 2013). Techniques and considerations to accomplish these objectives include the following (VDEQ 2013):

- Minimize impervious surfaces (SD-6).
- Minimize surface areas of permanent pools such as those associated with pond-type BMPs (P-BAS-01, P-BAS-02).
- Preserve existing forested areas and ground vegetation (SD-1,SD-2).
- Bypass existing baseflow and/or spring flow.
- Locate BMPs outside of stream buffers, where required or otherwise established (SD-2).
- Provide shade-producing landscaping as part of the proposed stormwater site design (P-FIL-07).
- Maximize infiltration to promote cooling of runoff and groundwater recharge (SD-7, P-FIL-02, P-FIL-05, P-FIL-08, P-FIL-09, P-CNV-04).

Elevated temperatures are also caused by reduced shading in developed riparian areas and heat absorption by impervious surfaces. This heat is transferred to runoff passing over the surface, resulting in runoff that can be dramatically warmer than natural groundwater inflow would be in a natural hydrologic cycle. Some BMPs, such as swales, shallow ponds, and large impoundments can also increase the temperature of runoff, as it is quickly warmed prior to discharge. Traditional peak reduction outlet structures and simple spillway outlets do not cool the water before discharge, so their use in proximity to cold water streams should be avoided. Alternative BMPs, such as buffers, infiltration, or under-drained filters can be used, or, if ponds are required, under-drained outlet structures can effectively cool runoff. Equally important to maintaining cool stream temperature is preservation and/or restoration of riparian trees and shrubs that provide shade. This is most important for headwater streams that are the root of the local ecosystem and the base of its food chain (VDEQ 2013).

Below is additional guidance for sensitive receiving waters like lakes, wetlands, and coastal waters.

**Freshwater Lakes and Ponds**

Freshwater lakes and ponds can be highly sensitive environmental resources that require unique stormwater management approaches. Often these resources can be highly sensitive to increases in nutrient and sediment loading, which can impact public health, aesthetics, fisheries, and other aspects of resource quality. Designers should look to maximize nutrient removal if lakes are prone to algal blooms or are nutrient limited. To further minimize impacts, always locate BMPs outside the shoreline buffer, where required or otherwise established (SD-2).

**Freshwater Wetlands**

Freshwater wetlands are regulated features that may trigger extensive permitting. Always locate BMPs outside the wetland buffer, where required or otherwise established (SD-2). Stormwater discharges to regulated wetlands should be avoided and existing wetlands should not be used for stormwater management functions.

**Coastal Water (including tidal wetlands)**

Coastal areas are subject to a variety of unique conditions that may influence BMP performance, such as tidal fluctuations and storm surge. Where possible, locate BMPs outside of coastal influence, where required or otherwise established. Where design in or around coastal waters is needed, it is important to understand the conveyance of stormwater (e.g., hydraulic grade line may be highly influenced by diurnal tidal cycles and storm surge). Therefore, conveyance modeling should account for a variety of hydraulic grade line conditions. Tidal gates and backflow prevention may be added to avoid the possibility of tidal intrusion. BMPs in coastal areas may also discharge close to public beaches; therefore, use BMPs with high bacteria removal near public beaches.

**Impaired Waters or Waters with an Established TMDL**

Many watersheds in Virginia are subject to TMDLs and in most cases, these TMDLs address similar pollutants to those addressed by BMPs authorized for use by VDEQ for post-construction management. That said, be aware of TMDLs that affect the development site, including all waters downstream of the discharge point. TMDL documents are generally available online or through local authorities. In some cases, local authorities may establish more rigorous BMP standards to assist with meeting TMDLs. Be aware that VDEQ standards are minimum standards and local ordinances may be more stringent (subject to requirements in § 62.1-44.15:33 of the Code of Virginia) .

Where possible, select BMPs based on specific PR targets established by TMDL or another source reduction plan. Load reduction efficiencies for pollutants with no VDEQ-established load reduction efficiencies can be derived from documented literature sources or reasonable assumptions developed in consultation with VDEQ.

**Stormwater Management Capability**

Determine whether one BMP can meet all design criteria, or a combination of practices is needed. In this step, screen the BMP list to determine whether a particular BMP can meet each of the stormwater management criteria: water quality, groundwater recharge, receiving channel/overland flow protection, and flood control storage requirements.

- Water Quality Treatment: Water quality treatment is key to the performance of many BMPs. Practices using filtration or infiltration can generally be used to provide for effective water quality treatment (i.e., PR). For detail on specific PR, see Table 6-21.
- Runoff Volume Reduction: RR contributes to PR and may contribute to groundwater recharge, and reduction in peak flows. VDEQ encourages developers to implement RR practices during site layout to the maximum extent practicable prior to the use of standardized practices like ponds. Practices can reduce runoff either through infiltration and/or evapotranspiration.
- Groundwater Recharge: Infiltration based BMPs can provide for groundwater recharge. It may also be possible to accomplish some groundwater recharge by using stormwater site design techniques (see Section 6.3.1).
- Receiving Channel/Overland Flow Protection: A range of BMPs can be used to fully or partially provide for channel protection storage volume, although larger BMPs are sometimes needed. Keep in mind that if a particular BMP cannot meet the channel protection requirement, this does not necessarily imply that the BMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream extended detention pond).

- Flood Control: All storage BMPs provide some level of flood control, but larger basin BMPs are typically the most effective for this function. Again, if a particular BMP cannot meet the flood control requirement, more than one practice may be needed at the site.

**Stormwater Function – Volume Reduction and PR**

Determine how each BMP option compares in terms of PR. In this step, focus on the removal of select pollutants to determine the best BMP options for water quality. Table 6-21 examines the capability of each BMP option to remove specific pollutants from stormwater runoff. Total pollutant reductions (TR) indicated in Table 6-21 for TP, TN, and TSS reflect a combination of PR processes. These numbers assume a typical concentration for each pollutant in the total site runoff. These concentrations are typically expressed as an amount per unit of volume (e.g., 0.26 milligram per liter of TP). When part of a site's total runoff volume is removed through the use of RR practices (e.g., rainwater capture, infiltration), the pollutants in that portion of the site runoff are removed from the remaining runoff that must still be managed. Then, as stormwater treatment processes (e.g., settling, filtration, chemical conversion, vegetation uptake) are applied to the remaining runoff, the actual concentration of pollutant in the runoff is further reduced. So, the total mass load removal of pollutants is a result of the combination of runoff volume reduction and supplementary treatment practices.

**Table 6-21 Pollutant Removal Efficiencies and Volume Removal Rates for Post-Construction BMPs**

| BMP Category | Specific BMP | Runoff Volume Reduction[1] (%RR) | TP EMC Reduction[2] (%PR) | Total TP Reduction[3] (%TR) | TN EMC Reduction[2] (%PR) | Total TN Reduction[3] (%TR) | TSS EMC Reduction[2] (%PR) | Total TSS Reduction[3] (%TR) | Total Bacteria Reduction[3,4] (%TR) |
|---|---|---|---|---|---|---|---|---|---|
| Conveyance | Regenerative Stormwater Conveyance | To Be Determined | | | | | | | |
| | Dry Swales Level 1 | 40 | 20 | 52 | 25 | 55 | 40 | 65 | 0 5 |
| | Dry Swales Level 2 | 60 | 40 | 76 | 35 | 74 | 70 | 90 | 25* |
| | Grass Channels | 10 or 20[10] | 15 | 24 or 32[10] | 20 | 28 or 36[10] | 30 | 35 | 0 |
| | Wet Swales Level 1 | 0 | 20 | 20 | 25 | 25 | 40 | 40 | 0 |
| | Wet Swales Level 2 | 0 | 40 | 40 | 35 | 35 | 70 | 70 | 0 |
| Filtration & Infiltration | Vegetated Roof Level 1 | 45 | 0 | 45 | 0 | 45 | 50 | 50 | 70 |
| | Vegetated Roof Level 2 | 60 | 0 | 60 | 0 | 60 | 50 | 50 | 80 |
| | Rooftop Disconnection | 25 or 50[10] | 0 | 25 or 50[10] | 0 | 25 or 50[10] | 50 | 50 | NA |
| | Soil Compost Amendment | Can be used to decrease runoff coefficient for turf cover at a site. See design specs for Rooftop Disconnect, Sheet Flow to Vegetative Filter, and Grass Channel. | | | | | 0 | 50 | NA |
| | Filtering Practices Level 1 | 0 | 60 | 60 | 30 | 30 | 60 | 60 | 35[5] |
| | Filtering Practices Level 2 | 0 | 65 | 65 | 45 | 45 | 85 | 85 | 70[6] |
| | Sheet Flow to Vegetative Filter Strip/ Open Space[15] | 50 or 75[10] | 0 | 50 or 75[10] | 0 | 50 or 75[10] | 60 or 85[10] | 60 or 85[10] | 20* |
| | Tree Planting | 16 or 12[10] 3.5 | 0 | 16 or 12[10] 3.5 | 0 | 16 or 12[10] 3.5 | | | |
| | Bioretention Level 1 | 40 | 25 | 55 | 40 | 64 | 50 | 70 | 40* |
| | Bioretention Level 2 | 80 | 50 | 90 | 60 | 90 | 75 | 95 | 40* |
| | Infiltration Practices Level 1 | 50 | 25 | 63 | 15 | 57 | 50 | 75 | 40* |
| | Infiltration Practices Level 2 | 90 | 25 | 93 | 15 | 92 | 50 | 95 | 40* |
| | Permeable Pavement Level 1 | 45 | 25 | 59 | 25 | 59 | 65 | 80 | NA |
| | Permeable Pavement Level 2 | 75 | 25 | 81 | 25 | 81 | 65 | 90 | NA |
| Basins | Extended Detention Pond Level 1 | 0 | 15 | 15 | 10 | 10 | 50 | 50 | 30[5] |
| | Extended Detention Pond Level 2 | 15 | 15 | 31 | 10 | 24 | 70 | 75 | 60[6] |
| | Wet Pond Level 1 | 0 | 50 (45[13]) | 50 (45[13]) | 30 (20[13]) | 30 (20[13]) | 50 | 50 | 70[7] |
| | Wet Pond Level 2 | 0 | 75 (65[13]) | 75 (65[13]) | 40 (30[13]) | 40 (30[13]) | 80 | 80 | 70 |
| | Constructed Wetlands Level 1 | 0 | 50 | 50 | 25 | 25 | 50 | 50 | 80[7] |

| Table 6-21 Pollutant Removal Efficiencies and Volume Removal Rates for Post-Construction BMPs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| BMP Category | Specific BMP | Runoff Volume Reduction[1] (%RR) | TP EMC Reduction[2] (%PR) | Total TP Reduction[3] (%TR) | TN EMC Reduction[2] (%PR) | Total TN Reduction[3] (%TR) | TSS EMC Reduction[2] (%PR) | Total TSS Reduction[3] (%TR) | Total Bacteria Reduction[3,4] (%TR) |
| | Constructed Wetlands Level 2 | 0 | 75 | 75 | 55 | 55 | 80 | 80 | 80 |
| | Rainwater Harvesting | 90[11,12] | 0 | 90[11,12] | 0 | 90[11,12] | 0 | 90[11] | NA |
| Manufactured Treatment Devices | Hydrodynamic Devices | 0 | NA | 20 | NA | NA | NA | NA | NA |
| | Filtering Devices | 0 | NA | 40-65 | NA | NA | NA | NA | NA |
| | Biofilter Devices | 0 | NA | 40-65 | NA | NA | NA | NA | NA |

**Notes:**

NA = Not Applicable

1. Based upon 1 inch of rainfall – 90% storm; Annual average RR as reported in CWP (2008b).
2. Change in stormwater event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in CWP (2008b).
3. TR = product of RR and PR.
4. Bacteria removal rates, as reported by Schueler et al. (2007). An asterisk denotes where monitoring data is limited.
5. Median value from International BMP database.
6. Q3 value from International BMP database.
7. Median value from the National Pollutant Removal Performance Database (managed by the CWP).
8. Average of zinc and copper, but only zinc for infiltration.
9. Based on fewer than five data points (i.e., independent monitoring studies).
10. The lower rate is for HSG class C and D soils; the higher rate is for HSG class A and B soils.
11. Credit up to 90% is possible if all water from storms 1 inch or less is used through demand, and the tank is sized such that no overflow occurs. Total credit is not to exceed 90% as an isolated practice.
12. See BMP design specification for an explanation of how additional PR can be achieved.
13. Lower nutrient removals in parentheses apply to wet ponds in Coastal Plain terrain or where wet pond is influenced by groundwater
14. The removal can be increased to 50% for HSG C and D soils by adding soil compost amendments and may be higher yet if combined with secondary RR practices.
15. The pollutant reduction values shown are applicable for sheet flow to conserved open space and sheet flow to vegetated filter strip.
16. Lower nutrient credit removals are for tree canopy over impervious cover.

### Community and Environmental Factors

Determine which BMPs have important community or environmental benefits or drawbacks that might influence the selection process. In this step, consider the following community and environmental factors for selecting BMPs.

- Maintenance: Maintenance of BMPs can be highly variable, even within a single BMP type. Broadly speaking, large-scale practices can be less costly to maintain, given the smaller number of structures per unit drainage area. Smaller practices that are distributed over the landscape can be more costly to maintain due to the added travel time and mobilization required to visit numerous practices, small distribution pipes and structures that are less efficient to clean, and the typically close proximity of smaller landscape practices to residents, customers, or workers. The expected rate of sediment loading to BMPs is also highly predictive of maintenance effort. BMPs receiving higher sediment loading may need more frequent maintenance due to sediment accumulation, clogging, and challenges with vegetation management.
- Overall Affordability: BMPs can vary significantly in both short- and long-term costs. Factors such as deep excavations, the amount of structural work (e.g., concrete), and the practice scale can all impact costs. Practices such as green roofs, which are commonly large in comparison to the incoming drainage area, tend to be expensive per unit of drainage area managed. By contrast, larger practices such as constructed wetlands can offer relatively low costs.

- Community Acceptance: Some BMPs may face issues with community acceptance, while others are readily accepted in most instances. With respect to vegetated BMPs, adapting landscape design elements to the development setting can help to avoid acceptance issues. Acceptance of vegetated practices is also highly tied to maintenance. If vegetated practices are not well maintained, they can accumulate trash and become overgrown, which can contribute to a negative perception in the community.
- Safety: BMPs can pose safety issues, particularly those associated with open or deep water. Safety issues are typically more significant if open water is present during dry weather, as is the case with wet ponds. Controlling access via fencing or dense vegetation can help to reduce safety concerns, while providing shallow benches along the shoreline of open water BMPs can reduce drowning risk.
- Habitat: BMPs differ markedly in their habitat benefits. Habitat benefits are associated with vegetated BMPs, especially when installed at a large scale. Habitat benefits include plant diversity and connections with other natural features such as stream buffers. The addition of habitat features such as basking rocks and bird boxes help to further increase the habitat value of vegetated BMPs.
- Aesthetic and Recreational Benefits: BMPs can offer a variety of aesthetic or recreational benefits. Aesthetic benefits are most commonly associated with vegetated BMPs. Both small- and large-scale vegetated BMPs can offer significant aesthetic benefits, while larger BMPs tend to support more recreational benefits (e.g., recreational trails that circumnavigate larger vegetated BMPs). Large open water BMPs like wet ponds can support additional benefits such as shoreline fishing. As with all vegetated BMPs, aesthetic benefits derive from an appropriate landscaping plan and a strong plan for and commitment to maintaining BMPs over time.

**Practice Scale**

BMPs vary in the spatial scale at which stormwater control measures can be applied to achieve RR and PR. Some BMPs, such as bioretention systems, are intended to be distributed throughout the landscape. These systems can be woven into the site layout, doubling as landscape features that are in close proximity to streets and residents. By contrast, features like constructed wetlands and wet ponds are larger in scale. These systems typically require significant conveyance systems to collect and transport water from a large contributing drainage area. Tradeoffs exist as BMPs change in scale. For instance, small-scale BMPs should be more aesthetically sensitive because they are commonly in close proximity to homes and businesses. This can mean higher aesthetic expectations and a lower tolerance for weeds and trash. These features, when designed and maintained properly, can offer a level of greening at human scales that simply is not possible with larger features. Some of the most innovative designs combine practices at a range of scales.

### 6.3.3.5 BMPs for Special Site and Climatic Conditions

Sites with unique climatic or geological conditions can lead to challenges regarding site layout and BMP selection. Among those conditions of concern are karst, sites near the coastline, pollution hotspots, sites where extremely cold temperatures and precipitation exist, and ultra-urban settings. The significance of stormwater site design in these unique settings is discussed below. The best approach to design is understanding there are unique climates and regions throughout Virginia that need to be treated with site-specific care. Also note that all approved BMPs have limitations on use and applicability, depending on the site.

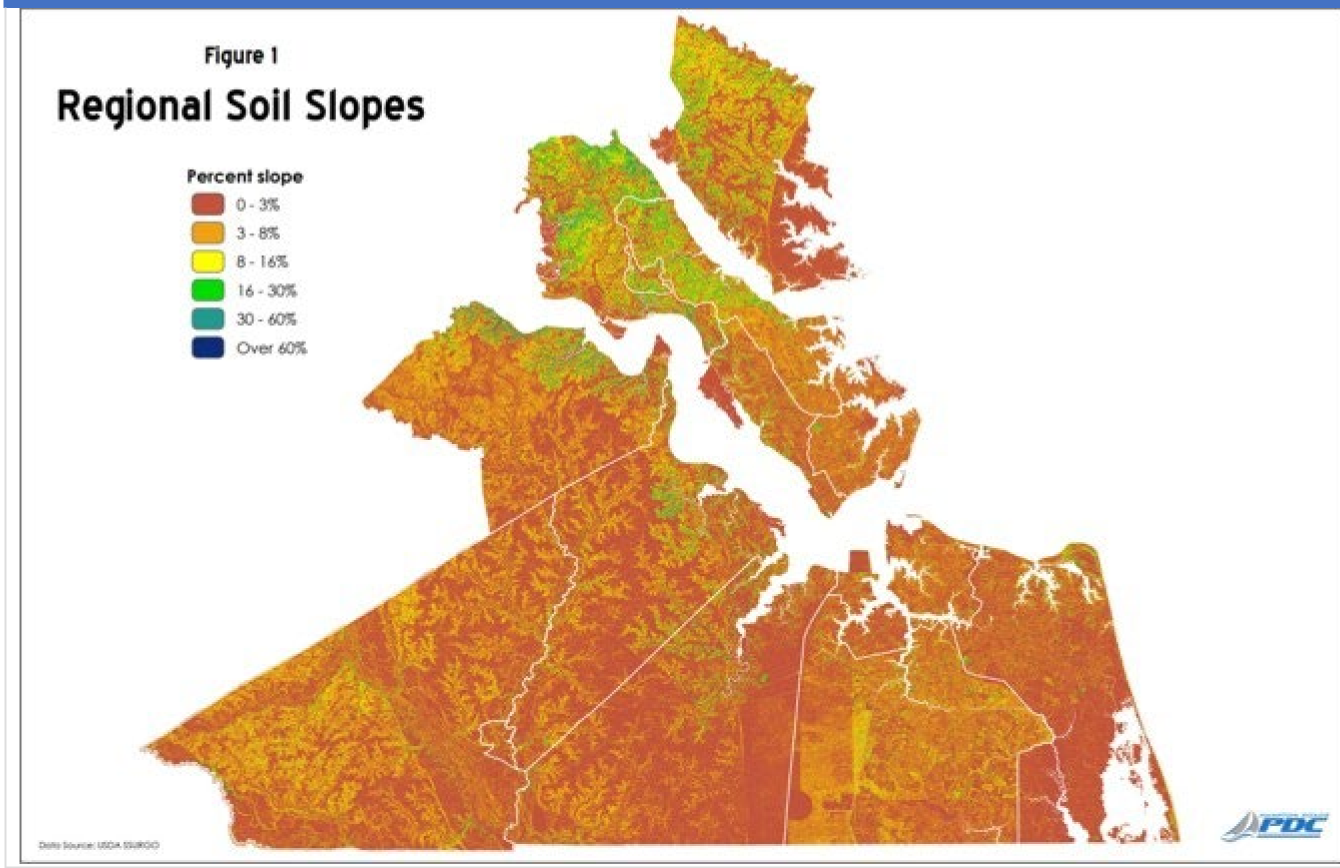
#### 6.3.3.5.1 Coastal Plain/High Groundwater Table

Traditional stormwater practices were developed for the Piedmont physiographic region and often require adaptations to properly function in the Coastal Plain. Implementation of these stormwater practices in the Coastal Plain is constrained by the flat terrain, high water table, and low permeable soils. These characteristics make stormwater management more complex and limit the BMPs that can be implemented to control the quality and quantity of runoff in the Coastal Plain region.

### Flat Terrain

The most notable feature of the Coastal Plain is its uniformly flat terrain (0 to 3% slopes) over many regions, which creates several watershed planning and stormwater site design challenges. Locations containing flat terrain throughout the Coastal Plain region are shown on Figure 6-32. The low relief makes it possible to develop land without regard to topography. From a hydrologic standpoint, flat terrain increases surface water/groundwater interactions and reduces the hydraulic head available to treat the quality of stormwater or move floodwaters through the watershed. Floodwaters are a concern in this region because it is prone to intense tropical storms and hurricanes, high-intensity rainfall over shorter durations, and high tide flooding.

***Figure 6-32 Landscape Slope Throughout Portions of the Lower Coastal Plain Region***




*Source: Hampton Roads Planning District Commission 2013*

### High Water Table

Groundwater is an important element in the hydrologic cycle. During long periods of dry weather, groundwater is the source of baseflow in rivers, canals, and stormwater drainage systems, especially in shallow groundwater regions like Hampton Roads. The proximity of the groundwater table to the surface increases the potential for groundwater contamination from stormwater infiltration and diminishes the performance and feasibility of many stormwater BMPs. In much of the Coastal Plain, the water table exists within a few feet of the surface; for example, 40% of the Hampton Roads area has a separation of less than 1 foot between the land surface and the seasonal high groundwater table, and 60% of land is within 2 feet.

**Low Permeability Soils**

Although underlying Coastal Plain sediments are often sandy, portions of the Lower and Middle Coastal Plain contain soils that are poorly drained and frequently do not allow infiltration to occur. As a result, the Coastal Plain watersheds contain extensive wetland complexes and contain a greater density of wetlands than any other physiographic region in the country. Wetland cover exceeds 25% of many Coastal Plain watersheds, which greatly exceeds the national average of 7%. Soil regulates the processes of surface runoff, infiltration, and percolation, and is a major controlling factor in evapotranspiration through the capacity of the soil to store and release water. The characteristics of site soils should be carefully considered during the development of a stormwater management strategy because runoff volumes and flow rates can be reduced through infiltration and storage in the pore space of the soil substrata and pollutants can be removed from the water column via sorption to soil particles.

In addition to the factors described above, the design of any conveyance system and BMPs in coastal areas must account for the unique characteristics including shoreline buffers and critical areas, highways as the receiving system, coastal flooding and hurricanes, impacts of tides, sea level rise, and increased rainfall due to climate change.

Follow these initial guiding principles when designing stormwater practices for the Coastal Plain:

- Use micro-scale and small-scale practices for development projects within 500 feet of shoreline or tidal waters.
- Exploit opportunities for upland RR prior to using end-of-channel/pipe practices such as wet ponds.
- Incorporate essential Coastal Plain design features within any ponds employed.
- Keep all stormwater practices out of the riparian buffer area, except for the use of conservation filters at their outer boundary.
- Relax some design criteria to keep practice depths shallow to avoid contact with the water table.
- Emphasize design factors that can increase bacteria removal (and will not exacerbate bacteria problems).
- Promote de-nitrification to maximize nitrogen removal by creating anaerobic and aerobic zones adjacent to one another in either the vertical or lateral direction.
- Use plant species that reflect the native Coastal Plain plant community and, in particular, can survive well in a high salinity environment.
- Take a linear design approach to spread treatment along the entire length of the drainage path, from the rooftop to tidal waters, maximizing the use of in-line treatment in the swale and ditch system.
- Consider the effect of sea level rise on future elevations of stormwater practices and infrastructure. In some cases, it may make more sense to utilize stormwater site design to increase the vertical elevation of building pads at Coastal Plain development sites.

The pollutants of concern and resource sensitivity of coastal waters also differ from standard stormwater site design. The pollutant of concern in the Piedmont is historically focused on phosphorus control, which is frequently a limiting nutrient for fresh waters but seldom for coastal waters. By contrast, the key pollutants of concern in Coastal Plain watersheds are nitrogen, bacteria, and metals. These pollutants significantly degrade the quality of unique Coastal Plain aquatic resources such as shellfish beds, swimming beaches, estuarine and coastal water quality, seagrass beds, migratory bird habitat, and tidal wetlands. Yet, the design of many stormwater practices is still rooted in phosphorus control because this is the overall pollutant of concern within Virginia.

The following considerations and modifications can reduce bacteria and nitrogen concentrations in runoff:

- Maintain setbacks from septic drainfields and connect household waste discharges to the local sanitary sewer system when feasible.
- Use dry or wet swales rather than grass channels.
- Minimize site runoff by utilizing infiltration and filtration practices.
- Avoid using turf around ponds and wetlands. Consider planting taller native vegetation to make shoreline access more difficult for geese and waterfowl.
- Use vegetated filter strips at the edge of riparian buffer areas.
- Use shallow wetlands and benches to create natural micro-predators for bacteria.
- Enhance sand filter media with a layer of organic matter.
- Create high light conditions to promote ultraviolet light (sunshine) in areas of standing water.
- Design treatment systems to prevent resuspension of bottom sediments.

#### 6.3.3.5.2 Industrial Settings and Pollution Hotspots

When managing stormwater at hotspot sites, focus on shelter and containment of potential spills and illicit discharges of potential pollutants. Designers should also keep in mind that certain stormwater control measures, such as infiltration, should be avoided on these sites and the practices that are applied will typically require some form of pretreatment before discharging to a natural channel, storm sewer, or most importantly, any type of infiltration practice.

Consider including the following implementation practices as part of the overall stormwater management and pollution prevention plan.

- Provide a controlled, covered area for unloading and hosing down fueling areas to prevent rainwater contamination and stormwater runoff.
- Connect outdoor vehicle storage areas to a separate stormwater collection system with an oil/grit separator that discharges to a holding tank, the sanitary sewer, or a stormwater treatment practice.
- Designate a specific location for outdoor containment measures:
  - Provide washing areas away from storm drains or where water may enter the groundwater.
  - Wash parts in a self-contained solvent sink rather than outdoors.
  - Prohibit discharge of wash water into the storm drain system by using temporary berms, storm drain covers, drain plugs or other containment system.
- Locate storm drain inlets away from the immediate vicinity of working areas.
- Label storm drains with “No Dumping” signs to deter disposal of wash water in the storm drain system.
- Pave the loading/unloading area with concrete rather than asphalt.

- Position roof downspouts to direct stormwater away from loading/unloading areas and into bioretention areas.

Consult the detailed procedures for hotspot identification in Appendix D.

#### 6.3.3.5.3 Cold Climate

Cold climates present challenges to BMP design as snow and ice melt can impact the effectiveness of these measures during colder seasons. High pollutant concentrations from road deicers, large amounts of sudden runoff from snow melt, and freezing of pipes are just some of the challenges designers in colder climates face when evaluating BMP effectiveness on a site.

In parts of Virginia, colder temperatures and longer lasting snow and ice events can occur throughout the winter months. Regions with an average daily temperature of 35 degrees Fahrenheit (°F) or less and a growing season less than 120 days are especially vulnerable to the effects of cold weather. The state-wide average temperature for January is just above 35°F, with some areas experiencing milder temperatures and some much colder. These colder climates are typically in the northern Blue Ridge and along the higher elevations in the far western part of the state, where temperatures during January are more similar to Chicago than to the coastal plain region. Because state winter temperatures are inconsistent, the standards discussed in this section must be applied to sites being developed in colder parts of Virginia for those projects to be environmentally successful.

Additionally, cold climates can present challenges to the selection, design, and maintenance of stormwater management BMPs due to one or more of the factors listed in Table 6--22. While there may be fewer runoff events during winter months, snow and ice may significantly impact the operation of some treatment practices during winter rain events and periods of snowmelt. Stormwater site designs should make provisions for these challenges.

**Table 6-22 Climatic Conditions and Design Challenges**

| Climatic Conditions | Design Challenge |
|---|---|
| Cold temperature | • Pipe freezing<br>• Permanent pool covered by ice<br>• Reduced biological activity<br>• Reduced oxygen levels during ice cover<br>• Reduced settling velocities<br>• Impacts of road salt/deicers/chlorides<br>• Winter sanding impacts on facilities<br>• Vegetation requiring full shade prone to winter kill |
| Deep frost line | • Frost heaving<br>• Reduced soil infiltration<br>• Pipe freezing |

| Table 6-22 Climatic Conditions and Design Challenges | |
|---|---|
| **Climatic Conditions** | **Design Challenge** |
| Significant snowfall | • High runoff volumes during snowmelt<br>• High runoff during rain-on-snow<br>• High pollutant loads during snowmelt<br>• Other impacts of road salt/deicers/chlorides<br>• Snow management may affect BMP storage<br>• Winter sanding impacts on facilities |

Potential wintertime impacts to the operation of BMPs include: (1) pipe freezing; (2) ice formation on permanent pools; (3) reduced biological activity; and (4) reduced soil infiltration. Frozen conditions typically inhibit performance throughout winter and generate a significant volume of melt water and associated pollutant loads. In particular, melted water from roadways typically contains high chloride and sediment content from salt and sand treatments. Additional challenges are listed below.

- Frost Heaving: Moisture in soil expands when it freezes, causing the soil to rise or "heave." This creates the potential for damage to structural components of BMPs, such as pipes or concrete infrastructure located within the soil. Another concern is that infiltration BMPs can cause frost heave damage to other structures, particularly roads. The water infiltrated into the soil matrix can flow under a permanent structure and then re-freeze. The sudden expansion associated with this freezing can cause damage to aboveground structures.
- Ice Formation on a Permanent Pool: The permanent pool of a wet pond serves several purposes. The water in the permanent pool slows down incoming runoff, allowing for increased settling of pollutants and biological activity in the pool can act to remove nutrients, since algae, plants, and bacteria require these nutrients for growth. In some systems, such as sand filters, a permanent pool acts as a pretreatment measure, settling out larger sediment particles before full treatment by the BMP. However, when the pool is frozen, the treatment pool's volume is reduced, and the surface is now impermeable. Runoff entering an ice-covered pond can follow two possible routes, neither of which provides sufficient PR. Either runoff is forced under the ice, causing scouring of bottom sediments, or runoff flows over the top of the ice, receiving little or no treatment. Sediment that settles on top of the ice can then easily be resuspended by subsequent runoff events.
- Reduced Biological Activity: Many stormwater treatment practices rely on biological mechanisms to help reduce pollutants, especially nutrients and organic matter. For example, wetland systems rely on plant uptake of nutrients and the activity of microbes at the soil/root zone interface to break down pollutants. During cold temperatures (below 40°F), photosynthetic and microbial activity is sharply reduced when plants are dormant during the non-growing season, limiting these PR pathways (CWP 1997).
- Reduced Soil Infiltration: The rate of infiltration in frozen soils is limited, especially when ice lenses form (CWP 1997). There are two results of this reduced infiltration. First, BMPs that rely on infiltration to function can be ineffective when the soil is frozen. Second, runoff volume from snowmelt is elevated when the ground underneath the snow is frozen.
- Increased Pollutant Loading During Thaw Periods: Snowmelt events are important because of increased runoff volumes and pollutant loads. Piles of snow along roads and in parking lots frequently contain high pollutant concentrations due to the buildup of pollutants from one or more snow events. Chloride loadings are highest in snowmelt events because of the use of deicing salts, such as sodium chloride and magnesium chloride. Excessive loadings can kill vegetation in swales

and other vegetative BMPs. During a site's first year of operation, inspections are recommended to be performed at least every month during this period of heavy contaminant loading due to the winter climate (VDEQ 1999). The inspection schedule can then be modified accordingly for subsequent years.

BMPs that use filtration, settling, or trapping to remove contaminants require frequent inspection and maintenance. Regular maintenance of BMPs located in cold climates is suggested just prior to the first snowfall or road sanding, after the last snowfall, and during spring snowmelt to ensure the proper treatment of runoff. See the individual stormwater control measure specifications for additional information on mitigating the potential effects of cold weather on treatment, practice, operation, and performance of each BMP.

Additional suggestions for design in cold climate environments include:

- Planning for snow loading when designing features like green roofs;
- Locating piping and conveyance systems and subsurface storage under the frost line;
- Heat tracing or locating cisterns indoors;
- Specifying salt tolerant vegetation to account for snow melt; and
- Clearly demarcating porous pavements to avoid damage from plowing and snow blowers.

#### 6.3.3.5.4 Ultra Urban Settings and Infill Development

The "ultra-urban" environment (a term coined by the city of Alexandria, Virginia) has been used to describe metropolitan areas of the country where space for stormwater BMP implementation is limited. These heavily urbanized areas present special challenges to those responsible for stormwater management. In urban areas, the soils are disturbed and usually compacted, runoff volumes and pollutant loadings are high, and pollutant types are more varied than in rural settings. Stormwater management in these ultra-urban areas may require retrofits to existing stormwater control and conveyance systems (Federal Highway Authority [FHWA], undated). This creates unique difficulties for achieving environmental objectives.

The FHWA compiled a comprehensive database of information about ultra-urban BMPs. The FHWA used the following factors to distinguish between ultra-urban BMPs and urban BMPs:

- Limited space available for BMP implementation (less than 0.5 hectare [1 acre]).
- Drainage area imperviousness greater than 50%.
- Location of BMP in right-of-way (only available space).
- Existence of build-out conditions at the site (lot-line to lot-line development).

However, these sites present an opportunity to make progress in stormwater management where it has not previously existed. Much of the opportunity is focused on BMP selection and design, as well as cohesive integration of the BMP treatment train into the development scheme. These ultra-urban settings are prone to more trash, debris, metals, and pollutants. Their methods of treatment must take this into consideration in order for the stormwater runoff to meet water quality standards. Pretreatment almost always needs to be added to the treatment train to achieve compliance with water quality. The methods of pretreatment that are used in these ultra-urban areas include sand filters, roof vegetation, planters, and oil/water separators. BMP and pretreatment selection for ultra-urban sites may be considered for approval by local plan review authorities as innovative/alternative designs, provided sufficient design/routing information is included.

Considerations for selecting BMPs for ultra-urban environments:

- Available surface area might be limited; unusual spaces (e.g., rooftop management), may be used to achieve compliance with stormwater management requirements.
- Maximum flow rates of surface runoff are encountered on a frequent basis due to the high amount of impervious surface.
- Consider the use of stormwater planters and small bioretention systems to add green space.
- Explore the use of rainwater harvesting systems to meet onsite water needs.
- Urban environments often contain highly variable subsurface conditions (e.g., historical fills, construction debris, hotspots). Use caution when implementing infiltration based BMPs. Over-excavation and
- replacement of loose or contaminated fill with stable material and/or adding a liner may be needed in some circumstances.
- Specific challenges are associated with each unique site, and it is best to gain background information on the local urban setting.
- MTDs tend to be prevalent in ultra-urban settings due to their small footprint and ease of integration into the normally existing storm sewer infrastructure.

Ultra-urban stormwater management units, particularly MTDs, often have flow-based design criteria. That is, they are designed to treat stormwater at a certain rate of input rather than a certain total volume. In instances where ultra-urban BMPs are proposed, the engineer or designer must determine if the flow-based BMP fulfills the goal established by volume-based regulatory requirementsre.

### 6.3.3.5.5 Karst

Karst is a term that describes terrain formed by the dissolution of carbonate rock and is characterized by closed depressions, sinkholes, disappearing streams, springs, caves, and an absence of surface streams and lakes.

Stormwater management facilities are particularly vulnerable to collapse in karst areas because most are designed to concentrate and detain surface water runoff. Ponding and associated soil saturation occur where surface-runoff is concentrated. Saturation of fine-grained soils that develop on weathered limestone can cause a reduction in soil strength and erosion into bedrock voids.

**BMP Selection in Karst**

The following are important factors to consider when selecting BMPs for karst:

- Employ stormwater management measures that minimize flow velocities and ponding to avoid erosion of over-saturated soils.
    - All stormwater management facilities, including grassed waterways, diversions, and lined waterways, should be designed to disperse flows across the broadest channel area possible. This reduces the level of soil saturation and reduces the potential for soil movement. Shallow trapezoidal channel cross-sections are preferred over parabolic or v-shaped channels.
    - Small-scale low impact development practices work best in karst areas, although they should be shallow, closed, and sometimes lined to prevent groundwater interaction. Distributed treatment is recommended over centralized stormwater facilities. The use of centralized stormwater practices with large drainage areas is strongly discouraged even when liners are used.
- Treat runoff as sheet flow in a series of small RR practices before it becomes concentrated. Practices should be designed to disperse flows over the broadest area possible to avoid ponding, concentration, or soil saturation. Use and mimic karst swales where possible.

- Distributed treatment is recommended over "centralized" stormwater facilities, which are defined as any practice that treats runoff from a contributing drainage area greater than 20,000 square feet of impervious cover and/or has a surface ponding depth greater than 3 feet (e.g., wet ponds, extended detention ponds, and infiltration basins).
- The use of centralized stormwater practices with large drainage areas is strongly discouraged even when liners are used. Centralized treatment practices require more costly geotechnical investigations and design features than smaller, shallower distributed practices. In addition, distributed practices generally eliminate the need to obtain an underground injection well authorization from the USEPA.
- As a general rule, the stormwater system should avoid large contributing drainage areas, concentration of flows, deep excavation, or pools of standing water.
- One preventive strategy is to provide a pretreatment method that does not use the detention of stormwater to settle out or filter pollutants. Consider manufactured water quality BMPs, which can serve as pretreatment devices, or even spill containment BMPs for commercial/industrial development in karst.
- These structures will not eliminate the potential for karst collapse, but they do provide water quality treatment that helps to minimize the potential for the contamination of groundwater.
- The following post-construction stormwater BMPs are preferred for use in karst:
    - BMP P-FIL-02 Vegetated Roof
    - BMP P-FIL-01 Rooftop Disconnection
    - BMP P-FIL-06 Filtering Practices
    - BMP P-FIL-07 Sheet Flow to Vegetated Filter Strip/Conserved Open Space
    - BMP P-BAS-04 Rainwater Harvesting
    - BMP P-FIL-05 Bioretention (small scale only)
    - BMP P-CNV-02 Dry Swales
    - MTDs.

See individual BMP specifications for more information on applicability within karst environments. See Appendix E for additional information related to stormwater management in karst areas.

### 6.3.3.5.6 Linear Projects

Linear development projects are land development projects that are linear in nature. Some examples of these projects include the construction of underground utilities, telephone and electric lines, pipelines, railroad tracks and any associated infrastructure, and roads. Due to the repetition within linear projects, many of them are subject to standards and specifications. However, for projects that are not, there are some special considerations to follow.

- Linear utility and highway easements can be narrow, creating space challenges for certain types of BMPs. Consider widening of easements to accommodate BMP siting early in the design/acquisition process or the use of linear BMPs such as grass channels or using a series of connected vegetated bioretention cells or sand filters arranged in a linear fashion.
- Maximize the use of disconnections and filter strip, being careful to ensure that road margins/easements are wide enough to provide adequate flow paths.
- Road construction operations can create heavy disturbance and compaction. Take extra care when selecting surface BMPs that require uncompacted soils (e.g., bioretention) unless operations can be tightly controlled to ensure BMP areas are avoided.

- Ensure the use of salt-tolerant species if using vegetated practices to manage stormwater in highway corridors (see 6.3.3.5.3).
- Use caution when using practices such as stormwater filters in mostly or fully vegetated rights-of-way because eroded sediments from the right-of-way can clog these practices.
- When using compost amendments for linear utility site restoration to natural vegetated state, a long-term vegetation management plan and deeded operation and management plan are required, as well as attainment of minimum ground cover and other plan-related requirements. See BMP P-FIL-08, Soil Compost Amendment, for details.
- Basin-like BMPs may be suitable for applications in cloverleaf interchanges but may be challenging to otherwise implement due to space constraints. Consult with VDOT specifications for guidance on using basin BMPs in these situations.

## 6.3.4 Offsite Compliance Options

The following sections describe VESMP and Virginia Stormwater Management Program (VSMP) authority authorization to allow an operator to fully or partially meet water quantity or water quality technical criteria in Articles 3 or 4 of Part V of the Virginia Erosion and Stormwater Regulation using nutrient credits and other offsite options.

Offsite options allowed through 9VAC25-875-610 include:

1. Offsite controls utilized in accordance with a comprehensive stormwater management plan for the local watershed within which a project is located;
2. A locality pollutant loading pro rata share program or similar local funding mechanism pursuant to § 15.2-2243 of the Code of Virginia;
3. A Nonpoint Source (NPS) nutrient credit program as established pursuant to § 62.1-44.15:35 of the Code of Virginia, commonly referred to as a nutrient bank;
4. Other offsite options approved by an applicable state agency or state board; and
5. Use of offsite facilities such that when an operator has additional properties available within the same hydraulic unit code (HUC) or upstream HUC that the land-disturbing activity directly discharges to or within the same watershed as determined by the VESMP/VSMP authority, offsite stormwater management facilities on those properties may be utilized to meet the required phosphorus nutrient reductions from the land-disturbing activity.

### 6.3.4.1 Comprehensive Stormwater Management Plans

A locality's VESMP authority may develop a comprehensive stormwater management plan to meet water quantity and/or water quality criteria of Article 3 of Part V of the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-660). These plans are created to account for the stormwater needs of a development with multiple parcels or areas being developed. The stormwater management plan can account for future development as well as the developer's own site. The comprehensive stormwater plan from the authority must be approved by VDEQ, which establishes the number of credits. During the program implementation, each individual development is tracked by the VESMP/VSMP authority regarding the total program credits available and those allocated to a project as a current registry. Others developing within the parcels covered under the comprehensive plan may buy into the program as described in § 15.2-2243 of the Code of Virginia.

State and federal agencies may develop comprehensive stormwater management plans and may participate in locality-developed comprehensive stormwater management plans where practicable and permitted by the locality VESMP authority.

### 6.3.4.2 Pro Rata Share Programs

Another option for offsite compliance is a pro rata share program, which some localities establish within their ordinances. These programs allow for developers to pay the locality the proportional cost of providing offsite stormwater management.

Consult the regulatory authority regarding program availability as a potential design consideration. These programs may address water quantity, water quality, or both. Note, the presence of a regional stormwater facility or program does not alleviate the applicant from conveying their site's drainage to the facility in an adequate system relating to quantity. For example, if there is a regional stormwater facility treating a large commercial subdivision, each parcel must ensure their runoff is conveyed from their site to the treatment facility through infrastructure appropriately sized for the development, which is usually storm sewer.

### 6.3.4.3 NPS Nutrient Credit Programs

NPS nutrient credits are the most commonly used compliance option to assist in meeting water quality technical criteria. Nutrient credits are typically generated by credit producers and then sold to developers with projects in nearby areas. VDEQ has established a few general rules for the use of nutrient credits (see § 62.1-44.15:35 of the Code of Virginia and 9VAC25-900):

- The credits must be from the same tributary as the land-disturbing activity and the same or adjacent eight-digit HUC. Credits outside the same or adjacent eight-digit HUC may only be used if, at the time of accepting the final stormwater site design, the VESMP/VSMP authority determines no credits are available within the same or adjacent eight-digit HUC.
- When NPS nutrient credits are utilized for water quality compliance, a letter of availability from the credit provider is required during permit application. The letter of availability must be requested from a VDEQ-approved nutrient bank and must be provided on the official letterhead naming the nutrient bank.
- Ultimately, a certification must be provided by the credit provider with the number of phosphorus nutrient credits acquired and the associated ration of nitrogen nutrient credits at the credit-generating entity. This must be provided to the VESMP/VSMP authority and VDEQ.
- Nutrient credits are applied at a 1:1 ratio of credits to the required phosphorus reduction.

Please note that NPS nutrient credits cannot be used to:

- Address water quantity control requirements; or
- Counteract an exceedance of local water quality-based limitations.

In addition, be aware that localities and MS4 operators have authority to impose additional limitations or restrictions on the use of NPS nutrient credits.

## 6.3.5 Criteria To Use NPS Nutrient Credits

Subject to the items above, nutrient credits are available for use, provided a number of criteria are met. Per 9VAC25-875-610.B, a VESMP/VSMP authority shall allow an operator to utilize NPS nutrient credits under any of the following conditions:

1. Less than five acres of land will be disturbed;
2. The post-construction phosphorus control requirement is less than 10 pounds per year; or
3. At least 75% of the required phosphorus nutrient reductions are achieved onsite. If at least 75% of the required phosphorus nutrient reductions cannot be met onsite, the operator must demonstrate the following to the satisfaction of the VESMP/VSMP authority:

a. Alternative stormwater site designs have been considered that may accommodate onsite BMPs.
b. Onsite BMPs have been considered in alternative stormwater site designs to the maximum extent practicable.
c. Appropriate onsite BMPs will be implemented.
d. Full compliance with the post-development nonpoint nutrient runoff compliance requirements cannot practicably be met onsite.

No offsite options may be utilized unless necessary nutrient reductions are achieved before the start of land disturbance. For phased projects, the operator may acquire or achieve offsite nutrient reductions before the start of each phase of land-disturbing activity in sufficient amount for each phase.

It should also be noted that per 9VAC25-900-91, for sites with a local nutrient TMDL or sites that drain to waters impaired for dissolved oxygen, benthic community, chlorophyll-a or nutrients, but do not have an approved TMDL, exchanging credits shall be limited to those credits generated in accordance with the following hierarchy:

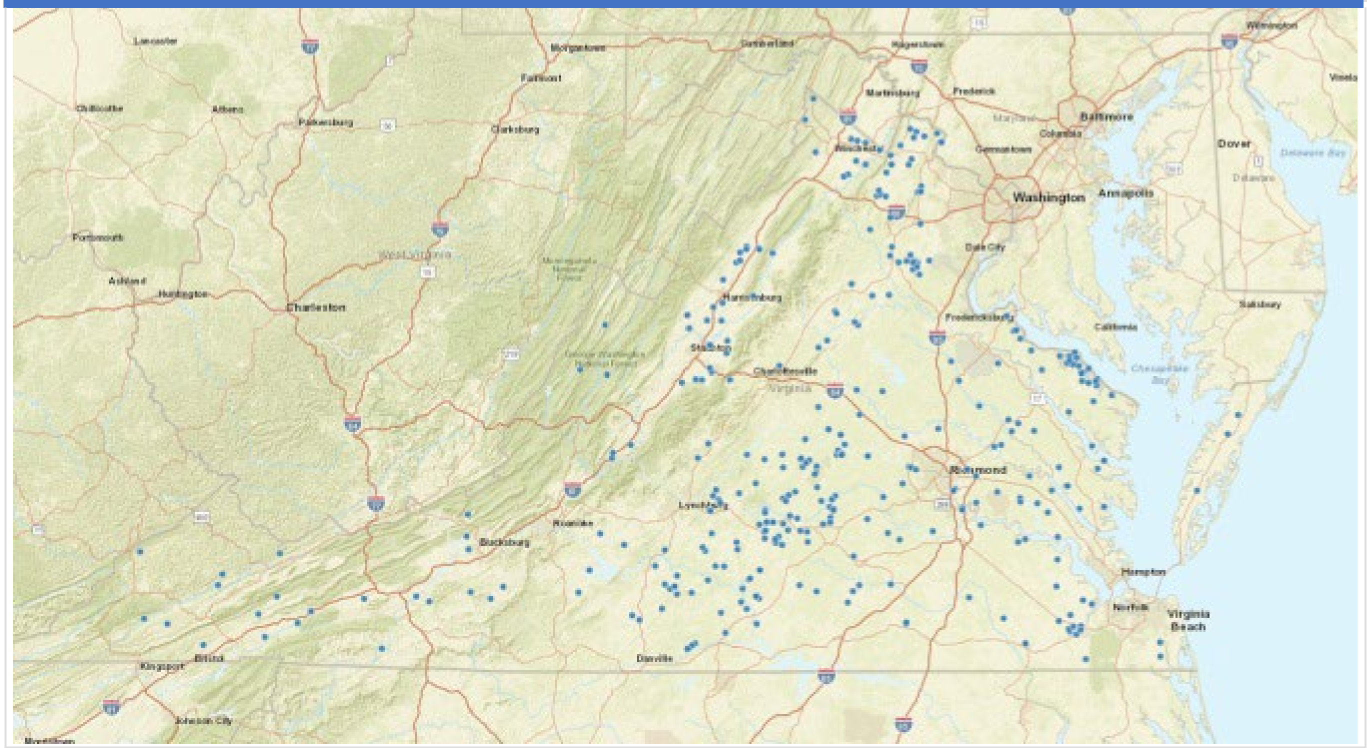
a. Upstream of where the discharge reaches impaired waters, if credits are available;
b. Within the same 12-digit HUC, if credits are available;
c. Within the same 10-digit HUC, if credits are available;
d. Within the same 8-digit HUC, if credits are available;
e. Within an adjacent 8-digit HUC within the same tributary, if credits are available; or
f. Within the same tributary.

### 6.3.6 Nutrient Credit Banks

Pursuant to 9VAC25-900, VDEQ is responsible for the approval of nonpoint source nutrient credit banks under the State Water Control Board. Nutrient credits can be generated through a variety of practices such as land use conversion, stream restoration, and urban stormwater BMPs that remove nutrients in excess of current conditions. A site-specific practice generating certified nutrient credits for sale on the Nutrient Credit Registry is commonly referred to as a nutrient bank. The credits generated by nutrient banks are certified through a process that involves VDEQ application approval, site verification, recordation of a deed restriction, and monitoring to ensure the practice is functioning and continues to generate credits listed on the registry. During the application review, VDEQ certifies the number of credits available for purchase in the nutrient bank.

The nutrient banks are privately owned and can sell credits to developers based on watershed and availability. Banks are continually being approved for nutrient credits through the VDEQ process and constructed. Figure 6-33 shows nutrient trading banks as of March 30,2023; however, VDEQ maintains a list of approved nutrient banks and pending applications based on the watersheds they serve;[16] consult this list for the most up-to-date information.

***Figure 6-33 Nonpoint Source Nutrient Trading Banks in Virginia approved as of March 30, 2023***




*Source: Virginia Geographic Information Network (Virginia Department of Emergency Management 2023)*

[16] https://www.deq.virginia.gov/permits/water/nutrient-trading

### 6.3.7 Nutrient Offset Credits

Nutrient offset credits are created when a property overtreats pollutants onsite to account for development of other owned properties within or upstream of that watershed. The additional nutrient credits generated may be used to offset other development in or adjacent to the watershed under the same operational control, which is key. Nutrient offset credits do not have to be approved by VDEQ like Nutrient Credit Banks that sell credits; however, the nutrient offset credits must be approved by the VESMP Authority, or VDEQ acting as VSMP in some instances, under different criteria and the credits must be tracked. The differentiating factor is that banks sell credits, and nutrient offset credits are essentially “traded” between properties under control of the same operational entity.

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# CHAPTER 7 DESIGN SPECIFICATIONS FOR CONSTRUCTION BMPS

**Contents:**

## 7.1 Introduction to the New Virginia Construction Best Management Practices

In this chapter, the Virginia Stormwater Management Handbook update provides guidance on the standards and specifications for construction best management practices (BMPs). Construction BMPs, formerly referred to as erosion and sediment (E&S or ESC) controls, are those practices installed during land-disturbing activity to control the impact of construction on the local watershed.

This Handbook builds on the BMPs established in the 1992 Virginia Erosion and Sediment Control Handbook (VESCH) by incorporating the latest in industry standards and practices, correcting errors and omissions, and consolidating information from multiple sources into one update.

## 7.2 Significant Updates

Several significant updates have been introduced with the Handbook. The updates include not only additional guidance and BMPs for the designer, but an updated framework, numbering, and nomenclature used to integrate the construction and post-construction BMPs into one guidance framework.

Practices approved for use outside of the 1992 VESCH through the variance and standards and specifications process have been incorporated as either new construction BMPs or as components to an updated construction BMP.

### 7.2.1 Construction BMP Specifications Framework

The specifications framework for construction BMPs has been developed as an integrated framework with the post-construction BMPs described in Chapter 8. The specification framework includes the following sections:

- **Definition** – The clear and distinct description of the BMP.
- **Purpose and Applicability of Best Management Practice** – This section describes the purpose of the BMP and the general conditions under which the BMP should be considered for specification. The purpose of this section is to provide guidance in the selection of the appropriate BMP for the project..
- **Planning and Considerations** – This section provides guidance for consideration in the selection of BMPs as it relates to potential environmental and community impacts and how the BMP may interact with the surrounding environment. The purpose of this section is to provide guidance in the selection of the appropriate BMP for the project.
- **Stormwater Performance Summary** – This section of the specification provides guidance to the designer in selection of the appropriate BMPs to comply with the minimum standards. This section also provides a rating for the erosion control and sediment removal efficiency of the BMP. This section is provided for awareness purposes, as there are no target removal efficiency requirements.
- **Design Criteria** – This section provides the design criteria that generally must be followed to properly specify and implement each BMP.
- **Construction Specifications** – This section provides detailed installation, materials, and assembly directions for the construction of the BMP. Construction details are also included in this section.
- **Operations and Maintenance Considerations** – This section provides detailed guidance on the operations and maintenance procedure required to ensure adequate performance of the BMP.

### 7.2.2 Construction BMP Numbering and Nomenclature

The construction BMPs contained within this chapter feature a leading 'C' in the nomenclature to designate the BMP as a "Construction BMP."

The nomenclature following the "C" identifies the subcategory of construction BMP:

- C-ECM – Erosion Control Measures;
- C-SCM – Sediment Control Measures;
- C-SSM – Surface Stabilization Measures;
- C-PCM – Perimeter Control Measures; and
- C-ENV – Environmentally Sensitive Area Protection.

The trailing number is the unique identifier for the BMP (e.g., Silt Fence [C-PCM-04]).

# 7.3 Overview of Best Management Practices

The following are summary overviews of the construction BMPs specified for use in Virginia. Complete standards and specifications for these practices are included in this chapter.

The construction BMPs are numbered and categorized in the following subsections.

## 7.3.1 Erosion Control Measures – C-ECM

These construction BMPS are intended to prevent sheet, rill and gully erosion. These BMPs reduce the overland flow velocities, shorten the length of flow, and divert and convey runoff safely through the site.

| EROSION CONTROL MEASURES | | |
|---|---|---|
| C-ECM-01 STRAW WATTLES | SW | SW SW |
| C-ECM-02 IMPERMEABLE DIVERSION FENCE | DF | DF DF |
| C-ECM-03 SLOPE INTERRUPTION DEVICE | SID | SID SID |
| C-ECM-04 TEMPORARY DIVERSION DIKE | DD | |
| C-ECM-05 DIVERSION | DV | |
| C-ECM-06 TEMPORARY FILL DIVERSION | FD | |
| C-ECM-07 TEMPORARY RIGHT-OF-WAY DIVERSION | RWD | |
| C-ECM-08 WATERBARS AND SHEET FLOW BREAKERS | SFB | SFB SFB |
| C-ECM-09 STORMWATER CONVEYANCE CHANNEL | SCC | |
| C-ECM-10 SUBSURFACE DRAIN | SD | |
| C-ECM-11 PAVED FLUME | PF | |
| C-ECM-12 TEMPORARY SLOPE DRAIN | SLD | |
| C-ECM-13 RIPRAP | RR | |
| C-ECM-14 TEMPORARY LEVEL SPREADER | LS | |
| C-ECM-15 OUTLET PROTECTION | OP | |
| C-ECM-16 FLEXIBLE TRANSITION MAT | FM | |

## 7.3.2 Sediment Control Measures – C-SCM

These construction BMPs are intended to prevent sediment transported by surface flows from leaving the site. These BMPs typically provide a means to capture or filter sediment practices.

| SEDIMENT CONTROL MEASURES | | |
|---|---|---|
| C-SCM-01 DUST CONTROL | DC | DC |
| C-SCM-02 CONSTRUCTION ROAD STABILIZATION | CRS | CRS |
| C-SCM-03 TEMP STONE CONSTRUCTION ENTRANCE | CE | |
| C-SCM-04 INLET PROTECTION | IP | |
| C-SCM-05 CULVERT INLET PROTECTION | CIP | |
| C-SCM-06 WOOD CHIP FILTER BERM | FB | FB FB |
| C-SCM-07 ROCK CHECK DAMS | CD | |
| C-SCM-08 ROCK FILTER OUTLET | RFO | |
| C-SCM-09 TURBIDITY CURTAIN | TC | |
| C-SCM-10 DEWATERING STRUCTURE | DS | |
| C-SCM-11 TEMPORARY SEDIMENT TRAP | ST | |
| C-SCM-12 TEMPORARY SEDIMENT BASIN | SB | |
| C-SCM-13 CONCRETE WASHOUT PIT | WOP | |

## 7.3.3 Surface Stabilization Measures – C-SSM

These construction BMPs are intended for use where final grade has been established to protect disturbed soil from surface runoff. The BMPs include both temporary covering and permanent vegetative cover that often become part of the final landscape.

| SURFACE STABILIZATION MEASURES | | |
|---|---|---|
| C-SSM-01 TREE PRESERVATION AND PROTECTION | TP | ← DC → |
| C-SSM-02 TOPSOILING | TO | ← DC → |
| C-SSM-03 SURFACE ROUGHENING | SR | ← SR → |
| C-SSM-04 COMPOST BLANKETS | CB | ← CB → |
| C-SSM-05 SOIL STABILIZATION BLANKETS AND MATTING | B/M | |
| C-SSM-06 SODDING | SO | ← SO → |
| C-SSM-07 BERMUDAGRASS AND ZOYSIAGRASS ESTABLISHMENT | BE/ZE | ← BE → ← ZE → |
| C-SSM-08 TREES, SHRUBS, VINES, AND GROUND COVER | VEG | ← VEG → |
| C-SSM-09 TEMPORARY SEEDING | TS | ← TS → |
| C-SSM-10 PERMANENT SEEDING | PS | ← PS → |
| C-SSM-11 MULCHING | MU | ← MU → |

## 7.3.4 Perimeter Control Measures – C-PCM

These construction BMPs are intended to intercept sheet flow from slopes and remove sediment and other contaminants through ponding, settling, and physical filtration, effectively preventing contaminants from leaving the site and entering surface waters.

| PERIMETER CONTROL MEASURES | | |
|---|---|---|
| C-PCM-01 SAFETY FENCE | SAF | |
| C-PCM-02 STRAW BALE BARRIER | STB | |
| C-PCM-03 BRUSH BARRIER | BB | |
| C-PCM-04 SILT FENCE | SF | — SF — SF — |
| C-PCM-05 COMPOST FILTER SOCK | CFS | — CFS — CFS — |

## 7.3.5 Environmentally Sensitive Area Protection – C-ENV

These construction BMPs are intended for use in environmentally sensitive areas, typically stream corridors, wetlands, and floodplains. These BMPs are typically applied where crossing or working within an environmentally sensitive area is necessary.

| ENVIRONMENTAL SENSITIVE AREA PROTECTION | | |
|---|---|---|
| C-ENV-01 VEGETATIVE STREAMBANK STABILIZATION | VSS | |
| C-ENV-02 STRUCTURAL STREAMBANK STABILIZATION | SSS | |
| C-ENV-03 TEMPORARY VEHICULAR STREAM CROSSING | SC | |
| C-ENV-04 UTILITY STREAM CROSSING | USC | |
| C-ENV-05 COFFERDAM CROSSING | CDC | — CDC — CDC — |
| C-ENV-06 STABLE WETLAND CROSSING | WC | |
| C-ENV-07 GABIONS/GABION DEFLECTORS | GAB | |
| C-ENV-08 PUMP AROUND DIVERSION | PD | — PD — PD — |
| C-ENV-09 OVERNIGHT CHANNEL PROTECTION | CP | |
| C-ENV-10 TRENCHLESS SILT FENCE | TSF | — TSF — TSF — |
| C-ENV-11 WETLAND BERM | WB | — WB — WB — |
| C-ENV-12 WETLAND WEIR OUTLET | WO | |
| C-ENV-13 WETLAND CELL SEDIMENT TRAP | WST | |
| C-ENV-14 MODIFIED TURBIDITY CURTAIN FOR STREAMS | TCS | |
| C-ENV-15 SEEDING, MULCHING, AND SOIL STABILIZATION WETLANDS STREAMS | SWS | ← SWS → |

# 7.4 Standards and Specifications for Construction BMPs

Standards and specifications for construction BMPs are presented below.

## List of BMPs

Select the title of the best management practice you want to view.

| | |
|---|---|
| C-ECM-01 | Straw Wattles |
| C-ECM-02 | Impermeable Diversion Fence |
| C-ECM-03 | Slope Interruption Device |

| | |
|---|---|
| C-ECM-04 | Temporary Diversion Dike |
| C-ECM-05 | Diversion |
| C-ECM-06 | Temporary Fill Diversion |
| C-ECM-07 | Temporary Right-of-Way Diversion |
| C-ECM-08 | Waterbars and Sheet Flow Breakers |
| C-ECM-09 | Stormwater Conveyance Channel |
| C-ECM-10 | Subsurface Drains |
| C-ECM-11 | Paved Flume |
| C-ECM-12 | Temporary Slope Drain |
| C-ECM-13 | Riprap |
| C-ECM-14 | Level Spreader |
| C-ECM-15 | Outlet Protection |
| C-ECM-16 | Flexible Transition Mat |
| C-ENV-01 | Vegetative Streambank Stabilization |
| C-ENV-02 | Structural Streambank Stabilization |
| C-ENV-03 | Temporary Vehicular Stream Crossing |
| C-ENV-04 | Utility Stream Crossing |
| C-ENV-05 | Cofferdam Crossing |
| C-ENV-06 | Stable Wetland Crossing |
| C-ENV-07 | Gabion Deflectors |
| C-ENV-08 | Pump Around Diversion |
| C-ENV-09 | Overnight Channel Protection |
| C-ENV-10 | Trenchless Silt Fence |
| C-ENV-11 | Wetland Berm |
| C-ENV-12 | Wetland Weir Outlet |
| C-ENV-13 | Wetland Cell Sediment Trap |
| C-ENV-14 | Modified Turbidity Curtain for Streams |
| C-ENV-15 | Seeding, Mulching, and Soil Stabilization Wetland Streams |
| C-PCM-01 | Safety Fence |
| C-PCM-02 | Straw Bale Barrier |
| C-PCM-03 | Brush Barrier |
| C-PCM-04 | Silt Fence |
| C-PCM-05 | Compost Filter Sock |
| C-SCM-01 | Dust Control |
| C-SCM-02 | Construction Road Stabilization |
| C-SCM-03 | Temporary Stone Construction Entrance |
| C-SCM-04 | Inlet Protection |
| C-SCM-05 | Culvert Inlet Protection |
| C-SCM-06 | Wood Chip Filter Berm |
| C-SCM-07 | Rock Check Dams |
| C-SCM-08 | Rock Filter Outlet |
| C-SCM-09 | Turbidity Curtain |
| C-SCM-10 | Dewatering Structure |

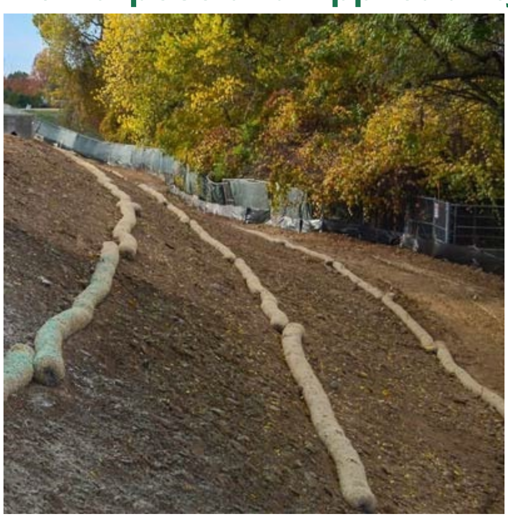
| | |
|---|---|
| C-SCM-11 | Temporary Sediment Trap |
| C-SCM-12 | Temporary Sediment Basin |
| C-SCM-13 | Concrete Washout Pit |
| C-SSM-01 | Tree Preservation and Protection |
| C-SSM-02 | Topsoiling |
| C-SSM-03 | Surface Roughening |
| C-SSM-04 | Compost Blankets |
| C-SSM-05 | Soil Stabilization Blankets |
| C-SSM-06 | Sodding |
| C-SSM-07 | Bermudagrass and Zoysiagrass Establishment |
| C-SSM-08 | Trees, Shrubs, Vines, and Ground Cover |
| C-SSM-09 | Temporary Seeding |
| C-SSM-10 | Permanent Seeding |
| C-SSM-11 | Mulching |

# C-ECM-01 Straw Wattles

## 1.0 Definition

Straw wattles are temporary erosion and sediment control best management practices (BMPs) consisting of weed- and seed-free agricultural straw wrapped in biodegradable netting, tubular plastic, or similar encasing material for the purpose of slowing water and trapping sediment.

## 2.0 Purpose and Applicability of Best Management Practice



*Source: Flickr 2014*

Straw wattles are used to break up the continuous length of a slope and to prevent concentrated flows from developing. Straw wattles reduce velocity, can spread the flow of rill and sheet runoff, and can filter and retain sediment. Straw wattles are most commonly available in 8- to 12-inch diameters.

Straw wattles can also be used to reduce flow rates and sedimentation to sinkholes that will be left in an undisturbed natural state located outside of the limits of disturbance (LODs) but that receive water flow from the LOD. Triangular dikes combined with straw wattles are the best method of reducing sediment load in a drainage channel leading to a sinkhole.

## 3.0 Planning and Considerations

Straw wattles are placed in shallow trenches and staked along the contour of disturbed or newly constructed slopes. Because of their lightweight composition, trenching and staking are required.

Straw wattles are biodegradable and do not necessarily need to be removed after site stabilization, although stakes should be.

Do not use straw wattles as check dams in conveyance channels or in areas of concentrated runoff.

Straw wattles are intended for use with low rates of flow, not to exceed 1 cubic foot per second at any point.

Straw wattles are not suitable to withstand vehicular traffic.

Straw wattles generally have a maximum longevity of 12 to 18 months.

## 4.0 Stormwater Performance Summary

**MS-4 First-Step Measures** – Construct sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment as a first step in any land-disturbing activity and make functional before the upslope land disturbance takes place.

9VAC25-875-560.

**Erosion Control Efficiency: Moderate**

**Sediment Control Efficiency: Low**

## 5.0 Design Criteria

Do not exceed a flowrate of 1 cubic foot per second to any point along the wattle from the maximum point upstream along a perpendicular flow path.

Determine the vertical spacing for slope installations based on the design criteria in Table C-ECM-01-1:

**Table C-ECM-01-1 Design Criteria for Straw Wattles**

| Slope Gradient | Maximum Vertical Spacing (ft) |
|---|---|
| 1:1 | 10 |
| 2:1 | 20 |
| 3:1 | 30 |
| 4:1 | 40 |

## 6.0 Construction Specifications

*Source: Olsen, Rikli, & Sillars, 2023*

Fill wattles with compacted weed- and seed-free agricultural straw compressed inside a biodegradable encasement and tie both ends closed.

Set wattles in a 2-inch-deep trench or place wattles over bare soil or atop Soil Stabilization Blankets and Matting (C-SSM-05). See spec for installation procedures.

At a minimum, use 1-inch by 1-inch (nominal) by 36-inch stakes for wattles less than or equal to 12 inches in diameter.

Do not allow stakes to project more than 2 inches above the crown of the straw wattle.

Secure wattles by stakes placed a maximum of every 4 linear feet. Set stakes through the center of the wattle and drive the stake into the ground at least 24 inches.

Install wattles parallel to the contour, with ends facing upstream at a 45-degree angle.

## 7.0 Operations and Maintenance Considerations

Inspect straw wattles weekly and after major rainfall events to ensure continued performance. If routine inspections observe flows bypassing around straw wattles, immediately correct the installation. When the accumulated sediment reaches half the height of the wattle roll, carefully remove the sediment and replace the wattle, taking care not to damage it (Resource Conservation District of Santa Cruz County n.d.).

Once a wattle is installed, unless damaged, it should remain in that location until its intended removal date. Wattles are not designed to be reused. Straw wattles are biodegradable, and in some applications may be left on site to decompose and allow vegetation to grow through it. However, it is advised to remove the stakes. Straw wattles generally have a maximum longevity of 12 to 18 months. Develop a replacement schedule when project durations are expected to exceed this length of time.

Wattles should only be removed after stabilization has been achieved. Proper wattle installation will capture sediment on the upslope side, accumulating fertile soil that will encourage vegetation to establish. When wattles are removed, the trench must be filled back in.

## 8.0 References


Dominion Energy. 2019. Standards & Specifications for Erosion & Sediment Control and Stormwater Management for Construction and Maintenance of Linear Electric Transmission Facilities (TE VEP 8000). May 2029.

Flickr. 2014. Hydroseeding a River Park neighborhood levee section. https://www.flickr.com/photos/usacehq/15919425935/in/photostream/

Olsen, Rikli, & Sillars. 2023. Investigation of Straw Wattle Influence on Surficial Slope Stability. Available online at: https://www.researchgate.net/publication/265478363_Investigation_of_Straw_Wattle_Influence_on_Surficial_Slope_Stability

Resource Conservation District of Santa Cruz County. No date. A Guide to Straw Wattle Installation. Available online at: https://www.rcdsantacruz.org/images/brochures/pdf/Straw_Wattle_Installation_Guildelines.pdf


# C-ECM-02 Impermeable Diversion Fence

## 1.0 Definition

Impermeable diversion fence is a temporary barrier of impermeable sheeting over chain-link fence located to direct water to a desired location.

*Source: The Advanced Group 2023*

## 2.0 Purpose and Applicability of Best Management Practice

Impermeable diversion fence is used to direct sediment-laden runoff to a sediment trapping device or to intercept and divert clean water away from disturbed areas.

Appropriate uses of diversion fences include:

1. To divert sediment-laden runoff from a disturbed area to a sediment trapping device;
2. To segment drainage areas for reducing acreage to sediment control devices; and

3. To divert clean water from an undisturbed area to a stable outlet at non-erosive velocities.

## 3.0 Planning and Considerations

Constructed along the limit of disturbance (LOD) or across disturbed areas, a diversion fence is used when there is insufficient space to construct an earth dike, temporary swale, or perimeter dike swale.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance occurs.

9VAC25-875-560.

**Erosion Control Efficiency: MODERATE**

**Sediment-Removal Efficiency: LOW**

## 5.0 Design Criteria

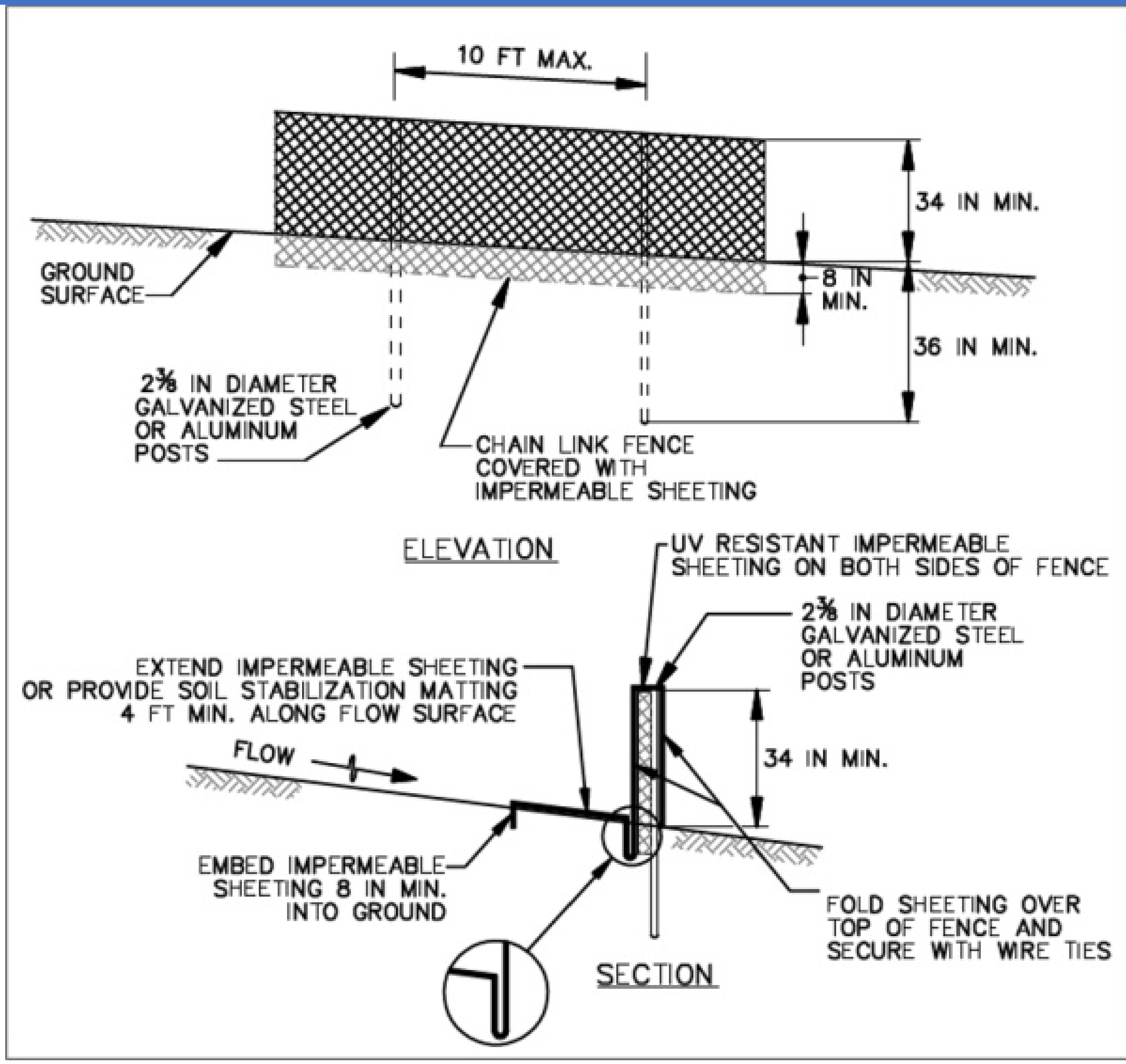
**Table C-SCM-02-1 Impermeable Diversion Fence Design Parameters**

| Parameter | Notes on Proper Use |
|---|---|
| Slope | The maximum slope along the fence is 10%. Maintain positive drainage along the entire length of the diversion fence. Provide spot elevations for diversion fence where the longitudinal slopes are flatter than 1%. |
| Drainage Area | The maximum drainage area is 2 acres.<br>For drainage areas larger than 2 acres, an engineering design may be used based on the 2-year frequency storm with Natural Resources Conservation Service (NRCS) methodologies (e.g., TR-55, TR-20) assuming that the worst soil cover conditions will prevail in the contributing drainage area over the life of the diversion fence. |
| Discharge | Ensure that discharge velocities from the diversion fence are non-erosive.<br>Discharge the outlet of the diversion fence to a sediment control device suitable for accepting concentrated flow where a diversion fence is used to convey runoff from disturbed areas. Silt fence and super silt fence are unacceptable for receiving discharges from diversion fences.<br>Discharge the diversion fence to an undisturbed, stable area at a non-erosive velocity, refer to the lowest permissible velocity based on the channel slope in the Permissible Velocities for Grass-Lined Channels table in Stormwater Conveyance Channel (C-ECM-09) where diversion fence is used to convey clean water runoff; otherwise, provide outlet protection.<br>When diversion fence is used in conjunction with a sediment trapping device, sequence construction so that the diversion fence installation follows that of the sediment trapping device(s). |

## 6.0 Construction Specifications

1. Use 42-inch-high, 9 gauge or thicker chain-link fencing (2.375-inch maximum opening).
2. Use 2.375-inch-diameter galvanized steel posts of 0.095-inch wall thickness and 6-foot length spaced no further than 10 feet apart. The posts do not need to be set in concrete.
3. Fasten chain-link fence securely to the fenceposts with wire ties.
4. Secure 10 mil or thicker ultraviolet (UV) -resistant, impermeable sheeting to chain-link fence with ties spaced every 24 inches at the top, mid-section, and below ground surface.
5. Extend the impermeable sheeting a minimum of 4 feet along the flow surface and embed a minimum of 8 inches into ground. Soil-stabilized matting may be used in lieu of impermeable sheeting along the flow surface.
6. When two sections of sheeting adjoin each other, overlap by 6 inches and fold with the seam facing downgrade.
7. Keep the flow surface along the diversion fence and the point of discharge free of erosion. Remove accumulated sediment and debris. Maintain positive drainage. Replace impermeable sheeting if torn. If undermining occurs, reinstall the fence.

**Figure C-ECM-02-1 Construction Specifications for Installing Impermeable Diversion Fence**




*(Source: Maryland DOE, 2011)*

## 7.0 Operations and Maintenance Considerations

Maintain the flow surface along the diversion fence and the point of discharge free of erosion and subsidence.

Remove accumulated sediment and debris and maintain positive drainage.

Replace impermeable sheeting if torn. Reinstall the fence if undermining occurs.

Impermeable diversion fence should be removed and properly disposed of when the tributary area is permanently stabilized. Following fence removal, permanently stabilize any areas disturbed during removal.

## 8.0 References

The Advanced Group. 2023. Impermeable Fencing. Located at: https://www.advancedns.com.au/environmental-protection/impermeable-fencing.

Maryland Department of the Environment. 2011. Detail C-9. Diversion Fence. Located at: https://mde.maryland.gov/programs/water/StormwaterManagementProgram/Documents/erosion%20sediment%20control%20details/Sect%20C%20Water%20Conveyance/PDF%20Files/C-9_Diversion%20Fence.pdf

# C-ECM-03 Slope Interruption Device

## 1.0 Definition

A slope interruption device is a three-dimensional tubular runoff and erosion control device used for sediment filtration and slope interruption.

## 2.0 Purpose and Applicability of Best Management Practice

The slope interruption device is a temporary measure used to reduce the velocity and slope length of runoff on slopes. A co-benefit of their use may also be sediment filtration.

Slope interruption slows runoff velocity and reduces soil erosion by dissipating the energy of overland sheet flow runoff, reducing its erosive potential while also trapping moving sediment and soluble pollutants.

Reducing runoff velocity reduces the potential of rill erosion formation on slopes. Slope interruption devices trap sediment and soluble pollutants by filtering runoff as it passes through the matrix of the slope interruption and by allowing water to temporarily pond behind the interruption device and the deposition of suspended solids.

## 3.0 Planning and Considerations

Slope interruption devices assist in preventing cut-and-fill slopes from becoming a critical erosion hazard. Install slope interruption devices horizontally across the hill slope and perpendicular to sheet flow, where erosion control practices or runoff velocity control is needed. Slope interruption is most effective where runoff is in the form of sheet flow and on long slopes prone to rill erosion.

**Figure C-ECM-03-1 Slope Interruption Device Accumulating Sediment**

*Source: ERTEC Environmental Systems 2022*

Slope interruption can be applied to areas of high sheet runoff, erosion, and slopes up to a 1H:1V grade.

Use slope interruption devices in conjunction with other forms of slope erosion control such as BMP C-SSM-05 Soil Stabilization Blankets and Matting.

Slope interruption may also be used in sensitive environmental areas where wildlife migration may be impeded using silt fences or where trenching may damage plant roots.

## 4.0 Stormwater Performance Summary

**MS-7: CUT AND FILL SLOPES -** Cut and fill slopes shall be designed and constructed in a manner that will minimize erosion. Slopes that are found to be eroding excessively within one year of permanent stabilization shall be provided with additional slope stabilizing measures until the problem is corrected.

9VAC25-875-560

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: Moderate**

## 5.0 Design Criteria

Slope spacing between slope interruption devices depends on rainfall intensity and duration, slope steepness, and slope length.

Design the spacing between slope interruption devices in accordance with Table C-ECM-03-1 below.

**Table C-ECM-03-1 Slope Interruption Device Spacing**

| Maximum Spacing (feet) | Slope (H:V) |
|---|---|
| 10 | greater 2:1 |
| 15 | from 2:1 to 4:1 |
| 20 | From 4:1 to 10:1 |
| 50 | Flatter than 10:1 |

## 6.0 Construction Specifications

1. Smooth soil surface and remove all obstructions greater than 2 inches in diameter.
2. Install slope interruption device parallel to the contour and perpendicular to sheet flow runoff. Do not construct slope interruption devices to concentrate runoff or channel water.
3. Install slope interruption devices to maintain intimate contact with the soil surface.
4. Install slope interruption devices before hydraulic or dry land seeding applications. The slope interruption device may be installed before or after the installation of soil stabilization blankets and matting. Do not install slope interruption devices underneath the soil stabilization blankets and matting.
5. Install slope interruption so that both ends of the device extend at least 8 feet upslope at 45 degrees to the main slope interruption alignment.
6. Install anchoring devices in accordance with the manufacturer's specifications to anchor the slope interruption in place.
7. Backfill and compact loose soil against the upslope/upstream side of the slope interruption device to one third the height of the device, filling the seam between the soil surface and the device.
8. Overlap adjacent slope interruption device ends by a minimum of 1 foot.

## 7.0 Operations and Maintenance Considerations

Inspect slope interruption devices after each rainfall and immediately repair or replace damaged devices in accordance with the manufacturer's specifications. Remove sediment from the upslope side of the slope interruption device when accumulation has reached half the height of the device.

During inspections, if rill erosion is noticed, immediately take measures to re-grade and stabilize problem areas.

Once the hill slope has been permanently stabilized, the slope interruption devices can be removed and disposed offsite. Permanently stabilize any areas disturbed during removal of the slope interruption devices.

### 8.0 References


ERTEC Environmental Systems. 2022. Protecting Global Lands and Waterways. Product Brochure. Available at:chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ertecsystems.com/wp-content/uploads/2022/02/ERTEC-Brochure.pdf

James Madison University. 2021. *JMU: Annual Standards and Specifications for ESC & SWM*. March 11.


## C-ECM-04 Temporary Diversion Dike

### 1.0 Definition

A temporary diversion dike is a temporary ridge of compacted soil constructed to convey clean stormwater runoff through or around a disturbed land area. In most cases, temporary diversion dikes collecting sediment-laden water work as conveyance in conjunction with other erosion and sediment control devices.

– CAD C-ECM-04 Temporary Diversion Dike

### 2.0 Purpose and Applicability of Best Management Practice

A temporary diversion dike is used to protect work areas from upslope runoff and to divert sediment-laden water to appropriate traps or stable outlets.

Use a temporary diversion dike wherever stormwater runoff must be temporarily diverted to protect disturbed areas and slopes or retain sediment on site during construction. Specific locations and conditions include:

- Above disturbed existing slopes and above cut or fill slopes to prevent runoff over the slope;
- Across unprotected slopes, as slope breaks, to reduce slope length;
- Below slopes to divert excess runoff to stabilized outlets;
- Where needed to divert sediment-laden water to construction best management practices (BMPs);
- At or near the perimeter of the construction area to keep sediment from leaving the site; and
- Above disturbed areas before stabilization to prevent erosion and maintain acceptable working conditions.

Temporary diversion dikes may also serve with a Temporary Sediment Trap (C-SCM-11) when the site has been over-excavated on a flat grade; they may also be used in conjunction with a sediment fence.

Temporary diversion dikes can also be used to divert clean water around disturbed or environmentally sensitive areas.

### 3.0 Planning and Considerations

A temporary diversion dike is intended to divert overland sheet flow to a stabilized outlet or a sediment trapping facility during construction and establish permanent stabilization on sloping disturbed areas. When used at the top of a slope, the structure protects exposed slopes by keeping upland runoff away. When used at the base of a slope, the structure protects adjacent and downstream areas by diverting sediment-laden runoff to a sediment trapping facility.

Stabilize temporary diversion dikes immediately following installation with temporary or permanent vegetation in accordance with Temporary Seeding (C-SSM-09) and Permanent Seeding (C-SSM-10) to prevent erosion of the dike itself.

The gradient of the channel behind the dike is also an important consideration. Construct the dike to have a positive grade to ensure drainage, but if the gradient is too great, take precautions to prevent erosion due to high-velocity channel flow behind the dike. Design the cross-section of the channel that runs behind the dike to be a parabolic or trapezoidal shape to help inhibit a high velocity of flow, which could arise in a vee ditch.

Diversion dikes become a logical choice for a control measure once the control limits of the silt fence, compost filter sock, or straw bale barrier have been exceeded.

Temporary diversion dikes are often used as a perimeter control in association with a sediment trap, a sediment basin, or a series of sediment-trapping facilities on moderate to large construction sites. If installed properly in the first phase of grading, maintenance costs are very low. Often, cleaning of sediment trapping facilities is the only associated maintenance requirement.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down a cut or fill slope unless contained in an adequate temporary or permanent channel, flume, or slope drain structure.

9VAC25-875-560.

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: LOW**

## 5.0 Design Criteria

No formal design is required, but the following criteria should be met.

**Table C-ECM-04-1 Design Criteria for Temporary Diversion Dike**

| Parameter | Notes on Proper Use |
|---|---|
| Drainage Area | The maximum allowable drainage area is 5 acres calculated from the area tributary to the lowest point on the BMP. |
| Capacity | Peak runoff from the 10-year storm. |
| Height | The minimum allowable height measured from the upslope side of the dike is 18 inches, which includes the minimum 6 inches of required freeboard. |
| Ridge Design | Side slopes of 2H:1V or flatter, along with a minimum top width of 2 feet and a minimum of 6 inches of freeboard. |
| Grade | Design the channel behind the dike to have a positive grade to a stabilized outlet. If the channel slope is less than or equal to 2%, no stabilization is required. If the slope is greater than 2%, stabilize the channel in accordance with Stormwater Conveyance Channel (C-ECM-09). |

| Table C-ECM-04-1 Design Criteria for Temporary Diversion Dike | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Outlet | 1. Release the diverted runoff, if free of sediment, through a stabilized outlet or channel or Level Spreader (C-ECM-14).<br>2. Divert and release sediment-laden runoff through a sediment trapping facility such as a Temporary Sediment Trap (C-SCM-11) or Temporary Sediment Basin (C-SCM-12). |

## 6.0 Construction Specifications

1. Install temporary diversion dikes as a first step in the land-disturbing activity and make the diversion dikes functional before upslope land disturbance.
2. Remove and properly dispose of all trees, brush, stumps, and other objectionable material.
3. Adequately compact the dike to prevent failure.
4. Ensure that the minimum constructed cross-section meets all design requirements.
5. Ensure that the top of the dike is not lower at any point than the design elevation plus the specified settlement.
6. Provide sufficient room around diversions to permit machine regrading and cleanout.
7. Apply temporary or permanent seeding and mulch to the dike immediately following its construction.
8. Locate the dike to minimize damage by construction operations and traffic.

## 7.0 Operations and Maintenance Considerations

Inspect temporary diversion dikes after every storm and repair the dike, flow channel, outlet, or sediment trapping facility as necessary. In karst areas, the upslope edge of the diversion dike should be inspected for subsidence, especially at the downstream end and at the associated outlet structure/BMP. Subsidence is considered a mode of failure.

Bi-weekly (whether a storm event has occurred or not), inspect the control measure and repair if needed. Repair damage caused by construction traffic or other activity before the end of each working day.

Construct temporary diversions to operate with 6 inches or more of freeboard. Make height adjustments if frequent instances of overtopping are observed.

## 8.0 References

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-ECM-05 Diversion

## 1.0 Definition

A diversion is a channel constructed across a slope with a supporting earthen ridge on the lower side.

– CAD C-ECM-05-1 Diversions

## 2.0 Purpose and Applicability of Best Management Practice

Diversions may be temporary conveyances to manage stormwater runoff at construction sites or they may be permanent stormwater management structures. Diversions are used to reduce slope length and to intercept and divert stormwater runoff to stabilized outlets at non-erosive velocities. Diversions apply to the following site conditions:

- Where runoff from areas of higher elevation may damage property, cause erosion, and/or interfere with the establishment of vegetation or the intended land use on lower areas;
- Where surface and/or shallow subsurface flow is damaging to sloped upland areas;
- Where the slope length needs to be reduced to minimize soil loss;
- Where runoff to sensitive site areas must be diverted, such as sinkholes in karst areas; and
- Where large drainage areas must be reduced for the purpose of flow distribution to post-construction stormwater BMPs.

## 3.0 Planning and Considerations

Diversions can be useful tools for managing surface water flows and preventing soil erosion. The characteristics of the watershed contributing runoff to the diversion must be analyzed to ensure that the diversion will function without overtopping or erosion.

On moderately sloped areas, diversion may be placed at intervals to trap and divert sheet flow before it has a chance to concentrate and cause rill and gully erosion.

Diversions may be placed at the tops of cut or fill slopes to prevent runoff from upland drainage areas from flowing on the slope. Diversions can also protect structures, parking lots, adjacent properties, and other special areas from flooding.

Diversions are preferable to other types of artificial stormwater conveyance systems because these measures more closely simulate natural flow patterns and characteristics. Flow velocities are generally kept to a minimum.

When properly coordinated into the landscape design of a site, diversions can be visually pleasing as well as functional.

As with any earthen structure, it is important to establish adequate vegetation as soon as possible after installation and stabilize the drainage area above the diversion such that sediment will not enter and accumulate in the diversion channel. See BMP C-ECM-07, BMP C-SSM-09, and BMP C-SSM-10.

Berm diversion is not necessary if constructed on the top of a slope. The berm aspect of a diversion is only necessary to provide additional freeboard and slope interception. The velocity and depth are based on 2-year storms and 10-year storms.

When material of slope (swale) contains karst features, a diversion should be replaced with another similar device that will not risk soil integrity and performance of the measure.

When designing for a sediment trap or basin, consider using a temporary right-of-way diversion on undisturbed areas to reduce the quantity of stormwater that feeds into the sediment trap or basin.

When conveying concentrated flow, plan the diversion in accordance with an appropriate outlet measure; refer to Table C-ECM-05-1 Diversion Design Criteria. To reduce velocity in the channel along with adding sediment trapping capability to the measure, consider using rock check dams (BMP C-SCM-07). Spacing calculations should be provided in instances where check dams are used in collaboration with diversions.

Care must be taken when siting the outlet of the diversion. Diversion outlets should be directed to stabilized areas where the discharge will not cause erosion. Outlets must not discharge to sinkholes or other karst features.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-5: EARTHEN STRUCTURE STABILIZATION** – Stabilization measures shall be applied to earthen structures such as dams, dikes and diversions immediately after installation.

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

**MS-9: SEEPAGE** – Whenever water seeps from a slope face, adequate drainage or other protection shall be provided.

**MS-19: STORMWATER STANDARD** – Properties and waterways downstream from development sites shall be protected from sediment deposition, erosion and damage due to increases in volume, velocity and peak flow rate of stormwater runoff...

9VAC25-875-560

**Erosion Control Efficiency: Moderate**

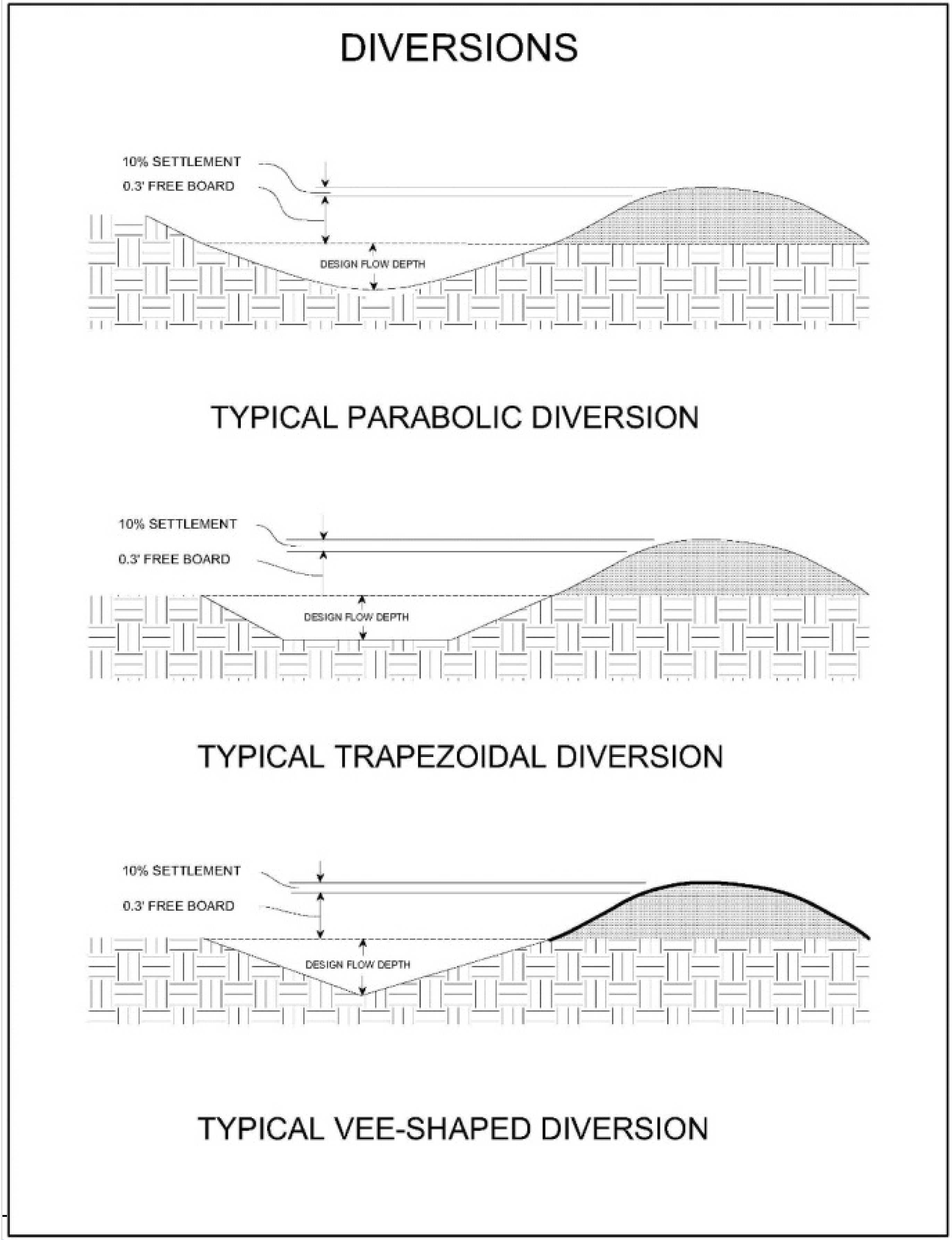
**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

| Table C-ECM-05-1 Diversion Design Criteria | |
|---|---|
| **Topic** | **Requirement** |
| Location | Determine the diversion location by considering outlet conditions, topography, land use, soil type, length of slope, seepage planes (where seepage is a problem), and the development layout. |
| Capacity | Design the diversion channel to have a minimum capacity to carry the runoff expected from a 10-year, 24-hour frequency storm with a freeboard of at least 0.3 foot (see Figure C-ECM-05-1).<br><br>Design diversions to protect homes, schools, industrial buildings, roads, parking lots, and comparable high-risk areas, as well as those designed to function in connection with other structures, to have sufficient capacity to carry peak runoff expected from a storm frequency consistent with the hazard involved. |
| Channel Design | The diversion channel may be parabolic, trapezoidal, or vee-shaped and designed and constructed according to stormwater conveyance channels (BMP C-ECM-09). |
| Ridge (Berm) Design | Design the supporting ridge cross-section to meet the following criteria (see Figure C- ECM-05-1):<br>• Side slopes no steeper than 2H:1V;<br>• Width at the design water elevation a minimum of 4 feet;<br>• Minimum freeboard of 0.3 foot; and<br>• 10% settlement factor included in the design. |

| Table C-ECM-05-1 Diversion Design Criteria | |
|---|---|
| **Topic** | **Requirement** |
| Outlet | Design diversions to have adequate outlets that will convey concentrated runoff without erosion. Acceptable outlets include stormwater conveyance channel (BMP C-ECM-09), level spreader (BMP C-ECM-14), outlet protection (BMP C-ECM-15), and paved flume (BMP C-ECM-11). |
| Stabilization | Use turf reinforcement mats and other rolled erosion control products (see BMP C- SSM-05) to provide erosion protection immediately after construction and before the establishment of vegetation.<br>Seed and mulch the ridge and channel immediately following construction in accordance with BMP C-SSM-10.<br>Seed and mulch disturbed areas draining into the diversion before the diversion is constructed in accordance with BMP C-SSM-10. Ensure that sediment trapping measures remain in place to prevent soil movement into the diversion if the upslope area is not stabilized. See BMP C-SSM-09, BMP C-SSM-10, and BMP C-ECM-07. |

**Figure C-ECM-05-1 Diversion Cross-Sections**




SOURCE: VA. DSWC

## 6.0 Construction Specifications

1. Remove and dispose of all trees, brush, stumps, obstructions, and other objectionable material so as not to interfere with the proper functioning of the diversion.
2. Excavate or shape the diversion to line, grade, and cross-section as required to meet the criteria specified herein, free of irregularities that will impede flow.
3. Compact fills as needed to prevent unequal settlement that would cause damage in the completed diversion. Use fill composed of soil that is free from excessive organic debris, rocks, or other objectionable materials.
4. Spread or dispose of all earth removed and not needed in construction so that the material will not interfere with the function of the diversion.
5. Permanently stabilize disturbed areas in accordance with the applicable standard and specification contained in this handbook. Permanent stabilization techniques include permanent seeding (BMP C-SSM-10) and soil stabilization blankets and matting (BMP C-SSM-05).
6. After permanent stabilization, inspect to maintain vegetative cover. Mow as required to maintain open channel section and reseed bare areas as necessary.

## 7.0 Operations and Maintenance Considerations

Before final stabilization, inspect the diversion after every rainfall event (0.01-inch or greater depth) and at least once every week.

Remove accumulated sediment from the channel and make repairs when required.

Reseed areas that fail to establish a vegetative cover as necessary.

Inspect outlets for obstructions, subsidence, erosive conditions, animal burrows, and other intrusions, and make immediate repairs when required.

## 8.0 References

New York Department of Environmental Conservation. 2016. New York State Standards and Specifications for Erosion and Sediment Control. November.

Virginia Department of Environmental Quality. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-ECM-06 Temporary Fill Diversion

## 1.0 Definition

A temporary fill diversion is a channel with a supporting ridge of soil on the lower side, constructed along the top of an active earth fill.

– CAD C-ECM-06 Temporary Fill Diversion

## 2.0 Purpose and Applicability of Best Management Practice

Temporary fill diversions are used to divert storm runoff away from the unprotected slope of the fill to a stabilized outlet or sediment trapping facility. A temporary fill diversion applies to site conditions where the drainage area at the top of an active earth fill slopes toward the exposed slope and where continuous fill operations preclude the use of a diversion (see C-ECM-05). Use a temporary fill diversion only for less than one week.

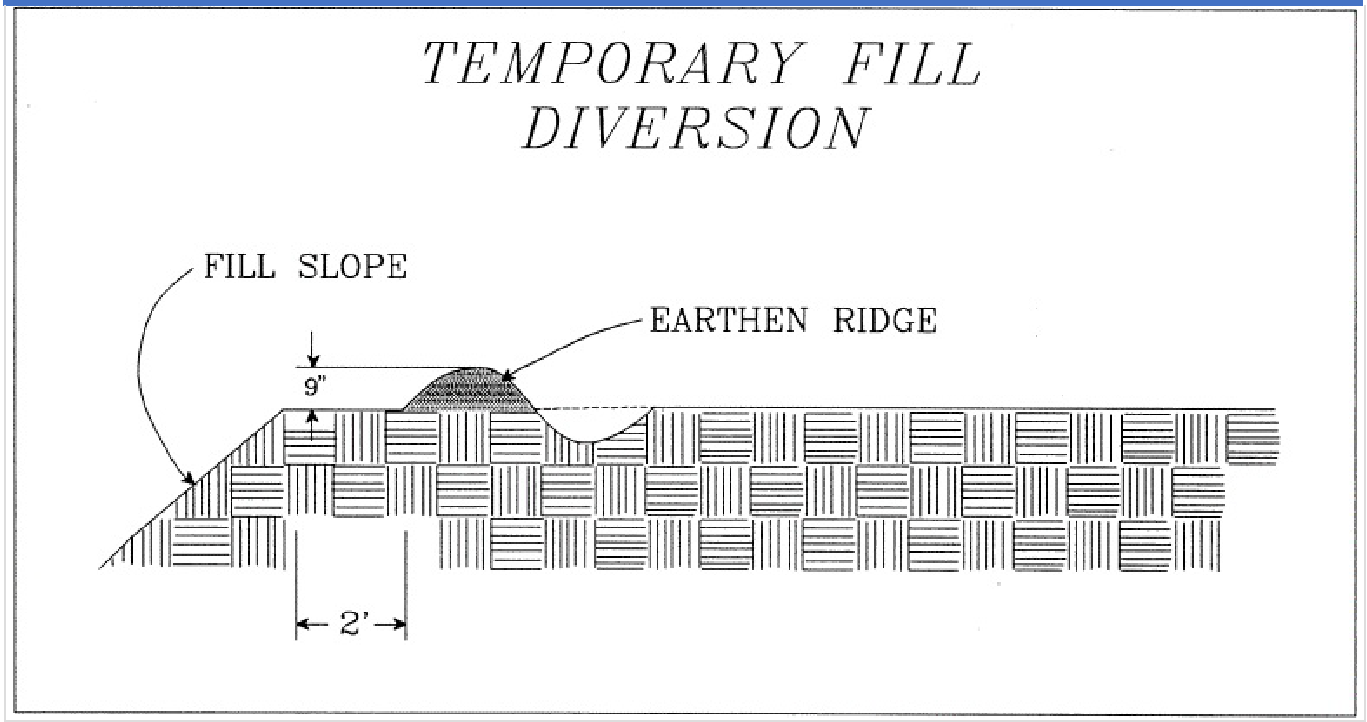
## 3.0 Planning and Considerations

Temporary fill diversion is intended to provide limited daily slope protection until final elevations are reached and a more permanent measure can be constructed.

This practice can be constructed using a motor grader or a small dozer. To shape the temporary fill diversion, the piece of machinery used may run near the top edge of the fill with its blade tilted to form the channel as depicted on Figure C-ECM-06-1. This work would be conducted at the end of the working day to provide a channel with a berm to protect the slope. Wherever possible, slope the temporary fill diversion to direct water to a stabilized outlet. If the runoff is diverted over the fill itself, the practice may cause erosion by concentrating water at a single point.

Complete the filling operation in a safe manner as quickly as possible, and then install the permanent slope protection and slope stabilization measures as soon after completion as possible.

***Figure C-ECM-06-1 Temporary Fill Diversion***




## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

9VAC25-875-560

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

No formal design is required other than compliance with the criteria shown in Table C-ECM-06-1.

| Table C-ECM-06-1 Design Criteria | |
|---|---|
| **Topic** | **Requirement** |
| Drainage Area | The maximum allowable drainage area is 5 acres. |
| Height | The minimum height of the supporting ridge is 9 inches (see Figure C-ECM-06-1). |
| Grade | Provide positive grade in the channel to a stabilized outlet. |
| Location | Locate the temporary fill diversion a minimum of 2 feet inside the top edge of the fill (see Figure C-ECM-06-1. |
| Outlet | Release the diverted runoff through a stabilized outlet, slope drain, or sediment trapping measure (see C-SCM-11 and C-SCM-12). |

## 6.0 Construction Specifications

1. Construct the temporary fill diversion at the top of the fill at the end of each workday as needed.
2. Construct the supporting ridge with a uniform height along its entire length. Without uniform height, the temporary fill diversion may be susceptible to breaching.

## 7.0 Operations and Maintenance Considerations

Because the practice is temporary and, under most situations, will be covered the next workday, minimal maintenance is required. If the practice is to remain in use for more than one day, inspect the temporary fill diversion at the end of each workday and repair the measure if needed. Avoid the placement of any material atop the structure while it is in use. Do not permit construction traffic to cross the diversion.

## 8.0 References

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-ECM-07 Temporary Right-of-Way Diversion

## 1.0 Definition

A temporary right-of-way diversion is a ridge of compacted soil, loose rock, or gravel constructed across disturbed steep slopes and similar sloping areas that is removed following construction once permanent stabilization has begun.

– CAD C-ECM-07 Temporary Right-Of-Way Diversions

## 2.0 Purpose and Applicability of Best Management Practice

A temporary right-of-way diversion is used to shorten the flow length and break up sheet flow within a terrain at pre-designed intervals, thereby reducing the potential for rill erosion, by diverting stormwater runoff to a stabilized outlet.

Temporary right-of-way diversions are typically used to control stormwater runoff on access roads and skid trails, pipeline and utility line corridors, and long slope areas where perimeter controls may not be adequate to handle the runoff from the disturbed area. Temporary right-of-way diversions are not appropriate for incised roadways where there is no opportunity to discharge runoff to either side.

Flow Path along a Right of Way Diversion.
Source: Texas A&M Forest Service

Generally, earthen right-of-way diversions apply where there will be little or no construction traffic within the work area. Gravel structures are more applicable to roads and other areas that accommodate vehicular traffic.

Temporary right-of-way diversions are removed once final grading is completed and permanent vegetative stabilization is being conducted. Restoration is typically completed by removing the rock or stone material or grading the compacted soil to remove the temporary ridge.

## 3.0 Planning and Considerations

Construction of utility lines and roads often requires the clearing of long strips of right-of-way over sloping terrain. The volume and velocity of stormwater runoff tends to increase in these cleared strips, and the potential for erosion is much greater because the vegetative cover is diminished or removed.

Disturbance and compaction promote gully formation in these cleared strips by increasing the volume and velocity of runoff. Gully formation may be especially severe in tire tracks and ruts. To prevent gullying, runoff can often be diverted across the width of the right-of-way to constructed outlets using small, pre-designed diversions. Give special consideration to each individual outlet area as well as to the cumulative effect of added diversions.

To compensate for the loss of vegetation, it is usually a good practice to break up the flow length within the cleared strip so that runoff does not have a chance to concentrate and cause erosion. At proper intervals, temporary right-of-way diversions can significantly reduce the amount of erosion that will occur until the area is permanently stabilized.

A right-of-way diversion can be both a temporary practice (as presented in this specification) or a permanent practice.

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down a cut or fill slope unless it is contained in an adequate temporary or permanent channel, flume, or slope drain structure.

9VAC25-875-560

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

No formal design is required. The following criteria should be met:

| Table C-ECM-07-1 Design Criteria for Temporary Right-of-Way Diversion | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Height | The minimum allowable height of the diversion is 18 inches. |
| Sideslopes | To allow the passage of construction traffic, construct the sideslopes to be 2H:1V or flatter with a minimum base width of 6 feet. |
| Width | Construct the right-of-way diversion completely across the disturbed portion of the right- of-way. |
| Spacing | Use Table C-ECM-07-2 to determine the spacing of right-of-way diversions. |
| Grade | Construct right-of-way diversions with cross-slope gradients of 2% or less to ensure that water entering the right-of-way diversion does not cause erosion within the right-of-way diversion channel or downgradient of the right-of-way diversion outlet. Wherever erodible soils are present, or where there is not a sufficient vegetative filter strip (50-foot minimum) between the right-of-way diversion and a receiving surface water, provide a temporary protective liner along the right-of-way diversion channel. Vegetate all right-of-way diversions immediately following construction. Do not place obstructions, (e.g., straw bales, silt fence, compost filter sock, rock filters) in or across right-of-way diversions. |
| Outlet | Design outlet protection at the ends of temporary right of way diversions in accordance with Table C-ECM-07-3. |

| Table C-ECM-07-2 Spacing of Temporary Right-of-Way Diversions | | |
|---|---|---|
| **Slope (%)** | **Spacing for Erosion Resistant Soil (ft.) k<0.37** | **Spacing for Highly Erodible Soil (ft.) k>0.37** |
| < 7% | 100 | 75 |
| 7% to 25% | 75 | 55 |
| 25% to 40% | 50 | 35 |
| > 40% | 25 | 18 |
| *Source: Va. DSWC* | | |

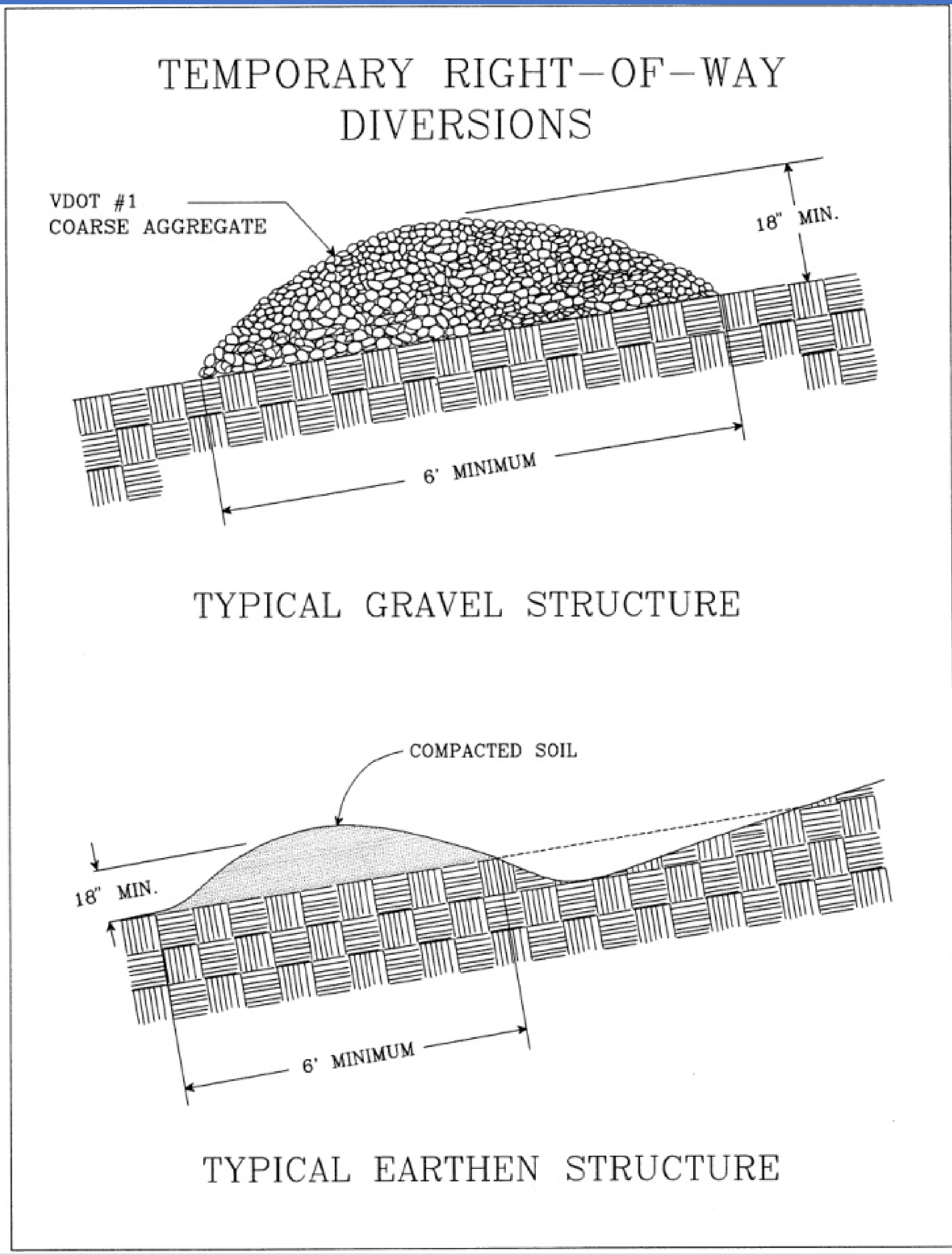
**Temporary Right-of-Way Diversion Outlet Protection Measures**

The following section outlines standard outlet protection measures to be installed at the outfall of each temporary right-of-way diversion.

If the area draining to the temporary right-of-way diversion exceeds 2 acres in area, design and install an appropriately sized Temporary Sediment Trap (BMP C-SCM-11) or Temporary Sediment Basin (BMP C-SCM-12) at the outlet of the temporary right-of-way diversion.

| Table C-ECM-07-3 Temporary Right-of-Way Diversion Outlet Protection Types | |
|---|---|
| **Type** | **Description** |
| Temporary Sump with Compost Filter Sock | Install a temporary sump with compost filter sock at the outlet of the temporary right-of-way.<br>1. Excavate a sump at the outfall of the temporary right-of-way diversion with the following dimensions:<br>▪ Minimum depth of 2 feet;<br>▪ Minimum width of 2 feet; and<br>▪ Minimum length of 10 feet.<br>2. Install 24-inch-diameter compost filter sock around the downgradient perimeter of the sump. |
| Compost Filter Sock J-Hook | Install a compost filter sock j-hook at the outlet of the temporary right-of-way diversion.<br>1. Install a 12-foot-long compost filter sock j-hook beginning at the end of the temporary right-of-way diversion, such that the first 2 feet are parralel to the contours and the last 10 feet run upslope.<br>2. Install a base layer of three 12-foot-long segments of 24-inch compost filter sock laid side by side.<br>3. Install an intermediate layer of two 12-foot-long segments of 18-inch compost filter sock on top of the base layer.<br>4. Intall a top layer of one 12-foot-long section of 12-inch compost filter sock.<br>5. Stake the base and top layers of compost filter sock in accordance with Temporary Sediment Trap (C-SCM-11) for the compost filter sock outlet. |
| Rock Outlet Apron | Install a rock outlet apron at the outlet of the temporary right-of-way diversion in accordance with Outlet Protection (BMP C-ECM-15). |

**Figure C-ECM-07-1 Temporary Right-of-Way Diversions**




Source: VDEQ, 1992

Virginia Department of Transportation (VDOT) #3, #357, or #5 coarse aggregate may be used in lieu of VDOT #1 coarse aggregate in areas of vehicular traffic where additional compaction of stone material is needed.

## 6.0 Construction Specifications

1. Install the right-of-way diversion as soon as the right-of-way has been cleared and/or graded.
2. Machine- or hand-compact all earthen diversions in 8-inch lifts.
3. Install the appropriately designed constructed outlet at the downgradient end of the right-of-way diversion in accordance with Table C-ECM-07-3. In karst areas, sediment traps and basins as outlet areas are prone to subsidence and should be inspected regularly and after each precipitation event. Subsidence is considered a mode of failure, and subsidence features should be repaired promptly following discovery using capped, inverted graded filters (e.g., VDOT Sinkhole Treatment Details).
4. Stabilize earthen diversions that will not be subject to construction traffic in accordance with Temporary or Permanent Seeding (BMP C-SSM-09 or C-SSM-10).
5. Install the right-of-way diversions and the constructed outlet and ensure functionality by the end of each workday, especially when work will be discontinued for several days, as on a weekend. Be aware of the weather forecast.

## 7.0 Operations and Maintenance Considerations

Inspect right-of-way diversions weekly and after each rainfall. Where construction is actively occurring or on active roads, inspect right-of-way diversions daily and repair damage caused by construction traffic or other activity before the end of the workday.

Keep the right-of-way diversion channel flow line clear of sediment accumulations and any obstructions that impede flow. Maintain earthen right-of-way diversion temporary or permanent stabilization. Restore damaged or eroded right-of-way diversions to original dimensions within 24 hours of inspection. Inspect constructed outlets and make repairs as needed including mitigation of any sinkholes that may form in or adjacent to outlet structures.

Maintain right-of-way diversions until the roadway, skid trail, or right-of-way has achieved permanent stabilization. Earthen right-of-way diversions on retired roadways, skid trails, and rights-of-way may be left in place after permanent stabilization has been achieved. Remove right-of-way diversions from all residential lawns and agricultural fields following completion of construction and remove all gravel right-of-way diversions. Provide permanent vegetative stabilization to earthen right-of-way diversions left as permanent structures.

## 8.0 References

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

Texas A&M Forest Service. Undated. Best Management Practices Pictorial Directory. Located at: https://tfsweb.tamu.edu/uploadedFiles/TFSMain/Manage_Forest_and_Land/Water_Resources_and_BMPs/Stewardship(1)/TFS%20BMP%20Pictorial%20Directory.pdf

# C-ECM-08 Waterbars and Sheet Flow Breakers

## 1.0 Definition

Waterbars and sheet flow breakers are used to shorten sheet flow length, reduce velocity, and flatten slopes within a terrain at pre-designed intervals. Waterbars and sheet flow breakers are permanent best management practices, intended to remain after permanent stabilization of the site has been achieved.

## 2.0 Purpose and Applicability of Best Management Practice

Waterbars and sheet flow breakers are typically used to control stormwater runoff on logging roads and skid trails, pipeline and utility line corridors, recreational trails, and long slope areas susceptible to rill erosion caused by sheet flow of stormwater.

Waterbars and sheet flow breakers are not appropriate for incised roadways where there is no opportunity to discharge runoff to either side.

## 3.0 Planning and Considerations

Construction of utility lines and roads often requires the clearing of long strips of right-of-way over sloping terrain. The volume and velocity of stormwater runoff tend to increase in these cleared strips, and the potential for erosion is much greater because the vegetative cover is diminished or removed.

Disturbance and compaction promote gully formation in these cleared strips by increasing the volume and velocity of runoff. Gully formation may be especially severe in tire tracks and ruts. To prevent gullying, runoff can often be diverted across the width of the right-of-way to constructed outlets using small, pre-designed diversions. Give special consideration to each individual outlet area as well as to the cumulative effect of added diversions.

On permanent unpaved paths, trails, and / or roads, it is a good practice to break up the length of sheet flow within the cleared strip so that runoff does not have a chance to concentrate and cause erosion. At proper intervals, waterbars and sheet flow breakers can significantly reduce the potential for rill erosion in these managed areas.

Temporary right-of-way diversions can be converted to a permanent structure (i.e., waterbar) after site construction. These temporary diversions can be planted with permanent vegetation and left in place following construction to break up long slopes and convey runoff to either side of the right-of-way.

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down a cut or fill slope unless it is contained in an adequate temporary or permanent channel, flume, or slope drain structure.

9VAC25-875-560

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

No formal design is required. The following criteria should be met:

| Table C-ECM-08-1 Design Criteria for Waterbars and Sheet Flow Breakers | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| **Height** | Height may vary based on the practice selected; however, except with in the case of open-top culverts, the maximum height of the waterbar or sheet flow breaker should be 18 inches. |
| **Sideslopes** | Construct the sideslopes to be 2H:1V or flatter with a minimum base width of 6 feet, and a maximum base width of 12 feet. |
| **Width** | Construct the waterbar or sheet flow breaker completely across the area subject to sheet flow. |
| **Spacing** | Use Table C-ECM-08-3 and Table C-ECM-08-4 to determine the spacing waterbars and sheet flow breakers. |
| **Area** | The drainage area to any one waterbar or sheet flow breaker must be less than 2 acres. |
| **Grade** | Waterbars and permanent sheet flow breakers should have a maximum 2.0%-3.0% outslope to divert sheet flow to a well stabilized outlet. |
| **Outlet** | Design waterbars and permanent sheet flow breakers to discharge to a rock apron designed in accordance with BMP C-ECM-15 or another constructed outlet, such as a basin. For a more streamlined approach, designers may also choose to install outlet protection in accordance with the dimensions in Table C-ECM-08-5. |

| Table C-ECM-08-2 Types of Sheet Flow Breakers | |
|---|---|
| **Type** | **Description** |
| **Waterbar** | A waterbar is an earthen right-of-way diversion that is permanently stabilized in accordance with Permanent Seeding and Soil Stabilization Blankets and Matting (C-SSM-10 and C-SSM-05, respectively) and left in place as a vegetated permanent practice. |
| **Open-Top Culvert** | Open-top culverts may be used to intercept runoff from access roads and divert the runoff to well-vegetated (erosion resistant) areas or sediment removal facilities. Such culverts are typically more easily traversed than right-of-way diversions or broad-based dips but can require more maintenance if crossed by heavy equipment or exposed to sediment-laden runoff. Do not use open-top culverts for stream crossings or in lieu of pipe culverts.<br>Install open-top culverts at the spacing shown in Table C-ECM-08-4. |
| **Water Deflector** | Deflectors may be used instead of open-top culverts to direct runoff from an access road to a well-vegetated area or stabilized outlet. This method of directing runoff from an access road works best on low-traffic roads.<br>Install water deflectors at the spacing shown in Table C-ECM-08-4. |
| **Broad-Based Dip** | Broad-based dips are an alternative method to ditch relief or cross-drain culverts to remove water across access roads to well-vegetated areas or an appropriately designed outlet.<br>Due to the nature of broad-based dips, do not construct broad-based dips on roads with grades exceeding 10%. Where access roads exceed 10% gradients, use waterbars or other sheet flow breakers.<br>Do not use broad-based dips to pass continuous flowing water across the road or under extended damp conditions such as where springs are located.<br>Design broad-based dips with the maximum spacing provided in Table C-ECM-08-4. |

| Table C-ECM-08-3 Maximum Spacing of Waterbars | | |
|---|---|---|
| Slope (%) | Spacing for Erosion Resistant Soil (ft.) k<0.37 | Spacing for Highly Erodible Soil (ft.) k>0.37 |
| < 2% | 445 | 335 |
| 2% to 5% | 335 | 250 |
| 6% to 15% | 200 | 150 |
| 16% to 30% | 135 | 100 |
| > 31% | 65 | 50 |

| Table C-ECM-08-4 Spacing of Sheet Flow Breakers – Open-Top Culverts, Water Deflectors, and Broad-based Dips | | |
|---|---|---|
| Slope (%) | Spacing for Erosion Resistant Soil (ft.) k<0.37 | Spacing for Highly Erodible Soil (ft.) k>0.37 |
| < 2% | 400 | 300 |
| 2% | 315 | 235 |
| 4% | 265 | 200 |
| 5% | 240 | 180 |
| 6% | 220 | 165 |
| 7% | 205 | 155 |
| 8% | 200 | 150 |
| 9% | 190 | 145 |
| 10% | 180 | 140 |

Source: Adapted from PADEP, 2012

| Table C-ECM-08-5 Standard Rock Apron Outlet Dimensions | | | | |
|---|---|---|---|---|
| Mean $D_{50}$ Riprap Size (in) | Riprap Thickness (in) | Length (ft) | Initial Width (ft) | Terminal Width (ft) |
| 6 | 18 | 12 | 4.5 | 16.5 |

1. Apron length is based on the methodology outlined in 9.0 Appendix C-ECM-08.
2. Apron initial width is based on three times waterbar berm height of 18 inches.
3. Riprap size and thickness are based on a maximum velocity of 9.0 feet per second.

## 6.0 Construction Specifications

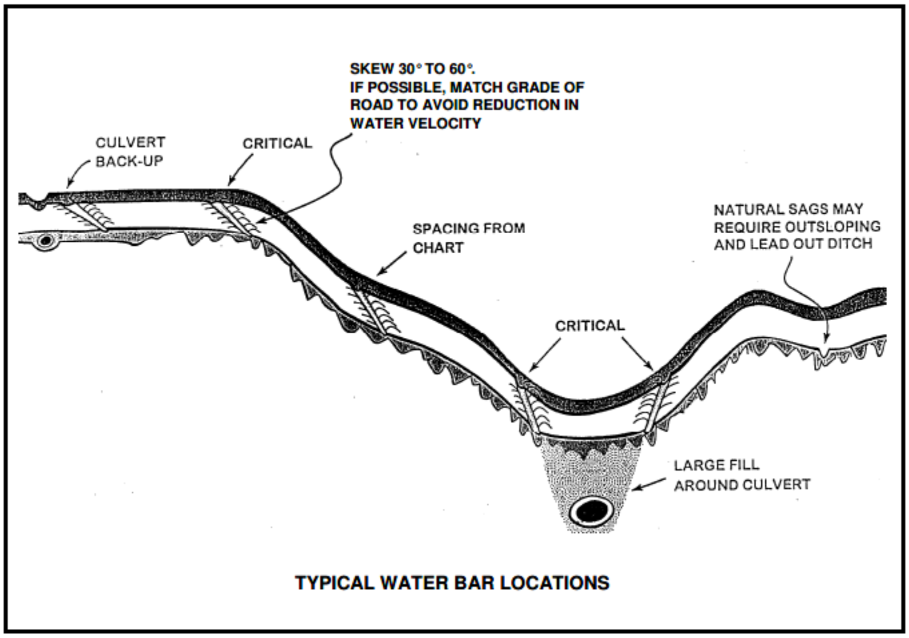
1. Installation of waterbars and sheet flow breakers should occur at a time when site stabilization is imminent to avoid conflicts with construction vehicles.
2. Machine- or hand-compact all earthen waterbars and sheet flow breakers in 8-inch lifts.
3. Install the appropriately designed constructed outlet at the downgradient end of the practice.
4. Stabilize waterbars and sheet flow breakers that will not be subject to construction traffic in accordance with Temporary or Permanent Seeding (BMP C-SSM-09 or C-SSM-10).

**Waterbars**

1. Compaction of the excavated material used to make the berm on the downhill side of the waterbar should occur by using wheel rolling or walking the excavation equipment over the downhill berm.

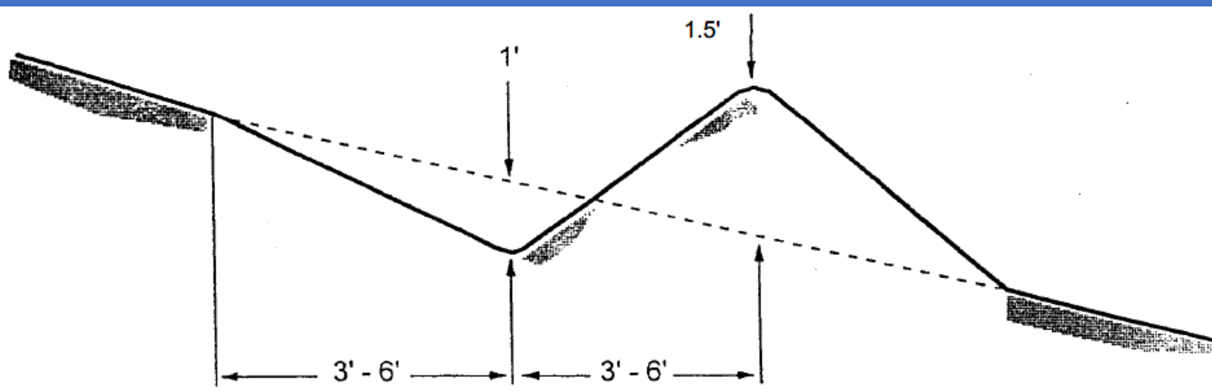
2. Construct with a 30-to-60-degree angle from centerline of right-of-way. Maintain 2.0% outslope for drainage.

**Figure C-ECM-08-1 Typical Waterbar Locations**



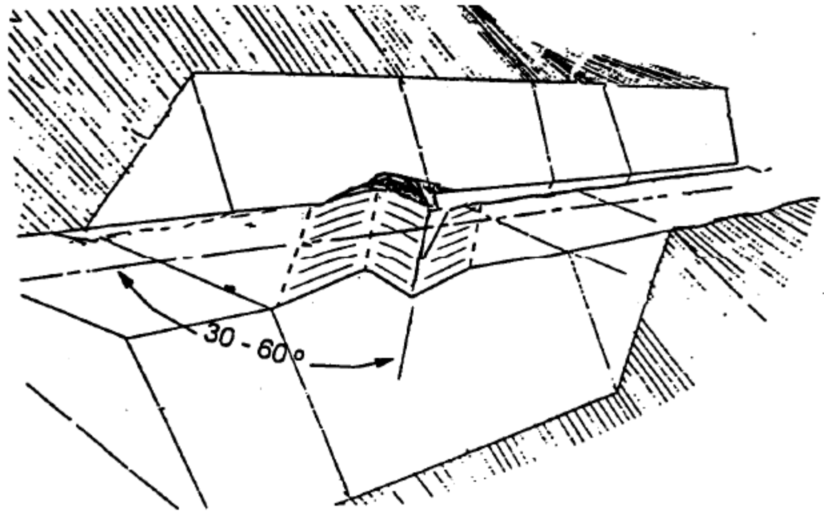

Source: Warren, 1994

**Figure C-ECM-08-2 Typical Waterbar Profile**




Source: Warren, 1994

**Figure C-ECM-08-3 Typical Waterbar Perspective View**




Source: Warren, 1994

**Open Top Culverts**

1. Construct open-top culverts using two 3-inch by 8-inch cedar or pressure-treated lumber sides and a 3-inch by 12-inch pressure-treated lumber base fastened together with 60d galvanized nails spaced 9 inches on center.

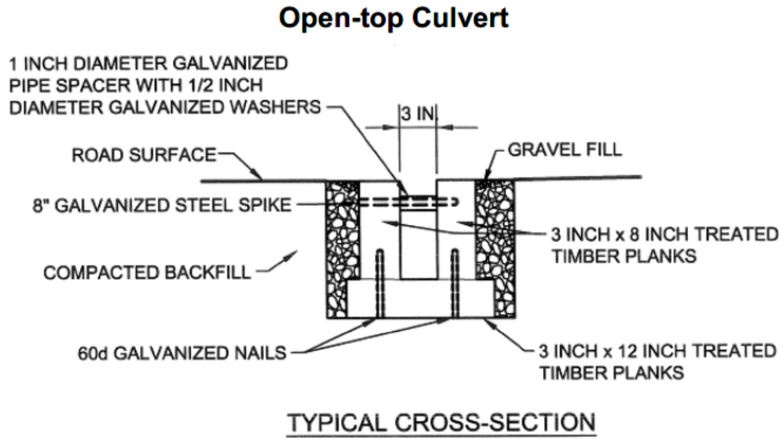
**Figure C-ECM-08-4 An open-top culvert along a low-volume driveway**

Source: PADEP, 2012

2. Place 1-inch-diameter galvanized pipe spacers with 0.5-inch-diameter galvanized washers in the open-top culvert at a maximum 18-inch distance between spacers. Hold the spacers in place with an 8-inch galvanized steel spike installed through the pipe and washers. Leave 6 inches between the end of the culvert and the first spacer. Maintain a minimum 3-inch opening in the top of the culvert across the length of the culvert.

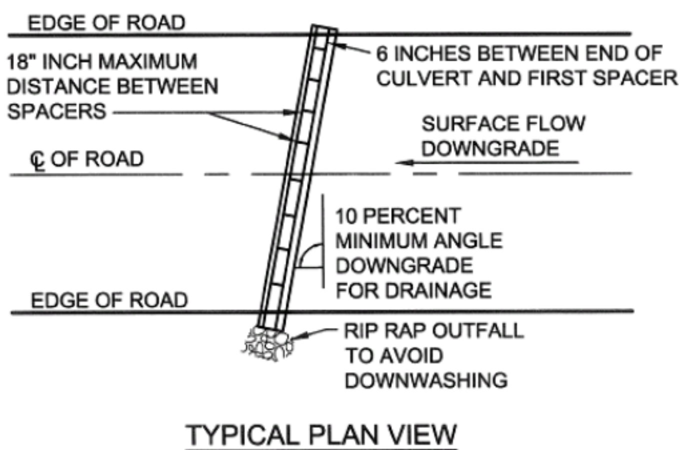
3. Install the culvert with a 10˚ minimum and 30˚ maximum downslope angle to the road and 2.0% outslope to allow for drainage. Install the culvert flush with the surface of the road. If placed too high, stormwater will not enter the structure; if placed too low, it may quickly fill with road material and sediment loosened during installation. Extend the outlet of the open-top culvert beyond the edge of the road. Remove any berms or other debris that could interfere with water flowing from the outlet. Provide suitable outlet protection (see BMP C-ECM-15) at the culvert outlet.

***Figure C-ECM-08-5 Typical cross section of open-top culvert***




Source: PADEP, 2012

***Figure C-ECM-08-6 Typical plan view of open-top culvert***

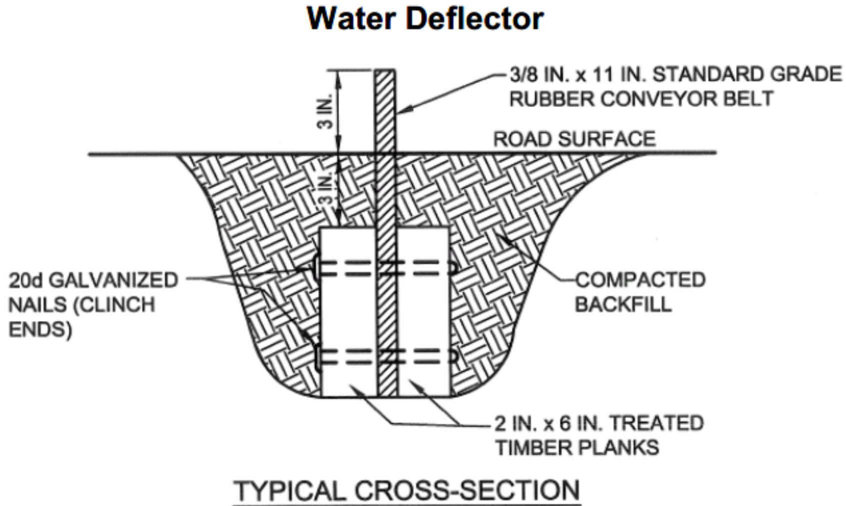



Source: PADEP, 2012

**Water Deflectors**

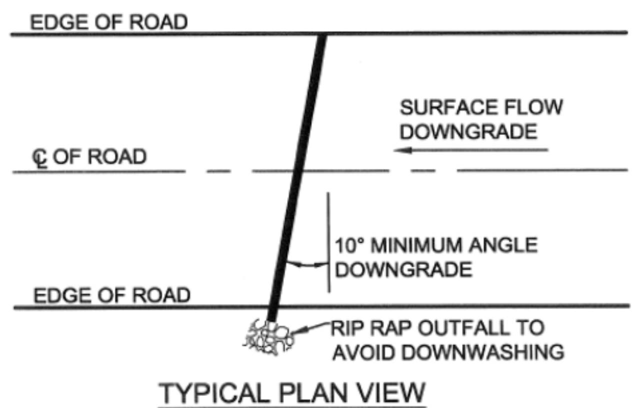
1. Construct water deflectors using a 0.375-inch-thick by 11-inch-wide standard grade rubber (such as used in a conveyor belt) held between two 2-inch by 6-inch pressure-treated lumber planks and fastened together with multiple 20d galvanized nails with clinch ends.
2. Install water deflector into an excavated trench in the access road so that a minimum of 3 inches of the rubber belt is exposed above the road surface. Install the deflector at a 10˚ minimum and 30˚ maximum downslope angle to the road to allow for drainage.

**Figure C-ECM-08-7 Water Deflactor Typical Cross Section**




Source: PADEP, 2012

**Figure C-ECM-08-8 Water Deflactor Typical Plan View**

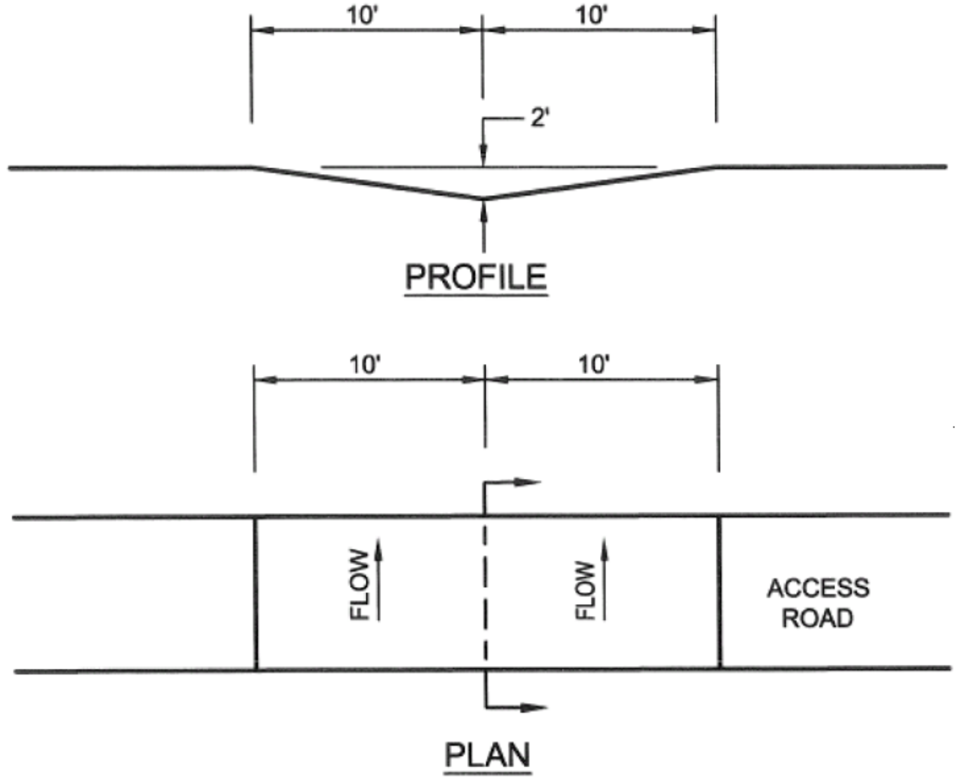



Source: PADEP, 2012

**Broad Based Dips**

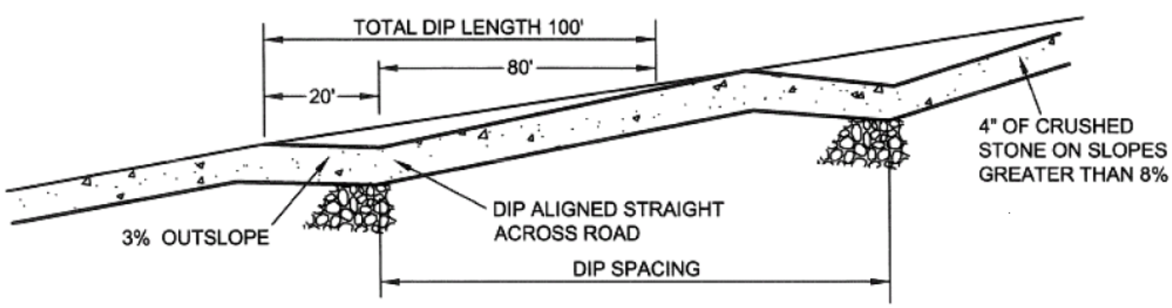
1. Design broad-based dips so that discharges are to the downslope sides of access roads with a maximum gradient of 3% in the dip.
2. For access roads with grades up to 5% (low gradient roads), construct the dip to be 2 feet below the road grade over a total length of 20 feet (10 feet on either side of the dip).
3. For access road between 5% and 10%, construct the dip to be a minimum of 12 inches below grade with a 3% outslope and a total length of 100 feet.

**Figure C-ECM-08-9 Broad-based Dip for Low Gradient (≤5%) Approach**




Source: PADEP, 2012

**Figure C-ECM-08-10 Broad-based Dip for High Gradient (>5% - 10%) Approach**




**MINIMUM DEPTH = 12"**

Source: PADEP, 2012

## 7.0 Operations and Maintenance Considerations

Inspect waterbars or sheet flow breakers weekly and after each rainfall. Keep the waterbars or sheet flow breakers channel flow line clear of sediment accumulations and any obstructions that impede flow. Ensure stabilization is maintained within the waterbar itself, and that erosion does not occur within the berm.

Restore damaged or eroded waterbars or sheet flow breakers to original dimensions within 24 hours of inspection. Inspect constructed outlets and make repairs as needed including mitigation of any sinkholes that may form in or adjacent to outlet structures.

Earthen waterbars or sheet flow breakers on retired roadways, skid trails, and rights-of-way may be left in place after permanent stabilization has been achieved. Provide permanent vegetative stabilization to earthen waterbars or sheet flow breakers left as permanent structures.

Maintenance of waterbars shall be provided until the tributary drainage area to the waterbar has been permanently stabilized.

Open top culverts should be inspected quarterly, and after rainfall events of depth greater than 1-inch per 24-hours. In case where the practice is used on active trails or skid roads, more frequent inspections will be required.

Damaged or non-functioning culverts should be repaired immediately.

Water deflectors should be inspected monthly, and after rainfall events of depth greater than 1-inch per 24-hours. Replace belts when they become worn, or otherwise no longer effective.

## 8.0 References


PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

Vermont Department of Environmental Conservation. Shoreland Best Management Practices. Available online at: https://dec.vermont.gov/watershed/lakes-ponds/lakeshores-lake-wise/bmp

Warren, Charles. 1994. Water Bar Placement and Construction Guide for Siuslaw Roads.


## 9.0 Appendix C-ECM-08

**Design of the Minimum Rock Apron Outlet Dimensions**

This appendix provides documentation of the methodology used to size the minimum rock apron outlet dimensions provided in Table C-ECM-08-5 of this Construction BMP to ensure flow leaving the waterbar or sheet flow breaker is non-erosive sheet flow. The minimum rock apron outlet dimensions are based on the contributing drainage area to the waterbar or sheet flow breaker.

**Flow Rate Computation**

To calculate the dimensions of the rock apron outlet, the flow rate to each waterbar or sheet flow breaker resulting from the 10-year, 24-hour storm event was calculated. The National Resources Conservation Service Technical Release 55 Hydrologic Method and HydroCAD® software were used to compute the runoff flow rate of the contributing drainage area to the waterbar or sheet flow breaker.

The rainfall pattern was modeled as a SCS Type C distribution for the 10-year, 24-hour storm event. Rainfall data were obtained from the National Oceanic and Atmospheric Administration Atlas 14 data server for Richmond, Virginia (Latitude: 37.5522°, Longitude: -77.4221°). The total storm precipitation value for a 24-hour duration for the 10-year storm used was 5.07 inches.

The land cover within the contributing drainage area to the waterbar or sheet flow breaker was modeled as meadow. The soils were assumed to be hydrologic soil group (HSG) D soils. Based on the meadow land cover with HSG D soils, a Runoff Curve Number of 78 was used for the model. The drainage area to the waterbar or sheet flow breaker was modeled at 2.0 acres.

The time of concentration for the contributing drainage area is 8.1 minutes based on a 100-foot length of sheet flow with a slope of 0.30 feet/foot and a Manning's n of 0.13 for range (natural), and a 1,200-foot length of shallow concentrated flow with a slope of 0.30 feet/foot and a velocity factor of 7.0 feet per second (fps) for short grass pasture.

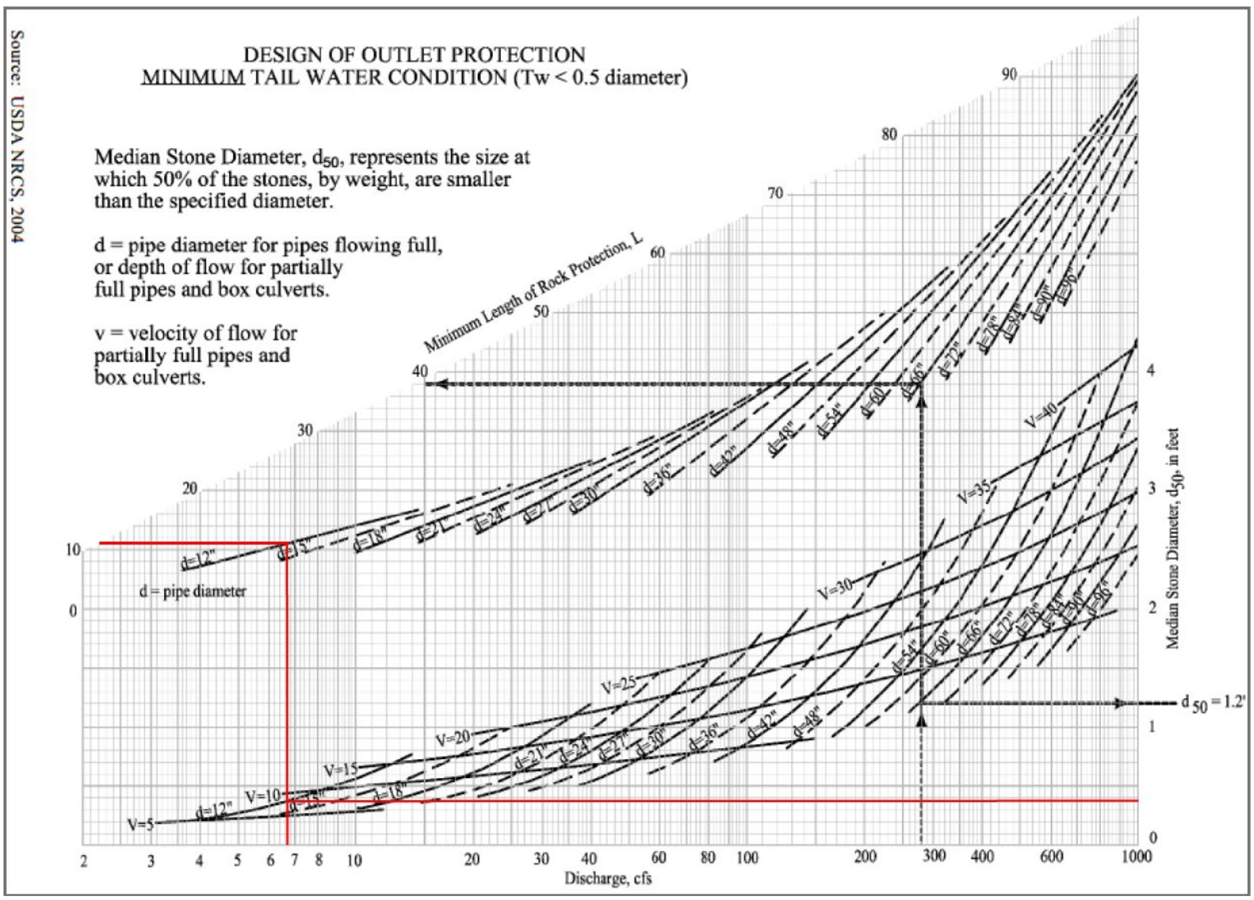
The runoff flow rate to the waterbar or sheet flow breaker was determined to be 6.73 cubic feet per second (cfs), as provided in the attached HydroCAD Report.

**Waterbar or Sheet Flow Breaker Flow Computation**

A 50-foot-long waterbar or sheet flow breaker was modeled in HydroCAD as a channel with no bottom width, 2H:1V sideslopes, a 1.5-foot depth, a slope of 0.020 feet/foot, and Manning's n of 0.30. The length of the waterbar or sheet flow breaker was modeled with a 50-foot length to coincide with the average permanent right-of-way easement of a linear gas pipeline. The resulting average depth of flow within the waterbar or sheet flow breaker at peak storage is 0.93 feet.

**Rock Apron Outlet Computation**

Using Figure C-ECM-14-5 – Minimum Tailwater Condition, a discharge rate of 6.73 cfs, and a depth of flow of 12 inches, the apron length was determined to be 12 feet and the median stone size ($d_{50}$) was determined to be 6 inches (minimum median stone size). The rock apron thickness was determined to be 1.5 times the maximum diameter of the rock but not less than 9 inches. The upstream apron width was determined to be 4.5 feet, based on three times the total waterbar or sheet flow breaker depth of 18 inches. The downstream end of the apron was determined to be 16.5 feet, based on upstream apron width plus the length of the apron of 12 feet.



**NOAA Atlas 14, Volume 2, Version 3**
**Location name: Richmond, Virginia, USA***
**Latitude: 37.5522°, Longitude: -77.4221°**
**Elevation: 135 ft****
* source: ESRI Maps
** source: USGS

**POINT PRECIPITATION FREQUENCY ESTIMATES**

G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

## PF tabular

**PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]**

| Duration | Average recurrence interval (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min | 0.374 (0.338-0.413) | 0.443 (0.402-0.489) | 0.519 (0.470-0.572) | 0.581 (0.525-0.642) | 0.653 (0.587-0.718) | 0.706 (0.634-0.777) | 0.757 (0.675-0.833) | 0.802 (0.712-0.883) | 0.857 (0.754-0.945) | 0.900 (0.787-0.993) |
| 10-min | 0.597 (0.541-0.659) | 0.709 (0.643-0.782) | 0.831 (0.753-0.917) | 0.930 (0.840-1.03) | 1.04 (0.936-1.14) | 1.12 (1.01-1.24) | 1.20 (1.07-1.32) | 1.27 (1.13-1.40) | 1.36 (1.19-1.49) | 1.42 (1.24-1.56) |
| 15-min | 0.746 (0.676-0.824) | 0.891 (0.808-0.983) | 1.05 (0.953-1.16) | 1.18 (1.06-1.30) | 1.32 (1.19-1.45) | 1.42 (1.28-1.57) | 1.52 (1.36-1.67) | 1.60 (1.42-1.76) | 1.71 (1.50-1.88) | 1.78 (1.56-1.96) |
| 30-min | 1.02 (0.926-1.13) | 1.23 (1.12-1.36) | 1.49 (1.35-1.65) | 1.70 (1.54-1.88) | 1.95 (1.76-2.15) | 2.14 (1.92-2.36) | 2.33 (2.08-2.56) | 2.50 (2.22-2.75) | 2.72 (2.39-2.99) | 2.88 (2.52-3.18) |
| 60-min | 1.28 (1.16-1.41) | 1.54 (1.40-1.70) | 1.92 (1.74-2.11) | 2.22 (2.00-2.45) | 2.60 (2.34-2.86) | 2.91 (2.61-3.20) | 3.21 (2.86-3.53) | 3.50 (3.11-3.85) | 3.90 (3.43-4.29) | 4.21 (3.68-4.64) |
| 2-hr | 1.52 (1.37-1.70) | 1.84 (1.66-2.05) | 2.30 (2.08-2.56) | 2.70 (2.43-3.00) | 3.22 (2.88-3.56) | 3.64 (3.24-4.03) | 4.08 (3.60-4.50) | 4.53 (3.97-5.00) | 5.15 (4.46-5.67) | 5.64 (4.85-6.23) |
| 3-hr | 1.64 (1.48-1.84) | 1.99 (1.79-2.22) | 2.49 (2.24-2.78) | 2.92 (2.61-3.25) | 3.49 (3.10-3.88) | 3.96 (3.50-4.39) | 4.44 (3.90-4.92) | 4.94 (4.31-5.47) | 5.62 (4.85-6.22) | 6.18 (5.28-6.84) |
| 6-hr | 1.99 (1.78-2.24) | 2.40 (2.14-2.70) | 3.00 (2.67-3.37) | 3.53 (3.14-3.97) | 4.26 (3.76-4.77) | 4.88 (4.28-5.44) | 5.53 (4.81-6.18) | 6.23 (5.37-6.94) | 7.21 (6.14-8.02) | 8.04 (6.76-8.94) |
| 12-hr | 2.38 (2.14-2.68) | 2.86 (2.57-3.24) | 3.61 (3.23-4.07) | 4.28 (3.81-4.82) | 5.23 (4.61-5.86) | 6.06 (5.29-6.78) | 6.95 (6.00-7.74) | 7.92 (6.75-8.79) | 9.32 (7.82-10.4) | 10.6 (8.72-11.7) |
| 24-hr | 2.75 (2.50-3.05) | 3.33 (3.04-3.70) | 4.27 (3.88-4.74) | 5.07 (4.59-5.61) | 6.26 (5.62-6.89) | 7.27 (6.49-8.00) | 8.40 (7.43-9.22) | 9.65 (8.46-10.6) | 11.5 (9.96-12.6) | 13.1 (11.2-14.4) |
| 2-day | 3.21 (2.92-3.55) | 3.89 (3.53-4.29) | 4.96 (4.49-5.47) | 5.84 (5.28-6.44) | 7.14 (6.41-7.86) | 8.24 (7.35-9.07) | 9.43 (8.35-10.4) | 10.7 (9.43-11.8) | 12.6 (11.0-13.9) | 14.2 (12.2-15.7) |
| 3-day | 3.39 (3.08-3.74) | 4.10 (3.73-4.52) | 5.22 (4.75-5.76) | 6.15 (5.58-6.77) | 7.51 (6.77-8.26) | 8.66 (7.76-9.51) | 9.89 (8.81-10.9) | 11.2 (9.92-12.3) | 13.2 (11.5-14.5) | 14.9 (12.8-16.3) |
| 4-day | 3.57 (3.25-3.93) | 4.32 (3.94-4.76) | 5.49 (5.01-6.05) | 6.46 (5.88-7.10) | 7.88 (7.13-8.66) | 9.07 (8.16-9.95) | 10.4 (9.26-11.3) | 11.8 (10.4-12.9) | 13.8 (12.1-15.1) | 15.5 (13.4-17.0) |
| 7-day | 4.11 (3.76-4.51) | 4.94 (4.52-5.43) | 6.19 (5.65-6.79) | 7.22 (6.59-7.92) | 8.71 (7.91-9.53) | 9.96 (8.99-10.9) | 11.3 (10.1-12.4) | 12.7 (11.4-13.9) | 14.8 (13.1-16.2) | 16.5 (14.4-18.2) |
| 10-day | 4.67 (4.29-5.11) | 5.60 (5.15-6.12) | 6.93 (6.36-7.57) | 8.01 (7.34-8.74) | 9.55 (8.72-10.4) | 10.8 (9.82-11.8) | 12.1 (11.0-13.2) | 13.6 (12.2-14.8) | 15.6 (13.8-17.0) | 17.2 (15.2-18.8) |
| 20-day | 6.28 (5.80-6.80) | 7.49 (6.92-8.11) | 9.05 (8.35-9.81) | 10.3 (9.48-11.1) | 12.0 (11.0-13.0) | 13.3 (12.2-14.4) | 14.7 (13.4-15.9) | 16.1 (14.6-17.4) | 18.0 (16.2-19.5) | 19.4 (17.4-21.1) |
| 30-day | 7.80 (7.26-8.38) | 9.25 (8.60-9.93) | 11.0 (10.2-11.8) | 12.3 (11.4-13.2) | 14.0 (12.9-15.0) | 15.3 (14.1-16.5) | 16.6 (15.3-17.9) | 17.9 (16.4-19.3) | 19.6 (17.9-21.1) | 20.9 (19.0-22.5) |
| 45-day | 9.82 (9.16-10.5) | 11.6 (10.8-12.4) | 13.6 (12.6-14.5) | 15.0 (14.0-16.1) | 17.0 (15.7-18.1) | 18.4 (17.1-19.7) | 19.8 (18.3-21.1) | 21.1 (19.5-22.6) | 22.8 (21.0-24.4) | 24.0 (22.0-25.8) |
| 60-day | 11.6 (10.9-12.4) | 13.7 (12.9-14.5) | 15.8 (14.8-16.8) | 17.4 (16.3-18.5) | 19.5 (18.2-20.6) | 21.0 (19.6-22.2) | 22.4 (20.9-23.8) | 23.8 (22.1-25.2) | 25.5 (23.6-27.1) | 26.7 (24.7-28.5) |

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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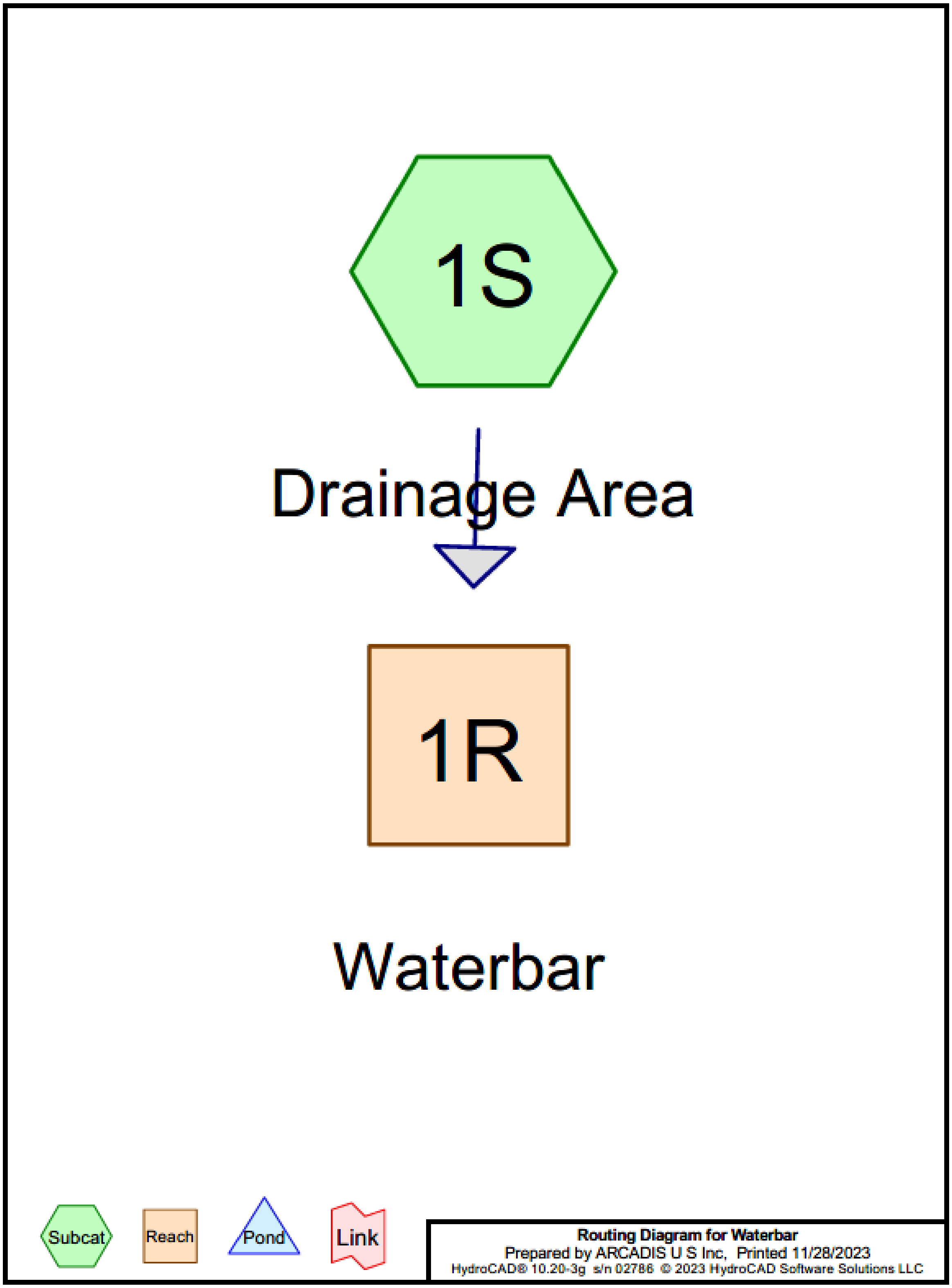
## PF graphical


1S
Drainage Area
1R
Waterbar
Subcat
Reach
Pond
Link
Routing Diagram for Waterbar
Prepared by ARCADIS U S Inc, Printed 11/28/2023
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## Summary for Subcatchment 1S: Drainage Area

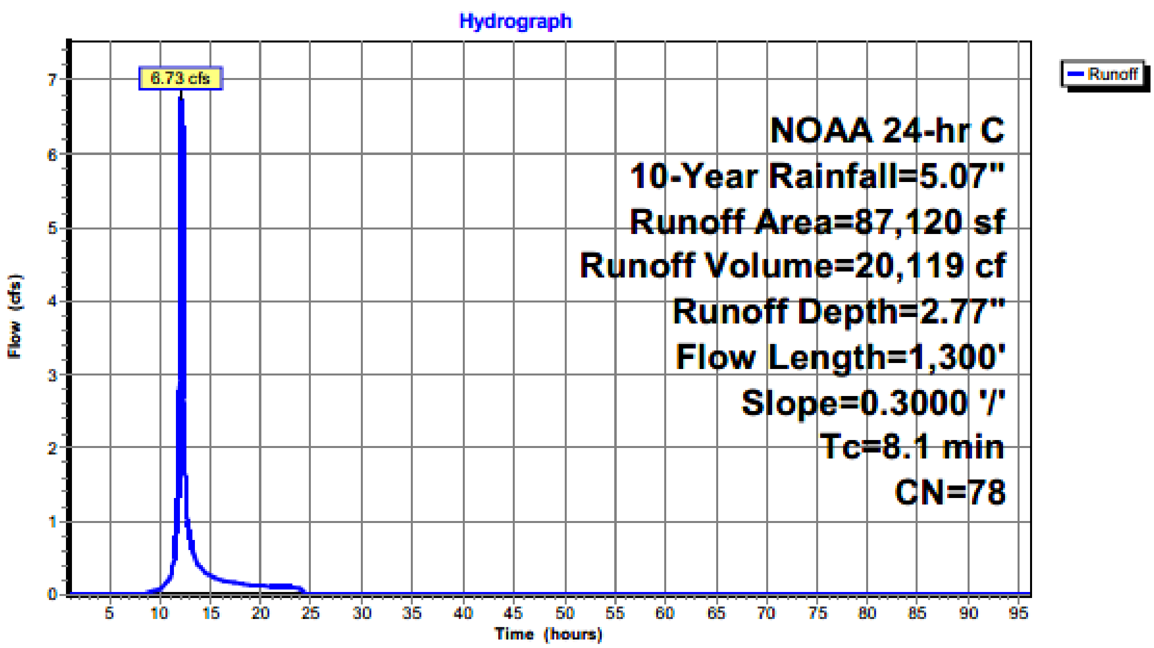
Runoff = 6.73 cfs @ 12.15 hrs, Volume= 20,119 cf, Depth= 2.77"
Routed to Reach 1R : Waterbar

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 1.00-96.00 hrs, dt= 0.01 hrs
NOAA 24-hr C 10-Year Rainfall=5.07"

| Area (sf) | CN | Description |
|---|---|---|
| 87,120 | 78 | Meadow, non-grazed, HSG D |
| 87,120 | | 100.00% Pervious Area |

| Tc (min) | Length (feet) | Slope (ft/ft) | Velocity (ft/sec) | Capacity (cfs) | Description |
|---|---|---|---|---|---|
| 2.9 | 100 | 0.3000 | 0.57 | | **Sheet Flow,** Range n= 0.130 P2= 3.33" |
| 5.2 | 1,200 | 0.3000 | 3.83 | | **Shallow Concentrated Flow,** Short Grass Pasture Kv= 7.0 fps |
| 8.1 | 1,300 | Total | | | |

### Subcatchment 1S: Drainage Area



**Waterbar** *NOAA 24-hr C 10-Year Rainfall=5.07"*
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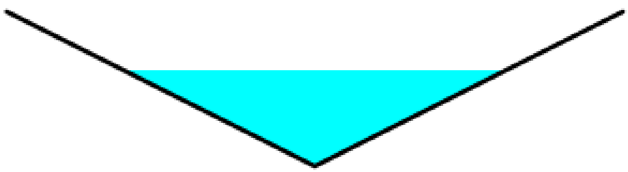
### Summary for Reach 1R: Waterbar

Inflow Area = 87,120 sf, 0.00% Impervious, Inflow Depth = 2.77" for 10-Year event
Inflow = 6.73 cfs @ 12.15 hrs, Volume= 20,119 cf
Outflow = 6.73 cfs @ 12.16 hrs, Volume= 20,119 cf, Atten= 0%, Lag= 0.1 min
Routed to nonexistent node 2R

Routing by Dyn-Stor-Ind method, Time Span= 1.00-96.00 hrs, dt= 0.01 hrs
Max. Velocity= 3.90 fps, Min. Travel Time= 0.2 min
Avg. Velocity = 1.56 fps, Avg. Travel Time= 0.5 min

Peak Storage= 86 cf @ 12.16 hrs
Average Depth at Peak Storage= 0.93' , Surface Width= 3.72'
Defined Flood Depth= 96.50' Flow Area= 571.7 sf, Capacity= 4,069.95 cfs
Bank-Full Depth= 1.50' Flow Area= 4.5 sf, Capacity= 24.16 cfs

0.00' x 1.50' deep channel, n= 0.030 Earth, grassed & winding
Side Slope Z-value= 2.0 '/' Top Width= 6.00'
Length= 50.0' Slope= 0.0200 '/'
Inlet Invert= 100.00', Outlet Invert= 99.00'




**Waterbar** *NOAA 24-hr C 10-Year Rainfall=5.07"*
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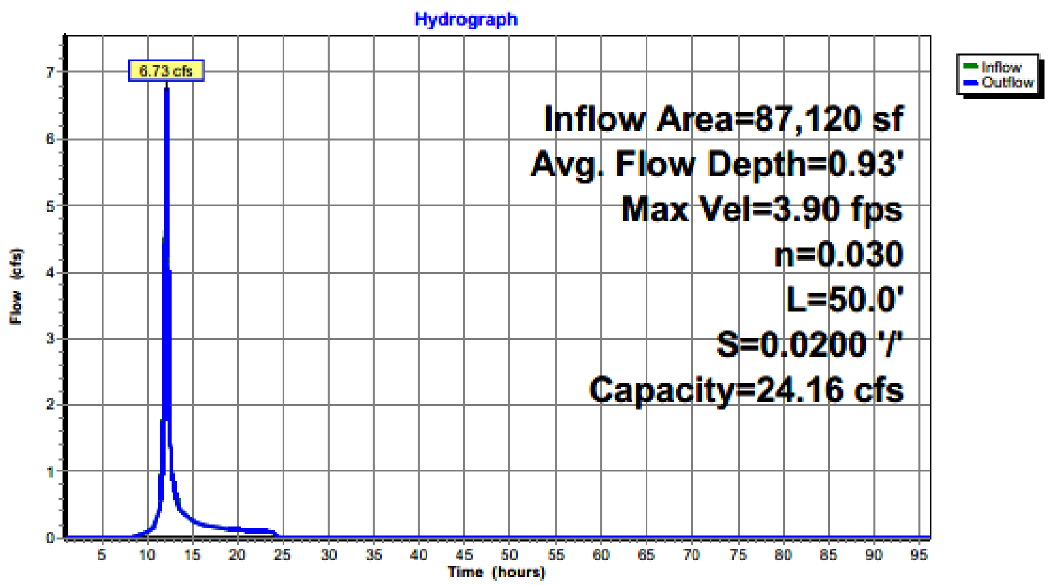
### Reach 1R: Waterbar




## C-ECM-09 Stormwater Conveyance Channel

## 1.0 Definition

A stormwater conveyance channel is a permanent, designed waterway that is shaped, sized, and lined with appropriate vegetation or structural material such that the channel safely conveys stormwater runoff within or away from a developing area.

– CAD C-ECM-09-1 Typical Waterway Cross-Sections

## 2.0 Purpose and Applicability of Best Management Practice

A stormwater conveyance channel conveys concentrated surface runoff water to a receiving channel or system without damage from erosion. They are also used to collect runoff from disturbed areas and convey it to a sediment removal facility such as a temporary sediment trap or basin (see C-SCM-11 and C-SCM-12) before discharge into receiving surface waters, as well as to divert runoff from undisturbed upslope areas and convey it around areas of earth disturbance (Pennsylvania Department of Environmental Protection [PADEP] 2012).

Stormwater conveyance channels generally apply to artificial channels, including roadside ditches and intermittent natural channels that are constructed or modified to accommodate flows generated by land development.

Implement the stormwater conveyance channel only after analyzing channel adequacy for capacity and velocity as discussed in Section 5.0 Design Criteria.

Install and stabilize stormwater conveyance channels before introducing post-development stormwater flows.

Stormwater conveyance channels do not generally apply to continuously flowing natural streams. Major streams need full design considerations and calculations. Provisions for protecting the banks of such streams are described in Vegetative Streambank Stabilization (C-ENV-01) and Structural Streambank Stabilization (C-ENV-02).

## 3.0 Planning and Considerations

The design of a channel cross-section and lining is based primarily on the volumetric flow rate and velocity of flow expected in the channel. If conditions are appropriate, grass or riprap channels are preferred. Only use concrete channels when grass-lined or riprap-lined channels prove to be infeasible.

In addition to the primary design considerations of capacity and velocity, consider these other factors when selecting a cross-section and lining: land availability, compatibility with land use and the surrounding environment, safety, maintenance requirements, outlet conditions, and the specific soil erodibility potential. If a riprap design is chosen, use filter fabric to act as a separator and stabilizer between the stone and the earth.

In steep slope situations (bed slope > 10%), consider the use of temporary slope drains (C-ECM-12). Align all channels and berms to provide positive drainage. Avoid sharp turns, high angles of confluence, and very low gradients (< 1% bed slope) wherever possible (PADEP 2012).

Design channels that require protective liners to be either trapezoidal or parabolic in cross-section. Do not use vee-shaped channels with fabric or geotextile liners due to the tendency for gaps to be left under the lining at the bottom of the channel (PADEP 2012).

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

9VAC25-875-560

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

| Table C-ECM-09-1 Design Criteria | |
|---|---|
| **Topic** | **Requirement** |
| Cross- Section Design | V-shaped channels are generally used where the quantity of water to be handled is relatively small, such as in roadside channels. A grass or sod lining will suffice where velocities in the channel are low. For steeper slopes where high velocities are encountered, a riprap lining may be appropriate.<br><br>Parabolic channels are often used where the quantity of water to be handled is larger and where space is available for a wide, shallow channel with low velocity flow.<br>Use riprap where higher velocities are expected and where some dissipation of energy (velocity) is desired.<br><br>Combinations of grass and riprap are also useful where there is continuous low flow in the channel.<br><br>Trapezoidal channels are often used where the quantity of water to be carried is large and conditions require the water to be carried at a relatively high velocity. Trapezoidal ditches are generally lined with riprap.<br><br>Figure C-ECM-09-1 and Figure C-ECM-09-2 illustrate the various types of cross-sections and channel linings. |
| Outlet Design | Consider the outlet conditions for all channels, which is particularly important for the transition from an artificial lining to a vegetated or non-vegetated lining. Ensure that appropriate measures are taken to dissipate the energy of the flow to prevent scour of the receiving channel. Also see Outlet Protection (C-ECM-15). |
| Capacity | Design all channels to satisfy MS-19 of the Virginia Erosion and Sediment Control Regulations. If channel modifications are necessary, ensure the capacity of the channel is sufficient to convey the 10-year, 24-hour frequency design storm with a freeboard of at least 0.5 foot.<br><br>If pre-development flooding problems exist, the consequences of flooding are severe, or drainage systems that convey larger storms converge with the channel in question, consider increasing the capacity beyond the 10-year, 24-hour frequency storm capacity. |

| Table C-ECM-09-1 Design Criteria | |
|---|---|
| Topic | Requirement |
| Permissible Velocity & Allowable Shear Stress | Design conveyance channels so that the velocity of flow expected from a 2-year, 24- hour frequency storm does not exceed the permissible velocity for the type of lining used.<br><br>Grass-lined channels provide good protection against erosion while also providing an aesthetic setting for conveyance of runoff. However, the velocities that grass linings can handle are much lower than those in riprap or concrete-lined channels. For grass linings, select the appropriate type of vegetation for the site conditions (e.g., drainage tolerance, shade tolerance, maintenance requirements). See Permanent Seeding (C-SSM-10) and Sodding (C-SSM-06). Where there will be a base flow in grass-lined channels, provide a stone center, a subsurface drain, or other suitable means to handle the base flow. Figure C-ECM-09-2 shows typical cross-sections for stone center channels. Refer to Riprap (C-ECM-13) to choose the correct stone size and for filter fabric specifications. Permissible velocities for non-lined and grass-lined channels are shown in Table C-ECM-15-3 and Table C-ECM-09-2.<br><br>Protect channels or outlets against erosion by vegetative means as soon after construction as practical. Ensure that vegetation is well established before diversions or other channels are discharged into grass-lined channels. Consider using turf- reinforcement mats and other rolled erosion control products (C-SSM-05) or sodding (C-SSM-06) of channels to provide erosion protection as soon after construction as possible and before the establishment of vegetation. Protect the center line of the waterway with one of these materials to avoid center gullies and to protect seedlings from erosion before establishment (New York Department of Environmental Conservation [NYDEC] 2016).<br><br>Riprap-lined channels can be designed to withstand most flow velocities by choosing a stable stone size (see C-ECM-13). Install riprap with a filter fabric or gravel (granular) underlining. Carefully design the transition from riprap lining to grass and earth linings to meet the allowable velocities of each type of lining.<br><br>The permissible velocity design method may be used for linings of channels with bed slopes less than 10%, while the allowable shear method is acceptable for all channel bed slopes (PADEP 2012). |
| Depth | Ensure the design water surface elevation of a channel receiving water from diversions or other tributary channels is equal to or less than the design water surface elevation of the diversion or other tributary channel at the point of intersection. Water surface elevation is typically noted in 0.5-foot increments.<br><br>Design the top widths of parabolic and v-shaped, grass-lined channels not to exceed 30 feet and the bottom widths of trapezoidal, grass-lined channels not to exceed<br>15 feet unless multiple or divided waterways, riprap center, or other means are provided to control meandering of low flows. |

| Table C-ECM-09-1 Design Criteria | |
|---|---|
| **Topic** | **Requirement** |
| Outlet | Protect the outlets of all channels from erosion. See Outlet Protection (C-ECM-15). |
| Calculations | Calculate the peak flow rate in accordance with the guidelines in Appendix A.<br>Determine whether the soil(s) in which the channel will be constructed have any limitations that will affect the stability of the channel or its protective lining. Soils having K factors less than or equal to 0.37 may be considered erosion-resistant; consider all others to be highly erodible (PADEP 2012).<br>Determine dimensions for roadside and median channels in accordance with applicable design procedures outlined in the latest edition of the Virginia Department of Transportation (VDOT) Drainage Manual (2021). Helpful design charts are also included in that publication to aid in the design of concrete-lined channels for many cross-sectional shapes.<br>Channel dimensions for parabolic, grass-lined channels may be determined from the tables in Appendix C-ECM-09-a.<br>Calculate the anticipated velocity using Manning's Equation in accordance with the guidelines in Appendix A and calculate the design shear stress. |

| Table C-ECM-09-2 Maximum Velocities for Grass-Lined Channels | | | |
|---|---|---|---|
| **Cover Type** | **Slope (%)** | **Erosion Resistant Soils (feet/second)** | **Easily Eroded Soils (feet/second)** |
| Bermudagrass | 0 – 5<br>5 – 10 | 6<br>5 | 4.5<br>3.8 |
| Kentucky bluegrass<br>Reed Canarygrass<br>Tall fescue | 0 – 5<br>5 – 10<br>> 10 | 5<br>4<br>3 | 3.8<br>3<br>2.3 |
| Grass-legume mixture | 0 – 5<br>5 – 10 | 4<br>3 | 3<br>2.3 |
| Red fescue | 0 – 5 | 2.5 | 1.9 |
| Sources: Virginia Department of Environmental Quality 1992; Ree 1949; Temple et al. 1987; NOVA 2007 | | | |

## 6.0 Construction Specifications

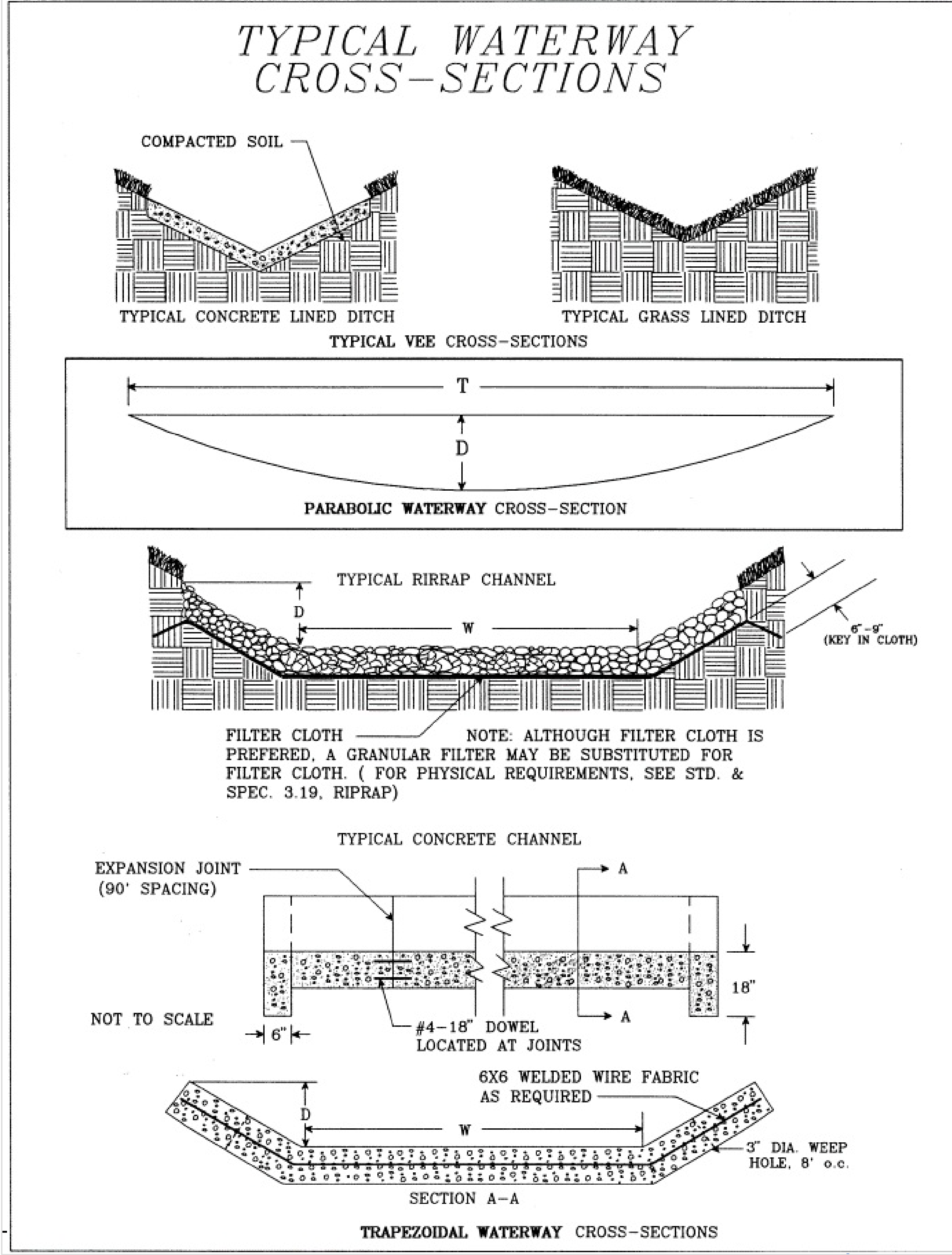
| Table C-ECM-09-3 Construction Specifications | |
|---|---|
| **Topic** | **Requirement** |
| General | Remove and properly dispose all trees, brush, stumps, roots, obstructions, and other unsuitable material.<br>Excavate or shape the channel to the proper grade and cross-section. Ensure proper compaction of any fills to prevent unequal settlement.<br>Remove and properly dispose any excess soil. |
| Grass-Lined Channels | The method used to establish grass in the ditch or channel will depend on the severity of the conditions encountered. The methods available for grass establishment are set forth in Permanent Seeding (C-SSM-10) and Sodding (C-SSM-06). Use turf reinforcement mats and other rolled erosion control products. See Soil Stabilization Blankets and Matting (C-SSM-05) to provide erosion protection as soon after construction as possible and before the establishment of vegetation (NYDEC 2016). |
| Riprap-Lined Channels | Install riprap in accordance with Riprap (C-ECM-13). |
| Concrete-Lined Channels | Construct concrete-lined channels in accordance with all applicable VDOT specifications. The following items highlight those specifications: Ensure that the subgrade is moist at the time the concrete is poured.<br>Provide traverse joints for crack control at approximately 20-foot intervals and when more than 45 minutes elapses between the times of consecutive concrete placements.<br>Ensure that all sections are at least 6 feet long. Crack control joints may be formed by using a 0.125-inch-thick removable template, by scoring or sawing to a depth of at least 0.75 inch, or by an approved leave-in type insert.<br>Install expansion joints every 100 feet. |

## 7.0 Operations and Maintenance Considerations

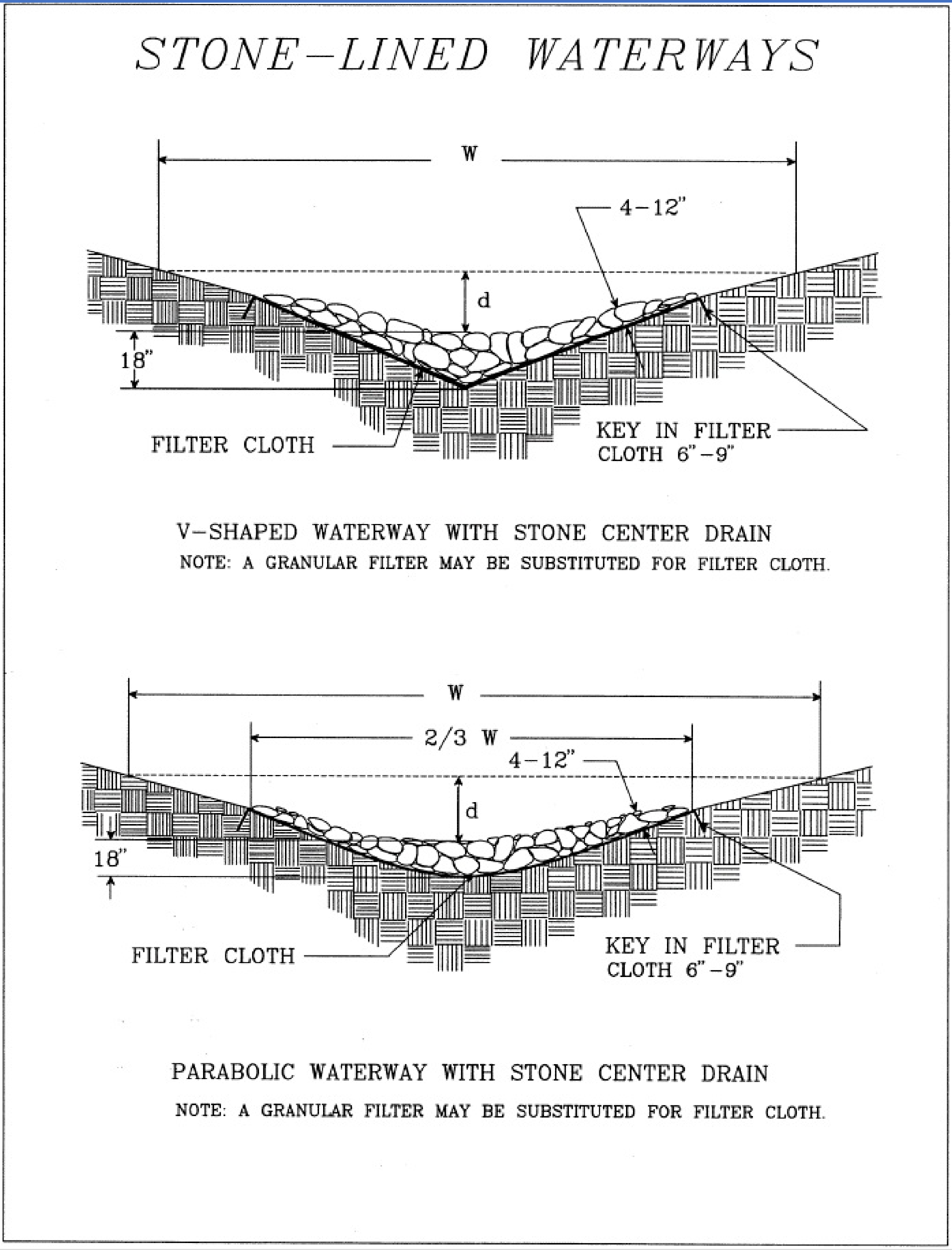
| Table C-ECM-09-4 Operation and Maintenance Specifications | |
|---|---|
| **Topic** | **Requirement** |
| Grass-Lined Channels | During initial establishment, immediately repair grass-lined channels and re-establish grass if necessary. After grass has been established, inspect the channel periodically to determine if the grass is withstanding flow velocities without damage. If the channel is to be mowed, cut the grass in the channel in a manner that will not damage the grass. |
| Riprap-Lined Channels | Periodically inspect riprap-lined channels to ensure that scour is not occurring beneath the fabric underlining of the riprap layer. Inspect the channel to determine that the stones are not dislodged by large flows. Replace any dislodged or displaced stones. |
| Concrete-Lined Channels | Periodically inspect concrete-lined channels to ensure there is no undermining of the channel. Pay particular attention to the outlet of the channel. If scour is occurring at the outlet, install appropriate measures. See Outlet Protection (C-ECM-15). |

| Table C-ECM-09-4 Operation and Maintenance Specifications | |
|---|---|
| **Topic** | **Requirement** |
| Sediment Deposition | If the channel is below a high sediment-producing area, trap the sediment before it enters the channel. Field experience has demonstrated that many newly constructed conveyance channels become damaged and require costly repairs because of improper upslope controls. If sediment is deposited in a grass-lined channel, promptly remove the sediment to prevent damage to the grass. Remove sediment deposited in riprap-lined and concrete-lined channels when the sediment reduces the capacity of the channel. |

## Figure C-ECM-09-1 Typical Waterway Sections



## *Figure C-ECM-09-2 Stone Lined Waterways*



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## 9.0 Appendix C-ECM-09-a

**Design of Parabolic Grass-Lined Channels**

Design the channel for capacity and erosion resistance. Capacity will be at a minimum when the grass is long and not mowed; this condition corresponds to V2 in Table C-ECM-09-5 below. Erosion will most likely occur when the grass is short; this condition corresponds to V1 in Table C-ECM-09-5. A design based on Table C-ECM-09-5 will result in a channel with adequate capacity when vegetation in the channel is long and thick, that will remain stable when the vegetation is short or recently mowed, and that will have adequate freeboard for the design flow.

Use the following procedure to design a grass-lined parabolic channel based on Table C-ECM-09-2 and Table C-ECM-09-5 (PADEP 2012):

1. Determine the required channel capacity (Q), which is the peak rate of runoff for the selected design storm.
2. Select an appropriate grass lining and note the maximum permissible velocity (V1) from Table C-ECM-09-2.
3. Choose the appropriate sheet of Table C-ECM-09-5 for the channel slope. Using the maximum permissible velocity (V1) and the required flow capacity (Q), read the top width (T) and the depth (D) for the correct parabolic section.
4. The top width (T), area (A), wetted perimeter (P), and hydraulic radius (R) can be calculated for the channel dimensions using the equations provided in Table C-ECM-09-6 (see Appendix C-ECM-09-b).

**Example Problem**

Design a parabolic waterway to be lined with Kentucky 31-Tall Fescue that will carry 50 cubic feet per second (cfs) on a 3% slope.

Solution:

1. Q = 50 cfs (given)
2. V1 = 5 ft./sec. for Kentucky 31-Tall Fescue (from Table C-ECM-08-2)
3. From sheet 9 of Table C-ECM-09-5 (for 3% slope): Read the top width (T) and depth (D) for Q = 50 cfs and V1 = 5.0 feet per second (fps)

$$T = 16.3 \text{ feet}$$

$$D = 1.45 \text{ feet}$$

## Table C-ECM-09-5 Design Tables for Parabolic Grass-Lined Channels

$V_1$ for RETARDANCE "D". Top Width (T), Depth (D) and $V_2$ for RETARDANCE "B".

Grade 0.25 Percent

| Q cfs | $V_1$ = 2.0 | | | $V_1$ = 2.5 | | | $V_1$ = 3.0 | | | $V_1$ = 3.5 | | | $V_1$ = 4.0 | | | $V_1$ = 4.5 | | | $V_1$ = 5.0 | | | $V_1$ = 5.5 | | | $V_1$ = 6.0 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | 11.3 | 3.27 | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 13.2 | 3.09 | 1.09 | | | | | | | | | | | | | | | | | | | | | | | | |
| 35 | 15.2 | 3.01 | 1.13 | | | | | | | | | | | | | | | | | | | | | | | | |
| 40 | 17.3 | 2.99 | 1.15 | 12.1 | 3.61 | 1.36 | | | | | | | | | | | | | | | | | | | | | |
| 45 | 19.3 | 2.94 | 1.18 | 13.4 | 3.49 | 1.42 | | | | | | | | | | | | | | | | | | | | | |
| 50 | 21.4 | 2.93 | 1.18 | 14.7 | 3.41 | 1.48 | | | | | | | | | | | | | | | | | | | | | |
| 55 | 23.5 | 2.92 | 1.19 | 16.1 | 3.38 | 1.50 | | | | | | | | | | | | | | | | | | | | | |
| 60 | 25.5 | 2.89 | 1.21 | 17.5 | 3.35 | 1.52 | | | | | | | | | | | | | | | | | | | | | |
| 65 | 27.6 | 2.89 | 1.21 | 18.8 | 3.30 | 1.56 | | | | | | | | | | | | | | | | | | | | | |
| 70 | 29.7 | 2.89 | 1.21 | 20.2 | 3.28 | 1.57 | 14.4 | 3.98 | 1.81 | | | | | | | | | | | | | | | | | | |
| 75 | 31.7 | 2.87 | 1.23 | 21.6 | 3.27 | 1.58 | 15.3 | 3.91 | 1.86 | | | | | | | | | | | | | | | | | | |
| 80 | 33.8 | 2.87 | 1.23 | 23.0 | 3.26 | 1.58 | 16.3 | 3.90 | 1.87 | | | | | | | | | | | | | | | | | | |
| 90 | 38.0 | 2.87 | 1.23 | 25.8 | 3.25 | 1.60 | 18.1 | 3.80 | 1.94 | | | | | | | | | | | | | | | | | | |
| 100 | 42.1 | 2.85 | 1.24 | 28.6 | 3.23 | 1.61 | 20.0 | 3.76 | 1.98 | | | | | | | | | | | | | | | | | | |
| 110 | 46.3 | 2.85 | 1.24 | 31.4 | 3.22 | 1.62 | 21.9 | 3.73 | 2.01 | | | | | | | | | | | | | | | | | | |
| 120 | 50.4 | 2.84 | 1.25 | 34.1 | 3.20 | 1.64 | 23.9 | 3.73 | 2.00 | 17.0 | 4.47 | 2.34 | | | | | | | | | | | | | | | |
| 130 | 54.6 | 2.85 | 1.24 | 36.9 | 3.19 | 1.64 | 25.8 | 3.70 | 2.02 | 18.3 | 4.42 | 2.39 | | | | | | | | | | | | | | | |
| 140 | 58.7 | 2.84 | 1.25 | 39.7 | 3.19 | 1.65 | 27.7 | 3.68 | 2.04 | 19.6 | 4.37 | 2.43 | | | | | | | | | | | | | | | |
| 150 | 62.9 | 2.85 | 1.25 | 42.5 | 3.19 | 1.65 | 29.6 | 3.67 | 2.06 | 20.9 | 4.33 | 2.47 | | | | | | | | | | | | | | | |
| 160 | 67.0 | 2.84 | 1.25 | 45.3 | 3.18 | 1.65 | 31.6 | 3.68 | 2.05 | 22.2 | 4.30 | 2.50 | | | | | | | | | | | | | | | |
| 170 | 71.1 | 2.84 | 1.26 | 48.1 | 3.18 | 1.65 | 33.5 | 3.66 | 2.07 | 23.5 | 4.27 | 2.53 | 18.5 | 4.95 | 2.76 | | | | | | | | | | | | |
| 180 | 75.3 | 2.84 | 1.25 | 50.9 | 3.18 | 1.66 | 35.4 | 3.65 | 2.08 | 24.8 | 4.24 | 2.55 | 19.5 | 4.90 | 2.80 | | | | | | | | | | | | |
| 190 | 79.4 | 2.84 | 1.26 | 53.7 | 3.18 | 1.66 | 37.4 | 3.66 | 2.07 | 26.1 | 4.22 | 2.57 | 20.5 | 4.87 | 2.84 | | | | | | | | | | | | |
| 200 | 83.5 | 2.84 | 1.26 | 56.5 | 3.18 | 1.66 | 39.3 | 3.65 | 2.08 | 27.3 | 4.23 | 2.56 | 21.5 | 4.83 | 2.87 | | | | | | | | | | | | |
| 220 | 91.8 | 2.84 | 1.26 | 62.1 | 3.18 | 1.66 | 43.2 | 3.65 | 2.08 | 30.1 | 4.19 | 2.60 | 23.5 | 4.77 | 2.92 | | | | | | | | | | | | |
| 240 | 100.0 | 2.83 | 1.26 | 67.6 | 3.17 | 1.67 | 47.0 | 3.63 | 2.10 | 32.7 | 4.15 | 2.64 | 25.5 | 4.72 | 2.97 | | | | | | | | | | | | |
| 260 | 108.3 | 2.84 | 1.26 | 73.2 | 3.17 | 1.67 | 50.9 | 3.63 | 2.10 | 35.4 | 4.15 | 2.64 | 27.5 | 4.68 | 3.01 | 21.4 | 5.50 | 3.29 | | | | | | | | | |
| 280 | 116.6 | 2.84 | 1.26 | 78.8 | 3.17 | 1.67 | 54.8 | 3.63 | 2.10 | 38.1 | 4.14 | 2.64 | 29.5 | 4.64 | 3.05 | 22.9 | 5.44 | 3.35 | | | | | | | | | |
| 300 | 124.8 | 2.84 | 1.26 | 84.4 | 3.17 | 1.67 | 58.6 | 3.62 | 2.11 | 40.8 | 4.14 | 2.65 | 31.5 | 4.61 | 3.08 | 24.5 | 5.42 | 3.37 | | | | | | | | | |

$V_1$ for RETARDANCE "D". Top Width (T), Depth (D) and $V_2$ for RETARDANCE "B".

Grade 0.50 Percent

| Q cfs | $V_1$ = 2.0 | | | $V_1$ = 2.5 | | | $V_1$ = 3.0 | | | $V_1$ = 3.5 | | | $V_1$ = 4.0 | | | $V_1$ = 4.5 | | | $V_1$ = 5.0 | | | $V_1$ = 5.5 | | | $V_1$ = 6.0 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ |
| 15 | 10.2 | 2.28 | 0.95 | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 13.3 | 2.18 | 1.02 | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | 16.5 | 2.15 | 1.05 | 10.5 | 2.60 | 1.35 | | | | | | | | | | | | | | | | | | | | | |
| 30 | 19.7 | 2.12 | 1.06 | 12.4 | 2.51 | 1.42 | 9.5 | 2.91 | 1.60 | | | | | | | | | | | | | | | | | | |
| 35 | 22.8 | 2.09 | 1.09 | 14.3 | 2.45 | 1.48 | 10.9 | 2.81 | 1.69 | | | | | | | | | | | | | | | | | | |
| 40 | 26.0 | 2.08 | 1.09 | 16.3 | 2.44 | 1.49 | 12.3 | 2.74 | 1.76 | | | | | | | | | | | | | | | | | | |
| 45 | 29.2 | 2.08 | 1.10 | 18.2 | 2.41 | 1.52 | 13.7 | 2.69 | 1.81 | | | | | | | | | | | | | | | | | | |
| 50 | 32.4 | 2.08 | 1.10 | 20.2 | 2.40 | 1.53 | 15.1 | 2.64 | 1.86 | 11.1 | 3.22 | 2.07 | | | | | | | | | | | | | | | |
| 55 | 35.6 | 2.08 | 1.11 | 22.1 | 2.38 | 1.55 | 16.6 | 2.64 | 1.86 | 12.0 | 3.11 | 2.18 | | | | | | | | | | | | | | | |
| 60 | 38.8 | 2.08 | 1.11 | 24.1 | 2.38 | 1.55 | 18.0 | 2.61 | 1.90 | 13.0 | 3.07 | 2.23 | | | | | | | | | | | | | | | |
| 65 | 42.0 | 2.08 | 1.11 | 26.0 | 2.36 | 1.57 | 19.5 | 2.61 | 1.89 | 14.0 | 3.03 | 2.27 | | | | | | | | | | | | | | | |
| 70 | 45.2 | 2.08 | 1.11 | 28.0 | 2.36 | 1.57 | 20.9 | 2.59 | 1.92 | 15.0 | 3.01 | 2.31 | | | | | | | | | | | | | | | |
| 75 | 48.4 | 2.08 | 1.11 | 29.9 | 2.35 | 1.59 | 22.4 | 2.59 | 1.92 | 16.0 | 2.98 | 2.34 | 12.7 | 3.48 | 2.52 | | | | | | | | | | | | |
| 80 | 51.6 | 2.08 | 1.11 | 31.9 | 2.36 | 1.58 | 23.8 | 2.58 | 1.94 | 17.0 | 2.96 | 2.36 | 13.4 | 3.41 | 2.60 | | | | | | | | | | | | |
| 90 | 57.9 | 2.07 | 1.12 | 35.8 | 2.35 | 1.59 | 26.7 | 2.56 | 1.96 | 19.1 | 2.95 | 2.37 | 15.0 | 3.37 | 2.64 | | | | | | | | | | | | |
| 100 | 64.3 | 2.07 | 1.11 | 39.7 | 2.34 | 1.60 | 29.6 | 2.55 | 1.97 | 21.1 | 2.92 | 2.42 | 16.5 | 3.31 | 2.72 | 13.3 | 3.77 | 2.96 | | | | | | | | | |
| 110 | 70.7 | 2.08 | 1.11 | 43.6 | 2.34 | 1.61 | 32.6 | 2.56 | 1.96 | 23.2 | 2.92 | 2.42 | 18.1 | 3.29 | 2.75 | 14.5 | 3.70 | 3.05 | | | | | | | | | |
| 120 | 77.0 | 2.07 | 1.12 | 47.5 | 2.33 | 1.61 | 35.5 | 2.56 | 1.97 | 25.2 | 2.89 | 2.45 | 19.6 | 3.24 | 2.81 | 15.7 | 3.64 | 3.12 | | | | | | | | | |
| 130 | 83.4 | 2.08 | 1.12 | 51.5 | 2.34 | 1.61 | 38.4 | 2.55 | 1.98 | 27.3 | 2.90 | 2.45 | 21.2 | 3.23 | 2.82 | 16.9 | 3.60 | 3.18 | | | | | | | | | |
| 140 | 89.7 | 2.08 | 1.12 | 55.4 | 2.34 | 1.61 | 41.3 | 2.55 | 1.98 | 29.3 | 2.88 | 2.47 | 22.8 | 3.22 | 2.84 | 18.1 | 3.56 | 3.23 | | | | | | | | | |
| 150 | 96.0 | 2.08 | 1.12 | 59.3 | 2.34 | 1.61 | 44.2 | 2.55 | 1.99 | 31.4 | 2.88 | 2.47 | 24.3 | 3.19 | 2.88 | 19.4 | 3.56 | 3.23 | 15.5 | 4.09 | 3.52 | | | | | | |
| 160 | 102.3 | 2.08 | 1.12 | 63.2 | 2.34 | 1.61 | 47.1 | 2.54 | 1.99 | 33.5 | 2.89 | 2.47 | 25.9 | 3.19 | 2.88 | 20.6 | 3.53 | 3.27 | 16.4 | 4.02 | 3.60 | | | | | | |
| 170 | 108.6 | 2.08 | 1.12 | 67.1 | 2.34 | 1.62 | 50.0 | 2.54 | 1.99 | 35.5 | 2.87 | 2.48 | 27.5 | 3.19 | 2.89 | 21.9 | 3.54 | 3.27 | 17.4 | 4.01 | 3.62 | | | | | | |
| 180 | 114.9 | 2.08 | 1.12 | 70.9 | 2.33 | 1.62 | 52.9 | 2.54 | 1.99 | 37.6 | 2.88 | 2.48 | 29.1 | 3.19 | 2.89 | 23.1 | 3.51 | 3.30 | 18.3 | 3.96 | 3.69 | | | | | | |
| 190 | 121.2 | 2.08 | 1.12 | 74.8 | 2.33 | 1.62 | 55.8 | 2.54 | 2.00 | 39.6 | 2.87 | 2.49 | 30.6 | 3.16 | 2.92 | 24.3 | 3.49 | 3.34 | 19.3 | 3.96 | 3.70 | | | | | | |
| 200 | 127.4 | 2.08 | 1.13 | 78.7 | 2.33 | 1.62 | 58.7 | 2.54 | 2.00 | 41.7 | 2.87 | 2.49 | 32.2 | 3.16 | 2.93 | 25.6 | 3.50 | 3.33 | 20.2 | 3.91 | 3.77 | 16.8 | 4.48 | 3.96 | | | |
| 220 | 140.0 | 2.08 | 1.13 | 86.5 | 2.33 | 1.62 | 64.5 | 2.54 | 2.00 | 45.8 | 2.87 | 2.50 | 35.4 | 3.16 | 2.93 | 28.1 | 3.49 | 3.35 | 22.1 | 3.87 | 3.83 | 18.3 | 4.39 | 4.08 | | | |
| 240 | 152.6 | 2.08 | 1.13 | 94.3 | 2.33 | 1.63 | 70.3 | 2.54 | 2.01 | 49.9 | 2.86 | 2.51 | 38.6 | 3.16 | 2.93 | 30.6 | 3.48 | 3.36 | 24.1 | 3.87 | 3.84 | 19.9 | 4.36 | 4.12 | | | |
| 260 | 165.2 | 2.08 | 1.13 | 102.1 | 2.33 | 1.63 | 76.1 | 2.54 | 2.01 | 54.0 | 2.86 | 2.51 | 41.7 | 3.15 | 2.95 | 33.1 | 3.47 | 3.38 | 26.0 | 3.84 | 3.88 | 21.5 | 4.34 | 4.15 | | | |
| 280 | 177.7 | 2.08 | 1.13 | 109.8 | 2.33 | 1.63 | 81.9 | 2.54 | 2.01 | 58.2 | 2.87 | 2.50 | 44.9 | 3.15 | 2.95 | 35.6 | 3.46 | 3.39 | 28.0 | 3.84 | 3.88 | 23.0 | 4.28 | 4.24 | 19.0 | 4.88 | 4.50 |
| 300 | 190.3 | 2.08 | 1.13 | 117.6 | 2.33 | 1.63 | 87.7 | 2.54 | 2.01 | 62.3 | 2.86 | 2.51 | 48.0 | 3.14 | 2.97 | 38.1 | 3.45 | 3.40 | 29.9 | 3.82 | 3.92 | 24.6 | 4.27 | 4.26 | 20.2 | 4.80 | 4.61 |

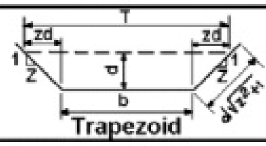
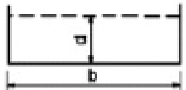
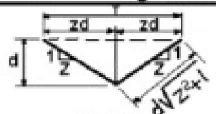
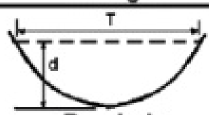
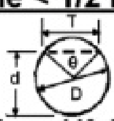
$V_1$ for RETARDANCE "D". Top Width (T), Depth (D) and $V_2$ for RETARDANCE "B".

Grade 0.75 Percent

| Q cfs | $V_1$ = 2.0 | | | $V_1$ = 2.5 | | | $V_1$ = 3.0 | | | $V_1$ = 3.5 | | | $V_1$ = 4.0 | | | $V_1$ = 4.5 | | | $V_1$ = 5.0 | | | $V_1$ = 5.5 | | | $V_1$ = 6.0 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ | T | D | $V_2$ |
| 15 | 13.7 | 1.76 | 0.92 | 8.0 | 2.22 | 1.24 | | | | | | | | | | | | | | | | | | | | | |
| 20 | 18.2 | 1.75 | 0.93 | 10.4 | 2.10 | 1.35 | | | | | | | | | | | | | | | | | | | | | |
| 25 | 22.6 | 1.73 | 0.95 | 12.8 | 2.03 | 1.42 | 9.5 | 2.33 | 1.66 | | | | | | | | | | | | | | | | | | |
| 30 | 27.1 | 1.73 | 0.95 | 15.3 | 2.02 | 1.44 | 11.2 | 2.25 | 1.76 | 8.9 | 2.56 | 1.94 | | | | | | | | | | | | | | | |
| 35 | 31.5 | 1.72 | 0.96 | 17.8 | 2.01 | 1.45 | 13.0 | 2.23 | 1.79 | 10.2 | 2.47 | 2.05 | | | | | | | | | | | | | | | |
| 40 | 36.0 | 1.72 | 0.96 | 20.2 | 1.98 | 1.48 | 14.8 | 2.21 | 1.81 | 11.6 | 2.44 | 2.09 | | | | | | | | | | | | | | | |
| 45 | 40.4 | 1.71 | 0.96 | 22.7 | 1.98 | 1.49 | 16.5 | 2.17 | 1.86 | 12.9 | 2.39 | 2.16 | | | | | | | | | | | | | | | |
| 50 | 44.9 | 1.72 | 0.96 | 25.2 | 1.98 | 1.49 | 18.3 | 2.16 | 1.87 | 14.3 | 2.38 | 2.18 | 10.6 | 2.82 | 2.47 | | | | | | | | | | | | |
| 55 | 49.3 | 1.72 | 0.96 | 27.6 | 1.96 | 1.51 | 20.1 | 2.16 | 1.88 | 15.7 | 2.37 | 2.19 | 11.6 | 2.80 | 2.51 | | | | | | | | | | | | |
| 60 | 53.7 | 1.72 | 0.97 | 30.1 | 1.96 | 1.51 | 21.9 | 2.16 | 1.89 | 17.1 | 2.36 | 2.20 | 12.5 | 2.73 | 2.61 | | | | | | | | | | | | |
| 65 | 58.1 | 1.72 | 0.97 | 32.5 | 1.95 | 1.52 | 23.6 | 2.14 | 1.92 | 18.4 | 2.33 | 2.25 | 13.5 | 2.71 | 2.63 | 11.2 | 3.04 | 2.83 | | | | | | | | | |
| 70 | 62.5 | 1.72 | 0.97 | 35.0 | 1.96 | 1.52 | 25.4 | 2.14 | 1.92 | 19.8 | 2.33 | 2.25 | 14.4 | 2.66 | 2.71 | 12.0 | 3.01 | 2.87 | | | | | | | | | |
| 75 | 66.9 | 1.72 | 0.97 | 37.4 | 1.95 | 1.53 | 27.2 | 2.14 | 1.92 | 21.2 | 2.33 | 2.26 | 15.4 | 2.65 | 2.73 | 12.8 | 2.99 | 2.91 | | | | | | | | | |
| 80 | 71.2 | 1.71 | 0.97 | 39.9 | 1.95 | 1.53 | 29.0 | 2.14 | 1.92 | 22.5 | 2.31 | 2.29 | 16.4 | 2.65 | 2.74 | 13.5 | 2.92 | 3.01 | | | | | | | | | |
| 90 | 80.0 | 1.71 | 0.97 | 44.8 | 1.95 | 1.53 | 32.5 | 2.12 | 1.94 | 25.3 | 2.31 | 2.29 | 18.4 | 2.63 | 2.76 | 15.1 | 2.89 | 3.07 | 12.4 | 3.26 | 3.30 | | | | | | |
| 100 | 88.8 | 1.72 | 0.98 | 49.7 | 1.95 | 1.54 | 36.1 | 2.13 | 1.94 | 28.1 | 2.31 | 2.29 | 20.4 | 2.62 | 2.78 | 16.7 | 2.86 | 3.11 | 13.7 | 3.22 | 3.36 | | | | | | |
| 110 | 97.6 | 1.72 | 0.98 | 54.7 | 1.95 | 1.53 | 39.7 | 2.13 | 1.94 | 30.8 | 2.30 | 2.31 | 22.4 | 2.61 | 2.79 | 18.3 | 2.84 | 3.15 | 14.9 | 3.15 | 3.48 | | | | | | |
| 120 | 106.3 | 1.72 | 0.98 | 59.6 | 1.95 | 1.54 | 43.2 | 2.12 | 1.95 | 33.6 | 2.30 | 2.31 | 24.4 | 2.61 | 2.81 | 19.9 | 2.82 | 3.18 | 16.2 | 3.13 | 3.52 | 13.4 | 3.49 | 3.81 | | | |
| 130 | 115.0 | 1.72 | 0.98 | 64.5 | 1.95 | 1.54 | 46.8 | 2.12 | 1.95 | 36.4 | 2.30 | 2.31 | 26.3 | 2.58 | 2.85 | 21.5 | 2.81 | 3.20 | 17.5 | 3.11 | 3.55 | 14.5 | 3.49 | 3.82 | | | |
| 140 | 123.7 | 1.72 | 0.98 | 69.4 | 1.95 | 1.54 | 50.3 | 2.12 | 1.96 | 39.1 | 2.29 | 2.33 | 28.3 | 2.58 | 2.85 | 23.1 | 2.80 | 3.22 | 18.7 | 3.07 | 3.63 | 15.5 | 3.44 | 3.91 | | | |

## 10.0 Appendix C-ECM-09-b

**Table C-ECM-09-6 Geometric Elements of Channel Sections**

| Section | Area a | Wetted Perimeter P | Hydraulic Radius r | Top Width T |
|---|---|---|---|---|
|  Trapezoid | $bd + zd^2$ | $b + 2d\sqrt{z^2+1}$ | $\frac{bd + zd^2}{b + 2d\sqrt{z^2+1}}$ | $b + 2zd$ |
|  Rectangle | $bd$ | $b + 2d$ | $\frac{bd}{b + 2d}$ | $b$ |
|  Triangle | $zd^2$ | $2d\sqrt{z^2+1}$ | $\frac{zd}{2\sqrt{z^2+1}}$ | $2zd$ |
|  Parabola | $\frac{2}{3}dT$ | $T + \frac{8d^2}{3T}$ [1] | $\frac{2dT^2}{3T^2+8d^2}$ [1] | $\frac{3a}{2d}$ |
|  Circle < 1/2 full [2] | $\frac{D^2}{8}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ | $\frac{\pi D\theta}{360}$ | $\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ | $D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$ |
|  Circle > 1/2 full [3] | $\frac{D^2}{8}\left(2\pi - \frac{\pi\theta}{180} + \sin\theta\right)$ | $\frac{\pi D(360-\theta)}{360}$ | $\frac{45D}{\pi(360-\theta)}\left(2\pi - \frac{\pi\theta}{180} + \sin\theta\right)$ | $D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$ |

[1] Satisfactory approximation for the interval $0 < d/T \leq 0.25$
When $d/T > 0.25$, use $p = 1/2\sqrt{16d^2 + T^2} + \frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta = 4\sin^{-1}\sqrt{d/D}$
[3] $\theta = 4\cos^{-1}\sqrt{d/D}$
Insert $\theta$ in degrees in above equations

National Engineering Handbook, Section 5, ES-33

*Source: PADEP 2012*

# C-ECM-10 Subsurface Drain

## 1.0 Definition

A subsurface drain is a perforated conduit (such as pipe, tubing, or tile) installed below grade to intercept, collect, and convey excess groundwater to a satisfactory outlet location (North Carolina Sediment Control Division et al. 2013).

– CAD C-ECM-10-1 Subsurface Drain Layout and CAD C-ECM-10-2 Effect of Subsurface Drainage on the Water Table

– CAD C-ECM-10-3 Surface Inlets

– CAD C-ECM-10-4 Drainage Envelope

– CAD C-ECM-10-8 Relief Drain Spacing

– CAD C-ECM-10-9 Interceptor Drain Spacing

## 2.0 Purpose and Applicability of Best Management Practice

Subsurface drains are used to:

1. Improve the soil-water conditions for vegetative growth by lowering the water table (New Jersey Department of Agriculture 2017).
2. Prevent sloping soils from becoming excessively wet and subject to sloughing.
3. Improve the quality of the growth medium in excessively wet areas by lowering the water table.
4. Drain stormwater detention areas or structures. Install cleanouts where subsurface drains are used to drain stormwater detention areas or structures.

Use of subsurface drains applies wherever excess water needs to be removed from the soil to improve soil-water conditions. Ensure the soil is sufficiently deep and permeable to allow installation of an effective system. Provide an outlet for the drainage system either consisting of a gravity outlet or by pumping. These standards do not apply to building foundation drains, storm drainage systems, or deep excavations (North Carolina Sediment Control Division et al. 2013).

Design the outlet of the subsurface drain to safely handle the quantity and quality of effluent to be released considering possible impacts above or below the point of discharge (New Jersey Department of Agriculture 2017).

## 3.0 Planning and Considerations

Subsurface drainage systems are broken down into two types (relief drains and interceptor drains) as described in Table C-ECM-10-1.

**Table C-ECM-10-1 Design Considerations for Subsurface Drains**

| Type | Notes on Proper Use |
|---|---|
| Relief Drains | Relief drains are used either to lower the water table to improve the growth of vegetation or to remove surface water in areas that are relatively flat and large. Relief drains are installed along a slope and drain in the direction of the slope. Relief drains can be installed in a gridiron pattern, a herringbone pattern, or a random pattern (see Plate 1). The system can be designed for either a single or dual purpose by providing a subirrigation/drainage system in addition to altering the elevation of the water table (North Carolina Sediment Control Division et al. 2013). |
| Interceptor Drains | Interceptor drains are used to remove water as it seeps down a slope to prevent the soil from becoming saturated and subject to slippage. Interceptor drains are installed across a slope (perpendicular) and drain to the side of the slope. Interceptor drains usually consist of a single pipe or series of single pipes instead of a patterned layout (see Plate 2). Interceptor drains can also be used to stabilize shallow foundations such as paved channels of construction access roads (North Carolina Sediment Control Division et al. 2013). |

## 4.0 Stormwater Performance Summary

**MS-9: WATER SEEPS** – Whenever water seeps from a slope face, adequate drainage or other protection shall be provided.

**MS-16: UTILITY CONSTRUCTION** – Underground utility lines shall be installed in accordance with the following standards in addition to other applicable criteria.

9VAC25-875-560.

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: LOW**

## 5.0 Design Criteria

| Table C-ECM-09-2 Design Criteria for Subsurface Drains | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Location | Tree roots can often clog subsurface drain systems. Consequently, locate subsurface drains such that there are no trees within 50 feet of the drain. |
| Capacity of Drains | The capacity of the underground drainage system is determined by calculating the maximum rate of groundwater or overland flow to be intercepted. |
| Relief Drains | Locate relief drains through the centers of wet areas. Install relief drains in the same direction as the slope and evenly throughout the wet area.<br>Install relief drains in a uniform pattern such that the drains remove a minimum of 1 inch of groundwater in 24 hours (0.042 cubic foot per second [cfs]/acre). Increase the design capacity accordingly to accommodate any surface water that enters the system directly (see Plate 3). |
| Interceptor Drains | Locate interceptor drains on the uphill sides of wet, unstable areas. Install interceptor drains on a positive grade across the slope and drain to the side of the slope.<br>Design interceptor drains or relief drains installed in a random pattern to remove a minimum of 1.5 cfs/1,000 feet of length. Increase the inflow rate for sloping land according to the values in Table C-ECM-10-3. In addition, if a flowing spring or surface water enters directly into the system, accommodate this flow by increasing the design capacity to address this flow (see Plate 3). |
| Velocity and Grade | To prevent silting, design the drains with a minimum velocity of 1.4 feet per second. Grade the line to achieve at least this velocity. Avoid steep grades. Table C-ECM-10-4 lists maximum velocities for various soil textures. |
| Envelopes | Use envelopes around all drains for proper bedding and improved flow of groundwater into the drain. Construct the envelope consisting of 3 inches of clean, washed Virginia Department of Transportation (VDOT) #68 aggregate placed completely around the drain. Encompass the stone with a filter fabric separator to prevent the migration of surrounding soil particles into the drain (see Plate 4). Use filter fabric that meets the physical requirements noted in Riprap (BMP C-ECM-13). |

| Table C-ECM-09-2 Design Criteria for Subsurface Drains | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Drain Size | Size subsurface drains for the required capacity using the formulas provided in Appendix A.<br>Use a minimum diameter of 4 inches for a subsurface drain. |
| Depth & Spacing | **Relief Drains** – Equally space relief drains installed in a uniform pattern between drains and install the drains at the same depth. Maximum depth is limited by the allowable load on the pipe, depth to impermeable layers in the soil, and outlet requirements. The minimum depth is 24 inches under normal conditions. Where the drain will not be subject to equipment loading or frost action, 12 inches is acceptable.<br>Spacing between drains depends on soil permeability and the depth of the drain. In general, a depth of 3 feet and a spacing of 50 feet is adequate. A more economical system may be designed, if the necessary information is available, using the equations provided in Appendix A with the figure showing the details in Plate 4.<br>**Interceptor Drain** – The depth of installation of an interceptor drain is influenced mainly by the depth to which the water table is proposed to be lowered. The maximum depth is limited by the allowable load on the pipe and the depth to an impermeable layer.<br>Minimum depth should be the same as those for relief drains.<br>One interceptor drain is usually sufficient. However, if multiple drains are to be used, determining the required spacing can be difficult. The best approach is to install the first drain. Subsequently, if seepage or high-water table problems occur downslope, install an additional drain at a suitable distance downslope. This distance can be calculated using equations provided in Appendix A with the figure showing the details in Plate 4. |
| Surface Water | Plate 3 shows two types of surface water inlets. Do not use the grated inlet where excessive sedimentation might be a problem. |
| Outlet | Design the outlet of the subsurface drain to discharge into a channel or some other watercourse, which will remove the water from the outlet. Locate the outlet above the mean water level in the receiving channel. Protect the outlet from erosion, undermining, damage from periods of submergence, and the entry of small animals into the drain.<br>Construct the outlet to consist of a 10-foot section of corrugated metal, cast iron, steel, high-density polyethylene (HDPE), or schedule 40 polyvinyl chloride (PVC) pipe without perforations. Do not use envelope material around the pipe. Bury at least two thirds of the outlet pipe length. |
| Materials | Acceptable materials for subsurface drains include perforated, continuous closed-joint conduits of HDPE, concrete, corrugated metal, asbestos cement, bituminous fiber, and PVC. Ensure the strength and durability of the pipe meet the requirements of the site in accordance with the manufacturer's specifications. |
| Source: Va. DSWC | |

| Table C-ECM-10-3 Water Removal Rates for Sloping Land* | |
|---|---|
| **Land Slope (%)** | **Water Removal Rates (cfs/1,000 feet)** |
| 2 – 5 | 1.65 |
| 6 – 12 | 1.80 |
| > 12 | 1.95 |

* These rates depend on the soil types where the drains are installed. Heavier soils may result in slower water removal rates.

Source: Va. DSWC

| Table C-ECM-10-4 Maximum Velocities for Various Soil Textures | |
|---|---|
| **Soil Texture** | **Maximum Velocity (ft./sec.)** |
| Sandy and Sandy Loam | 3.5 |
| Silt and Silt Loam | 5.0 |
| Silty Clay Loam | 6.0 |
| Clay and Clay Loam | 7.0 |
| Coarse Sand or Gravel | 9.0 |

Source: Va. DSWC

## 6.0 Construction Specifications

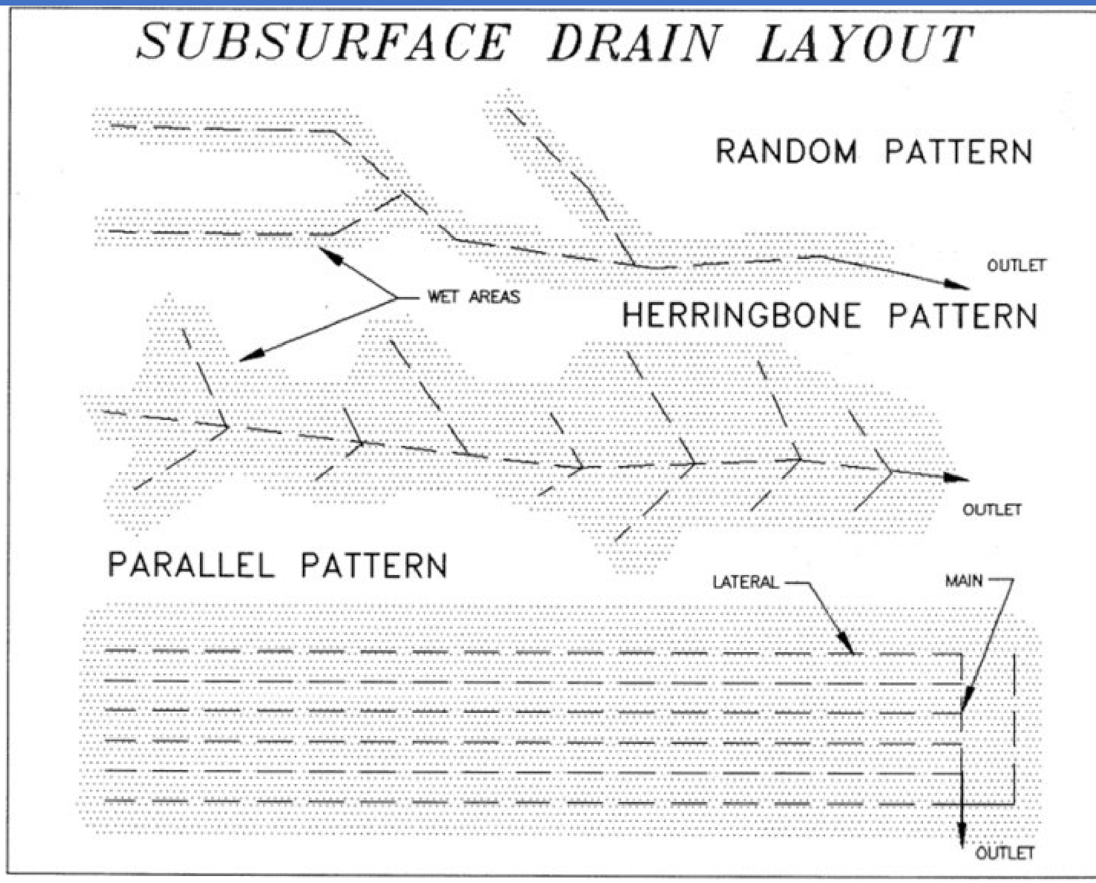
1. Construct the trench on a continuous grade with no reverse grades or low spots and to be 3 inches below the invert of the pipe.
2. Stabilize soft or yielding soils under the drain with gravel or other suitable material.
3. Do not use deformed, warped, or otherwise unsuitable pipe.
4. Place envelopes or filter material as specified with at least 3 inches of material on all sides of the pipe and place filter fabric around the envelope before backfilling.
5. Conduct backfilling immediately after placement of the pipe. No sections of pipe should remain uncovered overnight or during a rainstorm. Backfill the trench so that the pipe is not displaced or damaged.
6. Ensure the outlet section of the drain consists of at least 10 feet of non-perforated corrugated metal, cast iron, steel, smooth-walled HDPE, self-reinforced polypropylene (SRPP), or schedule 40 PVC pipe. Bury at least two thirds of its length.
7. Place a suitable trash/animal guard securely measure over the pipe outlet to keep out smaller animals such as rodents (North Carolina Sediment Control Division et al. 2013).
8. Do not exceed 500 feet for the interval/spacing between riser pipes used for flushing.

## 7.0 Operations and Maintenance Considerations

1. Periodically check subsurface drains to ensure that they are free-flowing and not clogged with sediment and that animals are not living in the pipes (North Carolina Sediment Control Division et al. 2013).
2. Keep the outlet clean and free of debris; clear away debris from trash/animal guard immediately as necessary.

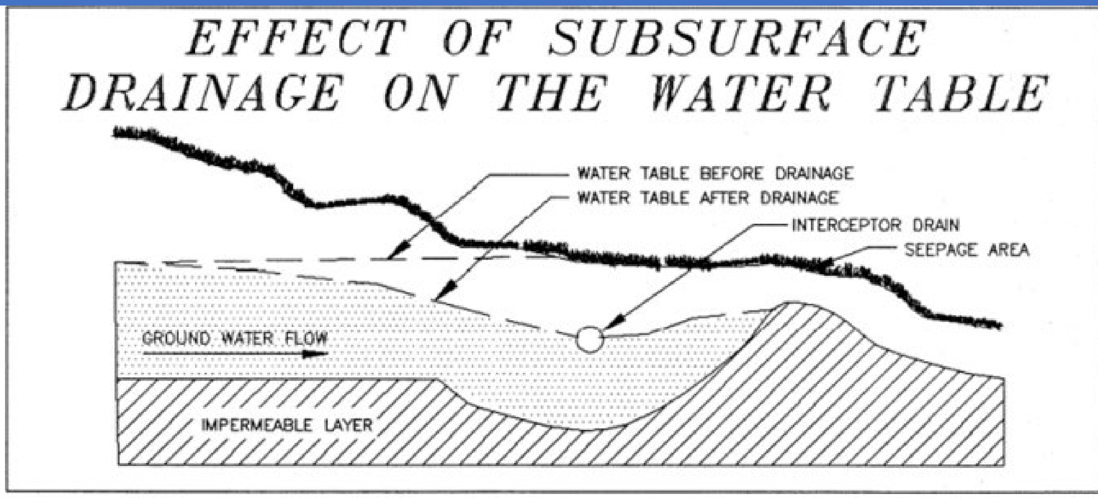
3. Keep surface inlets open and free of sediment and other debris and clear away sediment and other debris immediately as necessary.
4. Trees located too close to a subsurface drain often clog the system with their roots. If a drain becomes clogged, relocate the drain.
5. Where drains are crossed by heavy vehicles, check the line to ensure that it is not crushed.
6. Inspect the subsurface drains and maintain the system with periodic high-pressure flushing via the cleanouts.

***Figure C-ECM-10-1 Subsurface Drain Layout***



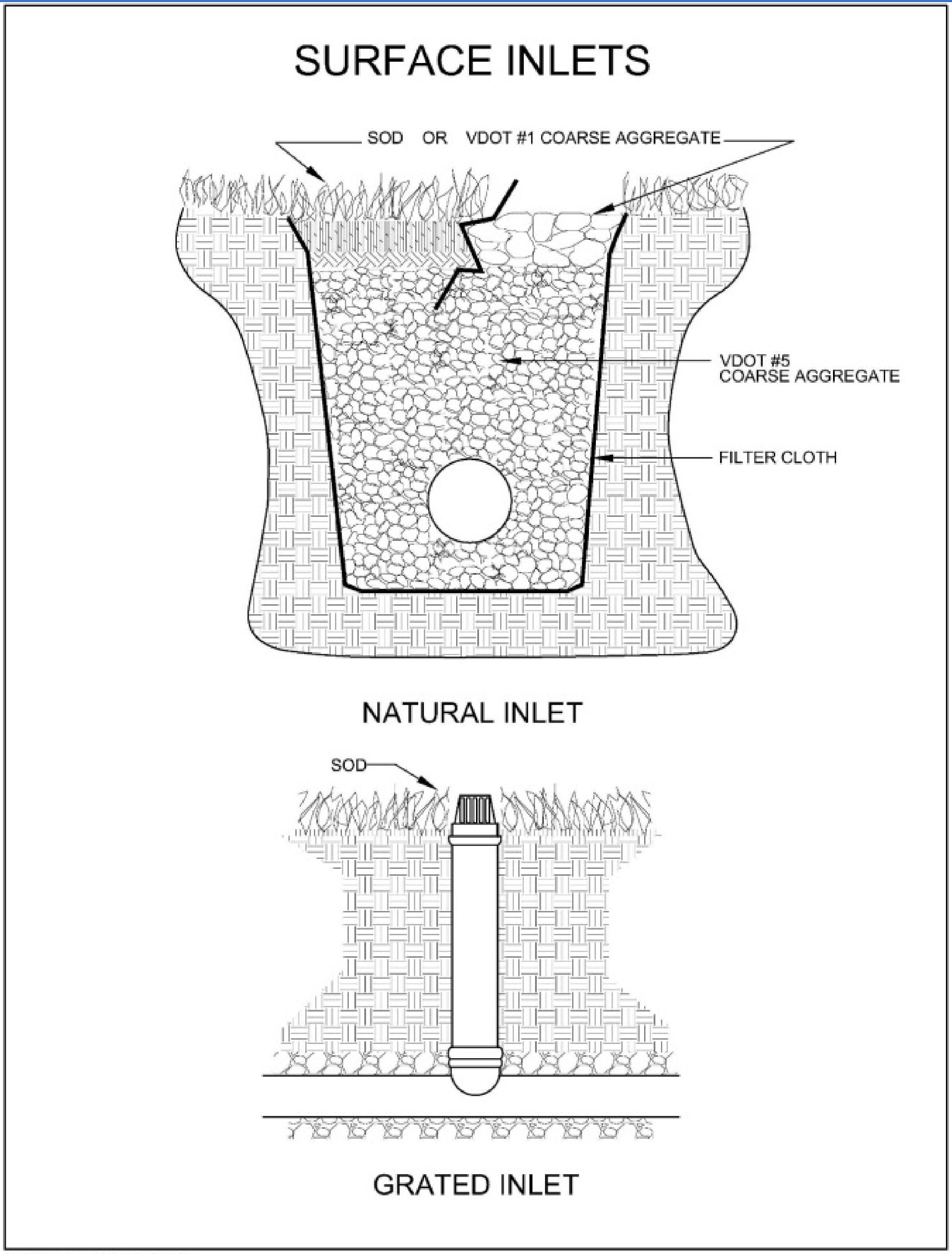

*Source: USDA-SCS*

**Figure C-ECM-10-2 Effects of Subsurface Drainage on the Water Line**




Source: USDA-SCS

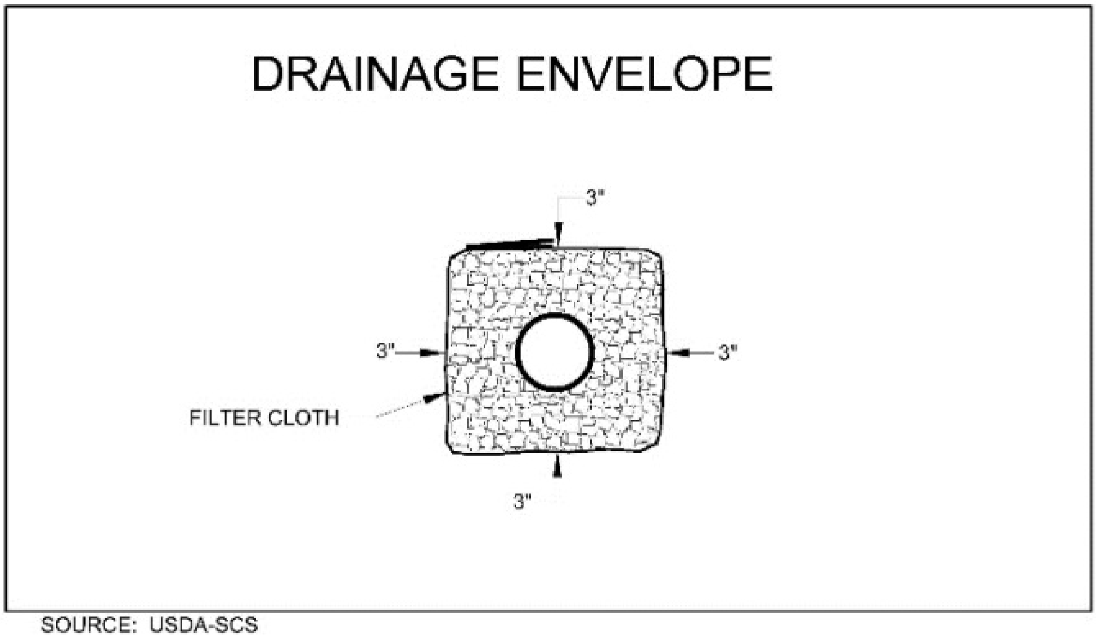
**Figure C-ECM-10-3 Surface Inlets**




SOURCE: USDA-SCS

*Source: USDA-SCS*

**Figure C-ECM-10-4 Effects of Subsurface Drainage on the Water Line**




*Source: USDA-SCS*

## 8.0 References

New Jersey Department of Agriculture. 2-17. The Standards for Soil Erosion and Sediment Control in New Jersey. July.

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

USDA NRCS. National Engineering Handbook. Chapter 14 water management (drainage). 2021.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

## 9.0 Appendix A

Subsurface drains are not generally designed to flow under pressure, and the hydraulic gradient is parallel with the grade line. Consequently, the flow is considered to be open channel, and Manning's Equation can be used to determine the flowrate of the drain. Determine the drain size using the following procedure.

1. Determine the flow the drain is to carry.
2. Determine the gradient of the drain.
3. From Table C-ECM-10-5, determine "n" for the type of drainpipe to be used. Choose the correct Figure (Figure-C-ECM-09-5 through Figure-C-ECM-09-7) for the "n" just determined.

4. Enter the appropriate plate with the gradient and the flow of the pipe. The intersection of the two lines must be to the right of the line for 1.4 feet per second. If it is not, increase the gradient, flow capacity, or both.

**Example 1**

**Given:**

A random subsurface drain is to be installed on a 1% grade, 700 feet long, using corrugated plastic pipe.

**Calculate:**

The required size of the drainpipe.

**Solution:**

From the Section 5.0 Design Criteria, the required capacity of the pipe is:

1.5 cfs/1,000 feet

$$\text{Capacity} = \frac{700 \text{ feet}}{1{,}000 \text{ feet}} \times 1.5 \text{ cfs} = 1.05 \text{ cfs}$$

* From Table C-ECM-10-5, n = 0.015 for corrugated plastic pipe.

* From Figure C-ECM-10-6, choose an 8-inch pipe.

**Example 2**

**Given:**

A relief drain installed in a gridiron pattern of eight laterals, 500 feet long, 0.5% grade, and 50 feet on centers. A main 400 feet in length on a 0.5% grade will connect to the laterals. Use bituminized fiber pipe for the main and laterals.

**Calculate:**

The required size of the drain pipe.

**Solution:**

The drainage area for each lateral is 25 feet on either side of the pipe times the length.

Therefore:

$$\frac{50 \text{ ft} \times 500 \text{ ft}}{43{,}560 \frac{\text{sf}}{\text{acre}}} = 0.57 \text{ acres}$$

From the Section 5.0 Design Criteria, design the drains to remove 1 inch of water in 24 hours or 0.042 cfs/acre.

$$0.42 \frac{\text{cfs}}{\text{acre}} \times 0.57 \text{ acre} = 0.02 \text{ cfs}$$

From Table C-ECM-10-5, n = 0.013 for bituminized fiber pipe.

From Figure C-ECM-10-5, a 4-inch pipe must be used for the laterals.

The first 25 feet of the main will drain 25 feet on either side of the pipe. The remaining 375 feet will drain only 25 feet on the side opposite from the laterals. In addition, the main will drain the laterals.

**Drainage from Main:**

$$\frac{25\text{ ft} \times 50\text{ ft}}{43{,}560\frac{\text{sf}}{\text{acre}}} + \frac{375\text{ ft} \times 25\text{ ft}}{43{,}560\frac{\text{sf}}{\text{acre}}} = 0.24\text{ acre}$$

**Drainage from Laterals:**

$$8 \times 0.57\text{ acre} = 4.56\text{ acre}$$

$$\text{Total} = 0.24 + 4.56 = 4.8\text{ acre}$$

**Required Capacity:**

0.042 cfs/acre x 4.8 acre = 0.20 cfs

From Figure C-ECM-10-5, choose a 5-inch pipe for the main.

**Spacing of Relief Drains**

If the necessary information is known, the following equation can be used to calculate drain spacing in lieu of the recommended standard:

$$S = \sqrt{\frac{4k\,(M^2+2\,AM)}{q}}$$

Where,

S = drain spacing (feet)

K = average hydraulic conductivity (in./hr.) (for practical purposes, hydraulic conductivity is equal to permeability).

M = vertical distance, after drawdown, of water table above drain at midpoint between lines (feet)

A = depth of barrier below the drain (feet)

q = drainage coefficient, rate of water removal (in./hr.)

Also, see Figure C-ECM-10-8.

This equation applies to most areas in Virginia. Limitations of the equation are listed in the Soil Conservation Service (SCS) National Engineering Handbook, Section 16, Drainage of Agricultural Land (66).

**Spacing of Interceptor Drains**

If one interceptor drain is not sufficient, the spacing of multiple drains can be calculated using the following equation:

$$Le = \frac{k\,i}{q}\,(de - dw + W_2)$$

Where:

Le = the distance downslope from the drain to the point where the water table is at the desired depth after drainage (feet). Locate the second drain at this point.

k = the average hydraulic conductivity of the subsurface profile to the depth of the drain (in./hr.)

q = drainage coefficient, rate of water removal (in/hr.)

i = the hydraulic gradient of the water table before drainage (feet/foot)

de = the effective depth of the drain (feet)

dw = the desired minimum depth to water table after drainage (feet)

$W_2$ = the distance from the ground surface to the water table, before drainage, at the distance (Le) downslope from the drain (feet)

Also, see Figure-C-ECM-09-9.

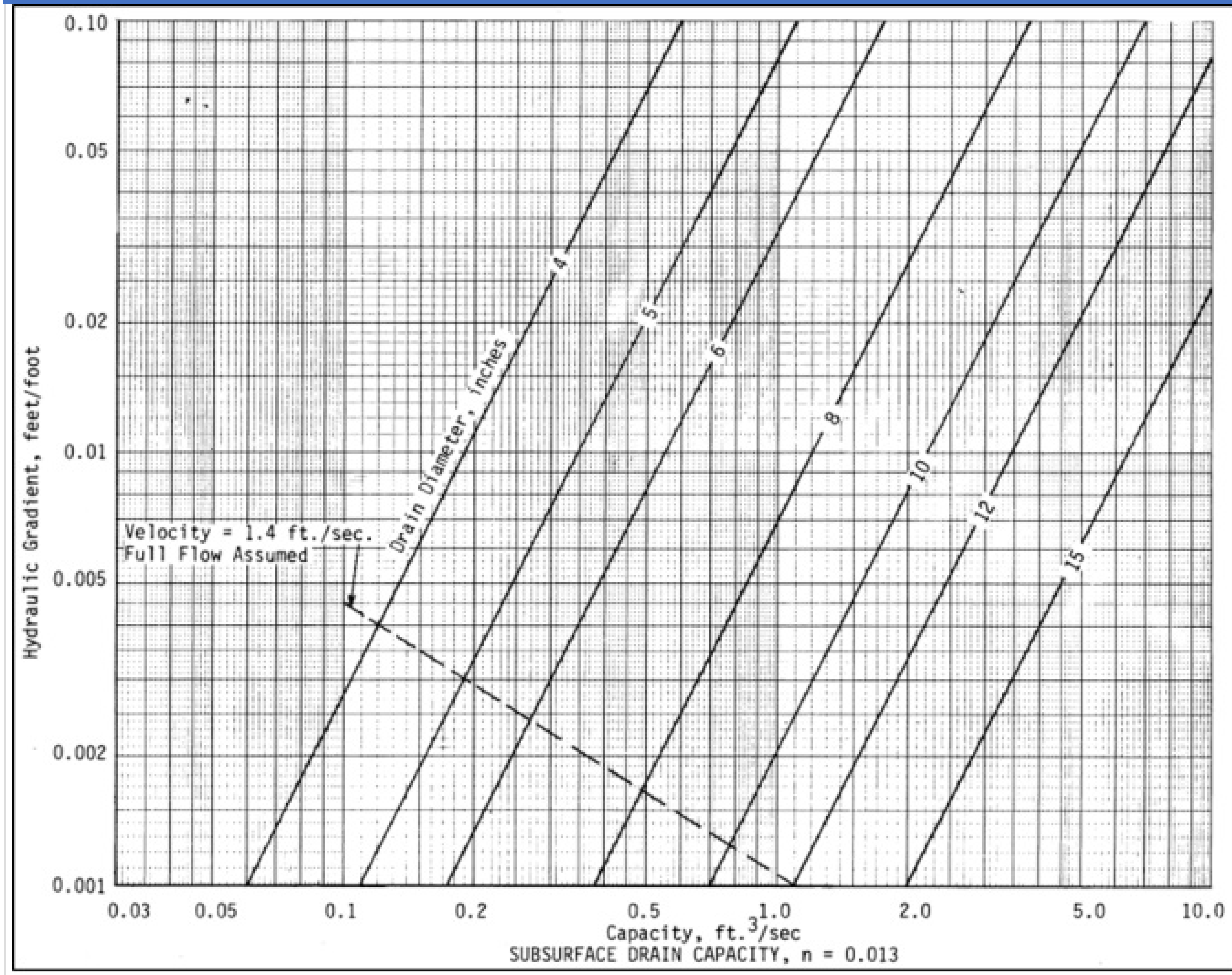
Further information on the equation can be obtained from the SCS National Engineering Handbook, Section 16, Drainage of Agricultural Land (66).

**Table C-ECM-10-5 "n" Values for Subsurface Drain Pipes**

| Composition of Pipe or Tubing | "n" Value |
|---|---|
| Asbestos Cement | 0.013 |
| Bituminized Fiber | 0.013 |
| Concrete | 0.015 |
| Corrugated Plastic | 0.015 |
| Corrugated Metal | 0.025 |

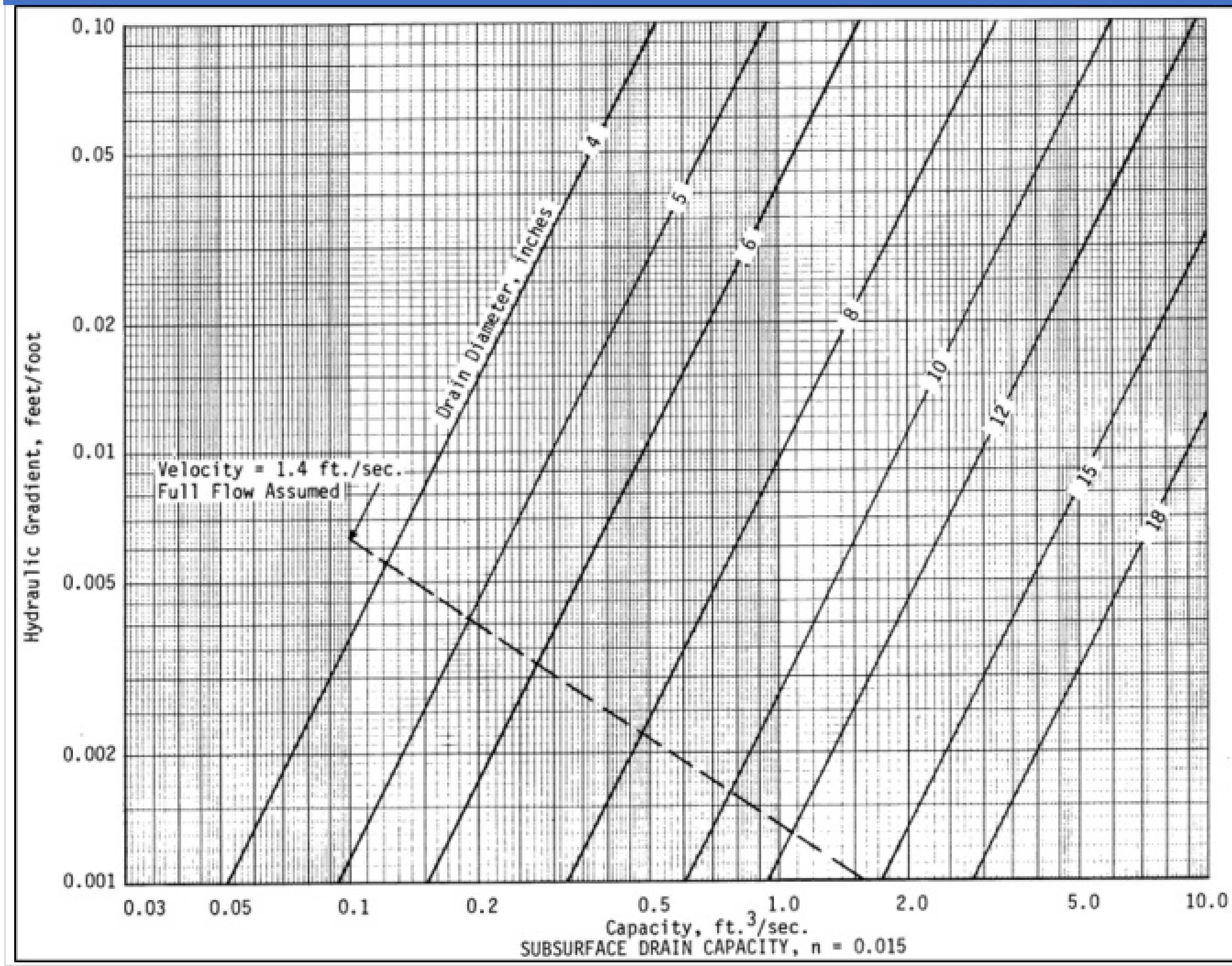
Source: Va. DSWC

## Figure C-ECM-10-5 Surface Drain Capacity (n=0.013)



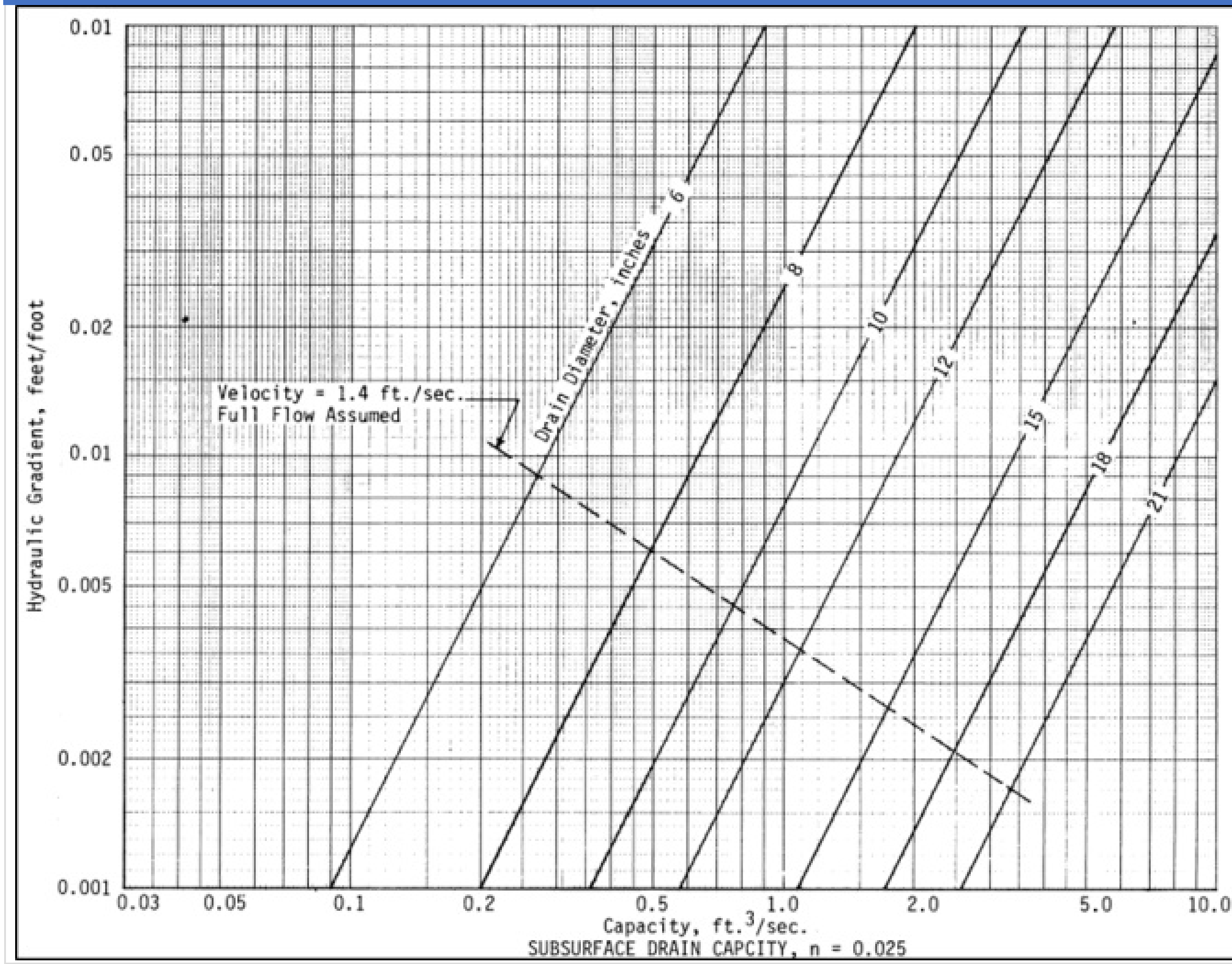

*Source: USDA-SCS*

## Figure C-ECM-10-6 Surface Drain Capacity (n=0.015)



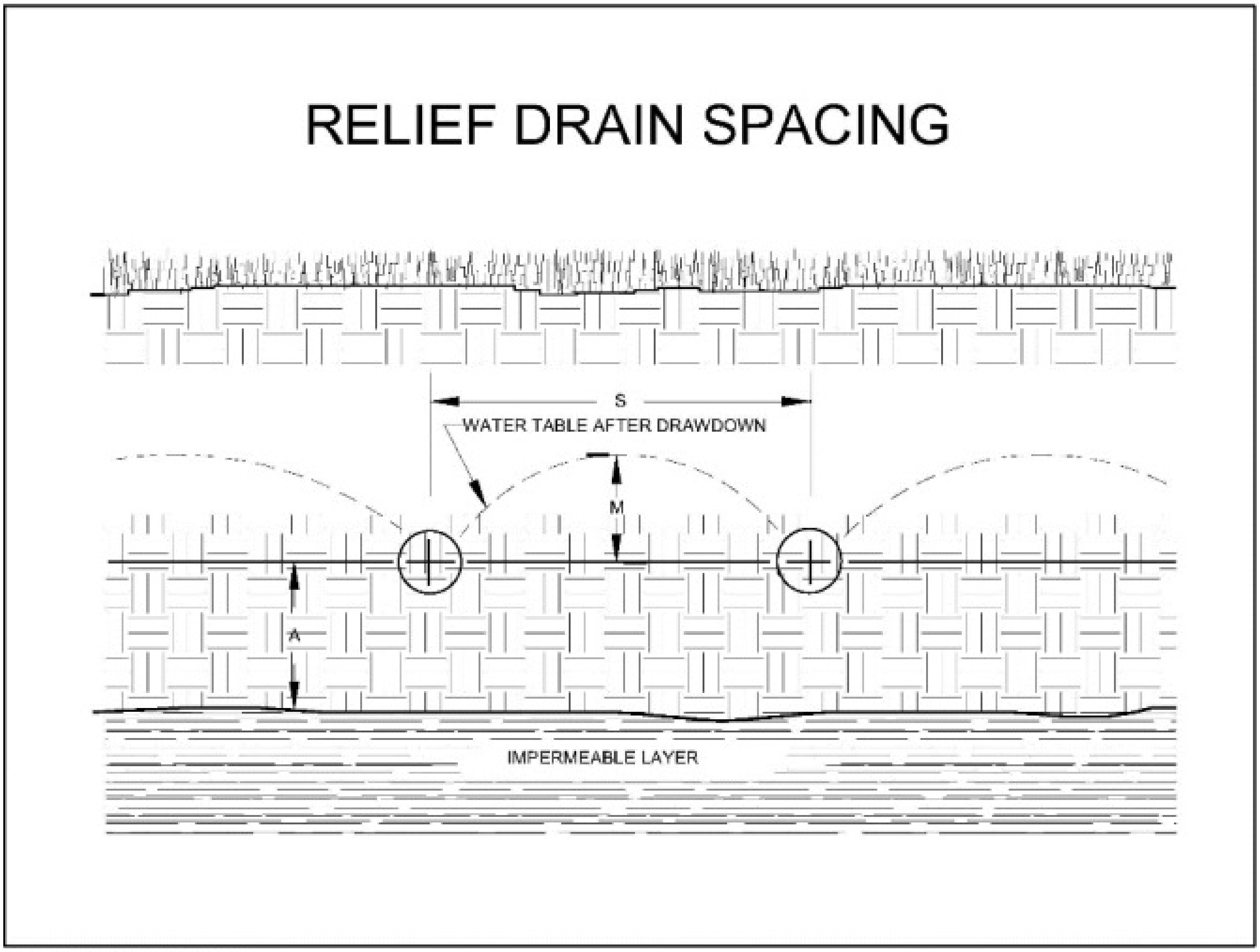

Source: USDA-SCS

## Figure C-ECM-10-7 Surface Drain Capacity (n=0.025)




Source: USDA-SCS

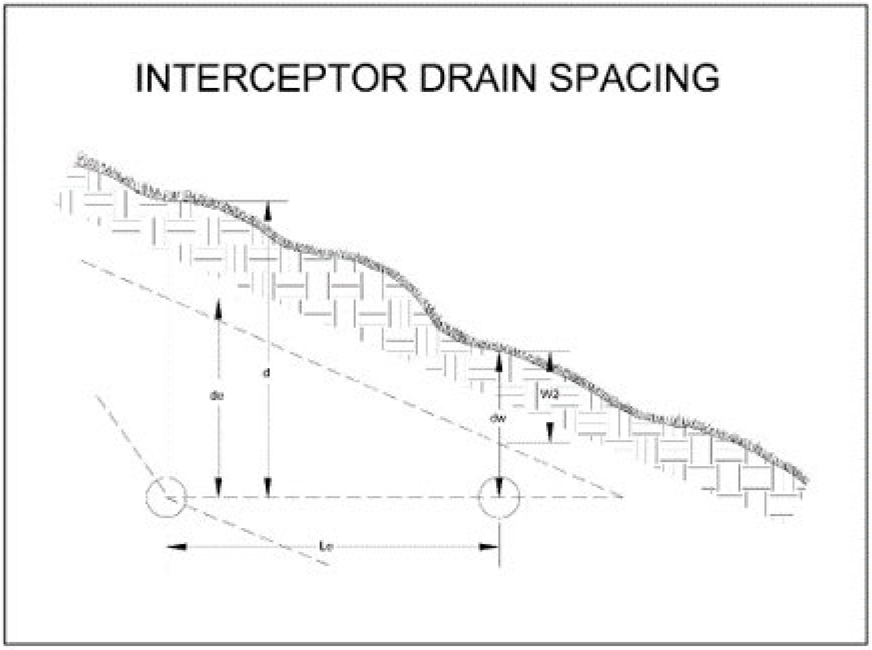
**_Figure C-ECM-10-8 Relief Drain Spacing_**



SOURCE: USDA-SCS

*Source: USDA-SCS*

**Figure C-ECM-10-9 Interceptor Drain Spacing**




SOURCE: USDA-SCS

*Source: USDA-SCS*

# C-ECM-11 Paved Flume

## 1.0 Definition

A paved flume is a permanent paved channel constructed on a slope to convey water from a higher to lower elevation in a short distance (New York Department of Environmental Conservation [NYDEC] 2016).

– CAD C-ECM-11-1 Paved Flume

– CAD C-ECM-11-2 Energy Dissipator

– CAD C-ECM-11-3 Energy Dissipator (Continued)

## 2.0 Purpose and Applicability of Best Management Practice

To convey stormwater runoff safely down the face of a cut or fill slope without causing erosion downstream of the slope.

Use of a paved flume applies where concentrated stormwater runoff must be conveyed from the top to the bottom of cut or fill slopes on a permanent basis and a riprap-lined channel is not capable of conveying the runoff without erosion.

## 3.0 Planning and Considerations

*Paved Flume Under Dry Conditions*
Source: Blucor Contracting, Inc.

Paved flumes are used routinely on highway cuts and fills to convey concentrated stormwater runoff from the top to the bottom of the slope without erosion.

These structures apply equally to cut and fill slopes for construction projects other than highways.

Give consideration to protecting structures against buoyancy failures. The potential for buoyancy failures due to hydrostatic uplift forces exists in channels constructed in periodically saturated areas (i.e., all channels will experience saturation of the subgrade by virtue of the function of the channel), especially if an outfall is submerged.

Use and carefully construct paved flumes, as field experience has revealed a significant number of post-construction problems with these controls. If the base contains some unsuitable material or is too “soft”, the flume will be subject to undermining and fracturing. There are also many cases where the outlet velocities and flowrates of stormwater in a paved flume are so great that erosion and flooding at the end of the structure are inevitable, regardless of the type of treatment installed at the outlet. In these cases, give strong consideration to a riprap-lined channel or to a system of inlets, manholes, and pipe to safely convey the stormwater to the receiving channel or drainage structure.

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

**MS-11: OUTLET PROTECTION** – Before newly constructed stormwater conveyance channels or pipes are made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and receiving channel.

9VAC25-875-560

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

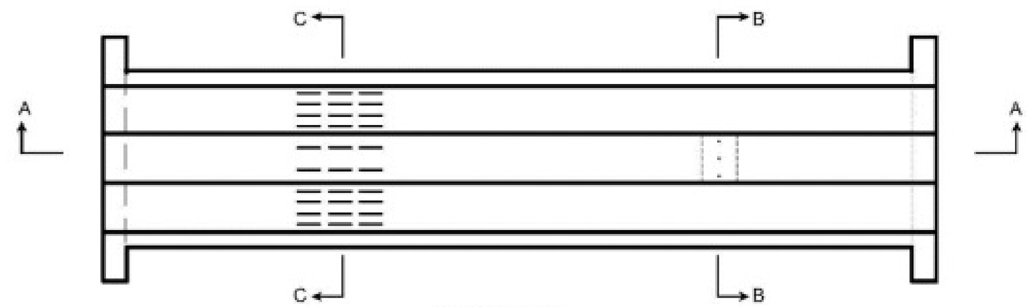
| Table C-ECM-11-1 Design Criteria for Paved Flumes | |
|---|---|
| **Topic** | **Requirement** |
| Capacity | Design paved flumes to be capable of conveying a minimum of the peak flow expected from a 10-year frequency storm. Design paved flumes to handle additional freeboard or enough bypass expected throughout the life of the structure (NYDEC 2016). |
| Cross-Sections | Figure C-ECM-10-1 illustrates a typical trapezoidal cross-section of a Virginia Department of Transportation (VDOT) "Standard Paved Flume (PG-4)" (VDOT 2021). Where additional flow capacity is required, larger trapezoidal cross-sections may be designed. The following criteria apply to all trapezoidal flume designs:<br>• Slope: design the maximum slope of the structure to be 1.5H:1V.<br>• Curtain Walls: Provide curtain walls at the beginnings and ends of all paved flumes not abutted to another structure. Design the curtain wall to be as wide as the flume channel, extend at least 18 inches into the soil below the channel, and have a thickness of 6-inches. Design curtain walls to be reinforced with #4 reinforcing steel bars placed on 6-inch centers.<br>• Anchor Lugs: Install anchor lugs spaced at a maximum of 10 feet on center for the length of the flume. Where no curtain wall is required, install an anchor lug within 2 feet of the end of the flume. Anchor lugs are to be as wide as the bottom of the flume channel, extending at least 1 foot into the soil below the channel, and having a thickness of 6 inches. Reinforce anchor lugs with #4 reinforcing steel bars placed on 4-inch centers.<br>• Channel: Design the flume channel to have at least a 4-inch thickness of class A-3 concrete with welded wire fabric (6 X 6 - W2.1 x W2.1) in the center for reinforcement.<br>• Expansion Joints: Provide expansion joints approximately every 90 feet. Locate 18-inch dowels of #4 reinforcing steel at 5-inch centers at all required joints. |
| Drainage Filters | Use a drainage filter with all paved fumes to prevent piping and reduce uplift pressures. Size of the filter material will depend on the soil material at and surrounding the paved flume (NYDEC 2016; North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service [NCDEQ] 2013). |
| Inlet | Ensure the inlet to the chute has the following minimum dimensions: side walls 2- feet high, length 6-feet, width equal to the flume channel bottom, and side slopes the same as flume channel side slopes (NCDEQ 2013). |

| Table C-ECM-11-1 Design Criteria for Paved Flumes | |
|---|---|
| **Topic** | **Requirement** |
| Outlet | Protect the outlets of paved flumes from erosion. The use of an energy dissipator with outlet protection (BMP C-ECM-15) is recommended to temporarily reduce the existing velocity of the flow, thus preventing undermining of the structure, and providing a stable transition zone between the flume and the receiving channel or drainage structure at the base of the slope. Figure C-ECM-10-2 and Figure C-ECM-10-3 show a “Standard Energy Dissipator (EG-1)” (VDOT 2021), which is designed for use in conjunction with the “Standard Paved Flume (PG-4)”. Use outlet protection with the use of an “EG-1” structure to further dissipate flow energy and provide a smooth transition into the receiving channel. Larger energy dissipator systems may be similarly designed for larger flume cross-sections. |
| Alignment | Keep flume channels straight because they often carry supercritical flow velocities (NCDEQ 2013). |
| Small Flumes | Where the drainage area is less or equal to 10 acres, the design dimensions for paved flumes may be selected from the appropriate information below in Table C-ECM-11-2. |

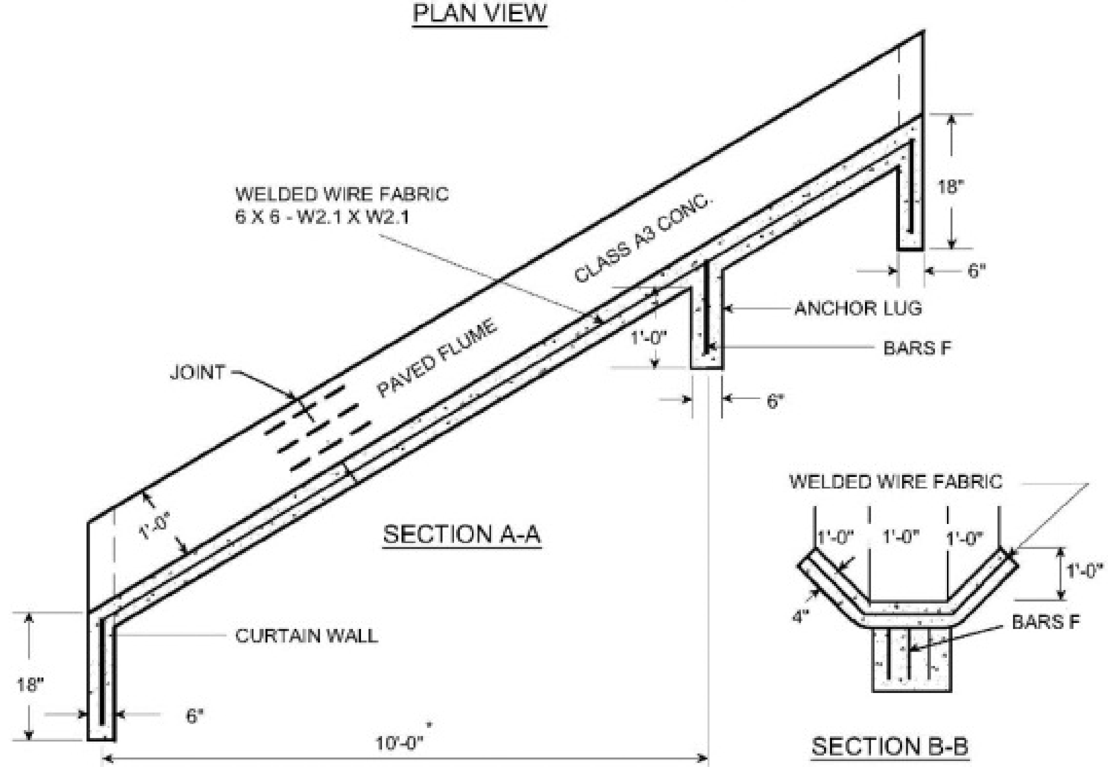
| Table C-ECM-11-2 Flume Dimensions for Small Drainage Area | | | | | |
|---|---|---|---|---|---|
| **Drainage Area (acres)** | **Min. Bottom Width (feet)** | **Min. Inlet Depth (feet)** | **Min. Channel Depth (feet)** | **Max. Channel Slope (feet)** | **Max. Side Slope (feet)** |
| 5 | 4 | 2 | 1.3 | 1.5H:1V | 1.5H:1V |
| 10 | 8 | 2 | 1.3 | 1.5H:1V | 1.5H:1V |
| Note: Due to complexity of inlet and outlet design, drainage areas have been limited to 10 acres per flume. | | | | | |

## *Figure C-ECM-11-1 Paved Flume*

# PAVED FLUME




PLAN VIEW




SECTION A-A

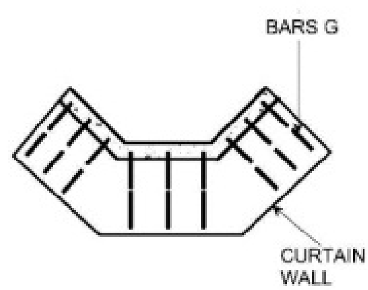
SECTION B-B

* 10'-0" C-C MAXIMUM TYPICAL SPACING BETWEEN ANCHOR LUGS. WHERE CURTAIN WALL IS NOT REQUIRED ANCHOR LUG IS TO BE A MAXIMUM OF 2' FROM END OF CHANNEL.

SCHEDULE OF REINFORCING STEEL

| MARK | NO. | LENGTH 2:1 | LENGTH 1 1/2:1 | SIZE | SPACING C-C | SHAPE |
|---|---|---|---|---|---|---|
| F | 3 | 1'-2" | 1'-2" | 4 | 4" | STRAIGHT |
| G | 9 | 1'-5" | 1'-5" | 4 | 6" | STRAIGHT |
| DOWELS | 10 | 1'-6" | 1'-6" | 4 | 5" | STRAIGHT |

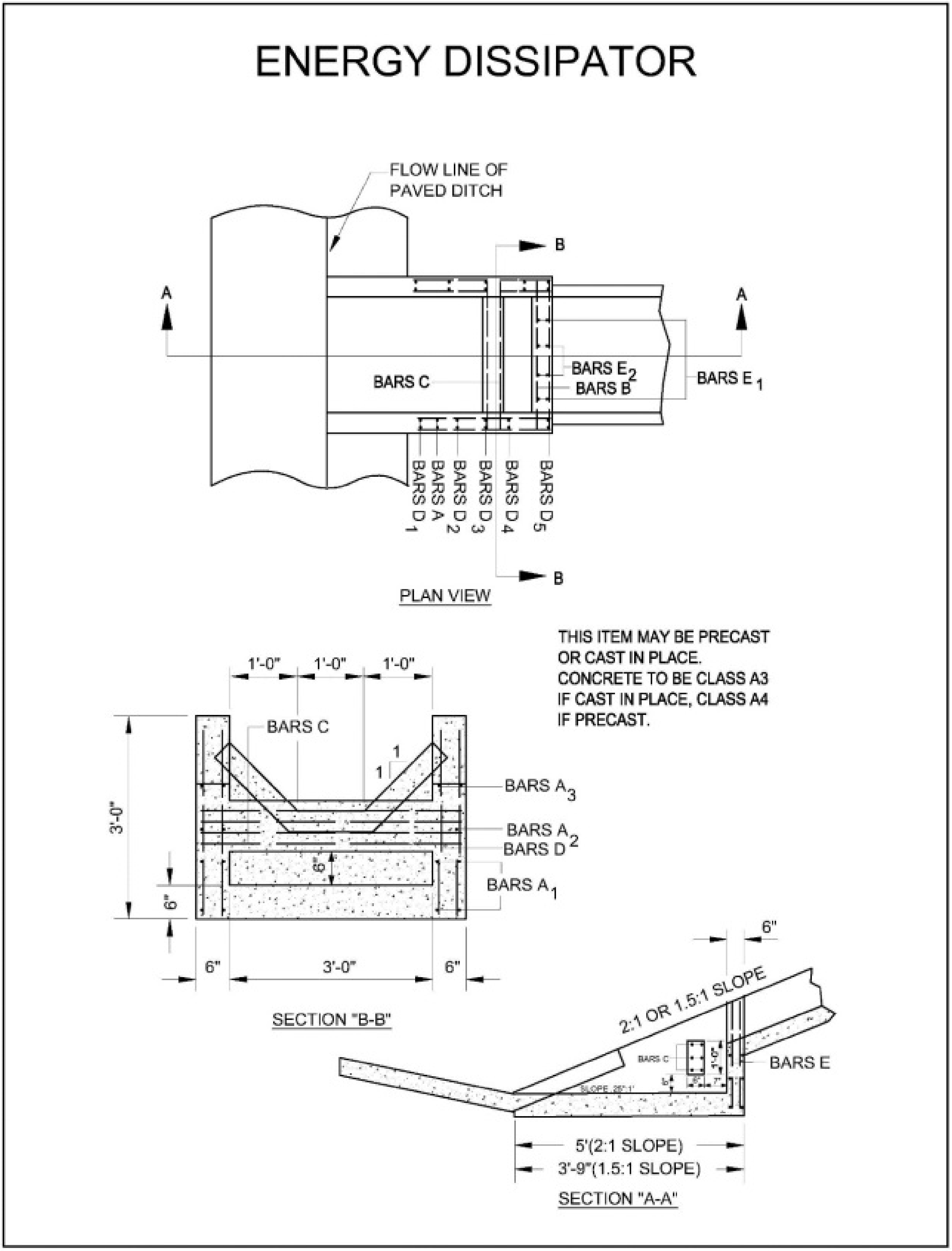
NO. SHOWN ARE FOR ONE ANCHOR LUG, CURTAIN WALL AND JOINT




SECTION C-C

SOURCE: VDOT ROAD AND BRIDGE STANDARDS

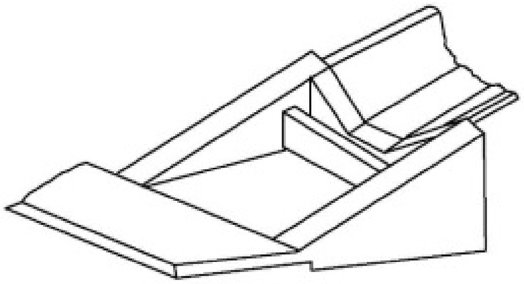
## Figure C-ECM-11-2 Energy Dissipator




SOURCE: VDOT ROAD AND BRIDGE STANDARDS

**Figure C-ECM-11-3 Energy Dissipator**

# ENERGY DISSIPATOR
## (CONTINUED)



ISOMETRIC

SCHEDULE OF REINFORCING STEEL

| MARK | NO. | LENGTH 2:1 | LENGTH 1.5:1 | SIZE | SPACING C-C | SHAPE |
|---|---|---|---|---|---|---|
| $A_1$ | 8 | 2'-10" | 2'-10" | 3 | 8" | STRAIGHT |
| $A_2$ | 4 | 2'-6 1/4" | 1'-10" | 3 | 8" | STRAIGHT |
| $A_3$ | 4 | 1'-0 3/4" | 0'-10" | 3 | 8" | STRAIGHT |
| B | 6 | 3'-9" | 3'-9" | 3 | 8" | STRAIGHT |
| C | 8 | 3'-8" | 3'-8" | 3 | 2 1/2" | STRAIGHT |
| $D_1$ | 4 | 1'-2 1/2" | 0'-8" | 3 | 8" | STRAIGHT |
| $D_2$ | 4 | 1'-6 1/2" | 1'-1 1/2" | 3 | 8" | STRAIGHT |
| $D_3$ | 4 | 1'-10 1/2" | 1'-7" | 3 | 8" | STRAIGHT |
| $D_4$ | 4 | 2'-2 1/2" | 2'-0 1/2" | 3 | 8" | STRAIGHT |
| $D_5$ | 4 | 2'-6 1/2" | 2'-6" | 3 | 8" | STRAIGHT |
| $E_1$ | 4 | 1'-11 1/2" | 1'-11 1/2" | 3 | 8" | STRAIGHT |
| $E_2$ | 4 | 1'-5 1/2" | 1'-5 1/2" | 3 | 8" | STRAIGHT |

APPROXIMATE QUANTITIES

| | | CONCRETE CU. YDS. | REINFORCING STEEL LBS. |
|---|---|---|---|
| ENERGY DISSIPATOR | 2:1 | 0.7479 | 61.20 |
| | 1.5:1 | 0.5921 | 57.63 |

SOURCE: VDOT ROAD AND BRIDGE STANDARDS

## 6.0 Construction Specifications

1. Construct the subgrade to the required elevations. Remove and replace all soft and/or unsuitable material with stable material. Thoroughly compact and shape the subgrade to a smooth, uniform surface. Ensure the subgrade is moist when the concrete is poured.
2. On fill slopes, ensure the soil adjacent to the flume is well compacted for a minimum of 5 feet on either side (NYDEC 2016).
3. Where drainage filters are placed under a structure, do not pour the concrete on the filter. Place a plastic liner, a minimum of 4 mils thick, over the filter to prevent contamination of the filter layer (NYDEC 2016).
4. Form anchor lugs and curtain walls to be continuous with the channel lining.
5. Provide traverse joints for crack control at approximately 20-foot intervals and when more than 45 minutes elapse between consecutive concrete placements. Ensure all sections are at least 6 feet long. Form crack control joints by using a 0.125-inch-thick removable template, by scoring or sawing to a depth of at least 0.75 inch, or by an approved leave-in type of insert.
6. Take adequate precautions to protect freshly poured concrete from extreme temperatures and other weather factors to ensure proper and required curing of concrete (NCDEQ 2013).
7. Immediately after construction, perform final grading and seed all disturbed areas.

## 7.0 Operations and Maintenance Considerations

Before permanent stabilization of the slope, inspect the structure after each rainfall. Immediately repair any damage to the slope, flume, or outlet area. After the slope is stabilized, inspect the structure to ensure continued adequate functioning. Inspect the structure periodically and after major rainfall events. Inspect the outlet and rock riprap to ensure presence and stability, if applicable (NCDEQ 2013; NYDEC 2016).

## 8.0 References


NCDEQ. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

NYDEC. 2016. New York State Standards and Specifications for Erosion and Sediment Control. November.

Virginia Department of Environmental Quality. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

VDOT. 2021. Drainage Manual. Virginia Department of Transportation, Location and Design Division. Issued April 2002. Revised January 2021. Available online at: https://virginiadot.org/business/locdes/hydra-drainage-manual.asp.


# C-ECM-12 Temporary Slope Drain

## 1.0 Definition

A temporary slope drain is a flexible tubing or conduit extending from the top to the bottom of a cut or fill slope.

– CAD C-ECM-12-1 Temporary Slope Drain

– CAD C-ECM-12-2 Flared End-Section

– CAD C-ECM-12-3 Flared End-Section (Continued)

## 2.0 Purpose and Applicability of Best Management Practice

Temporary slope drains temporarily conduct concentrated stormwater runoff safely down the face of a cut or fill slope without causing erosion on or below the slope.

This practice applies on cut or fill slopes where there is a potential for upslope flows to move over the face of the slope, causing erosion and preventing adequate stabilization.

## 3.0 Planning and Considerations

There is often a significant lag between the time at which a cut or fill slope is completed and the time at which a permanent drainage system can be installed. During this period, the slope is usually not stabilized and is particularly vulnerable to erosion. This condition also occurs on slope construction that is temporarily delayed before final grade is reached. Temporary slope drains can provide valuable protection for exposed slopes until permanent drainage structures can be installed or vegetation can be established.

Temporary slope drains can be used in conjunction with diversion dikes to convey runoff from the entire drainage area above a slope to the base of the slope without erosion. It is important that these temporary structures be installed properly because their failure will often result in severe gully erosion on the site and sedimentation below the slope. Securely entrench the entrance section, ensure all connections are watertight, and securely stake the conduit.

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

9VAC25-875-560

**Sediment Removal Efficiency: N/A**

**Erosion Control Efficiency: Moderate**

## 5.0 Design Criteria

| Table C-ECM-12-1 Design Criteria for Temporary Slope Drains | |
|---|---|
| **Topic** | **Requirement** |
| Drainage Area | The maximum allowable drainage area per slope drain is 5 acres. |
| Flexible Conduit | Use a slope drain that consists of heavy-duty, flexible material designed for this purpose. Ensure the diameter of the slope drain is consistent over its entire length.<br>Install reinforced hold-down grommets spaced at 10-foot (or less) intervals to secure the drain in place.<br>Size slope drains as listed in Table C-ECM-12-2. |

| Table C-ECM-12-1 Design Criteria for Temporary Slope Drains | |
|---|---|
| **Topic** | **Requirement** |
| Entrance Sections | Design the entrance to the slope drain to consist of a standard Virginia Department of Transportation (VDOT) flared end section for metal pipe culverts (see Figures C-ECM-11-2 and C-ECM-11-3) with appropriate inlet protection as set forth in Culvert Inlet Protection (BMP C-SCM-05).<br>If ponding will cause a problem at the entrance and make such protection impractical, install appropriate sediment-removing measures at the outlet of the pipe. Use extension collars that consist of 12-inch-long corrugated metal pipe. Provide watertight fittings (see Figure C-ECM-12-1).<br>Note: End sections made of heavy-duty, flexible material may be used if determined by the certified plan reviewer to provide a stable inlet or outlet section. |
| Dike Design | Use an earthen dike to direct stormwater runoff into the temporary slope drain and construct the earthen dike as set forth in Diversion (BMP C-ECM-05). Refer to Figure C-ECM-12-1 for placement of dike in relation to the slope drain.<br>Design the height of the dike at the centerline of the inlet to be equal to the diameter of the pipe plus 6 inches. Where the dike height is greater than<br>18 inches at the inlet, slope the dike at the rate of 3H:1V or flatter to connect with the remainder of the dike (see Figure C-ECM-12-1). |
| Outlet Protection | Protect the outlet of the slope drain from erosion as set forth in Outlet Protection (BMP C-ECM-15). |

| Table C-ECM-12-2 Slope Drain Sizing | |
|---|---|
| **Maximum Drainage Area (acres)** | **Pipe Diameter (inches)** |
| 0.5 | 12 |
| 1.5 | 18 |
| 2.5 | 21 |
| 3.5 | 24 |
| 5.0 | 30 |
| Source: Virginia Department of Conservation and Recreation [VDCR] 2004 | |

## 6.0 Construction Specifications

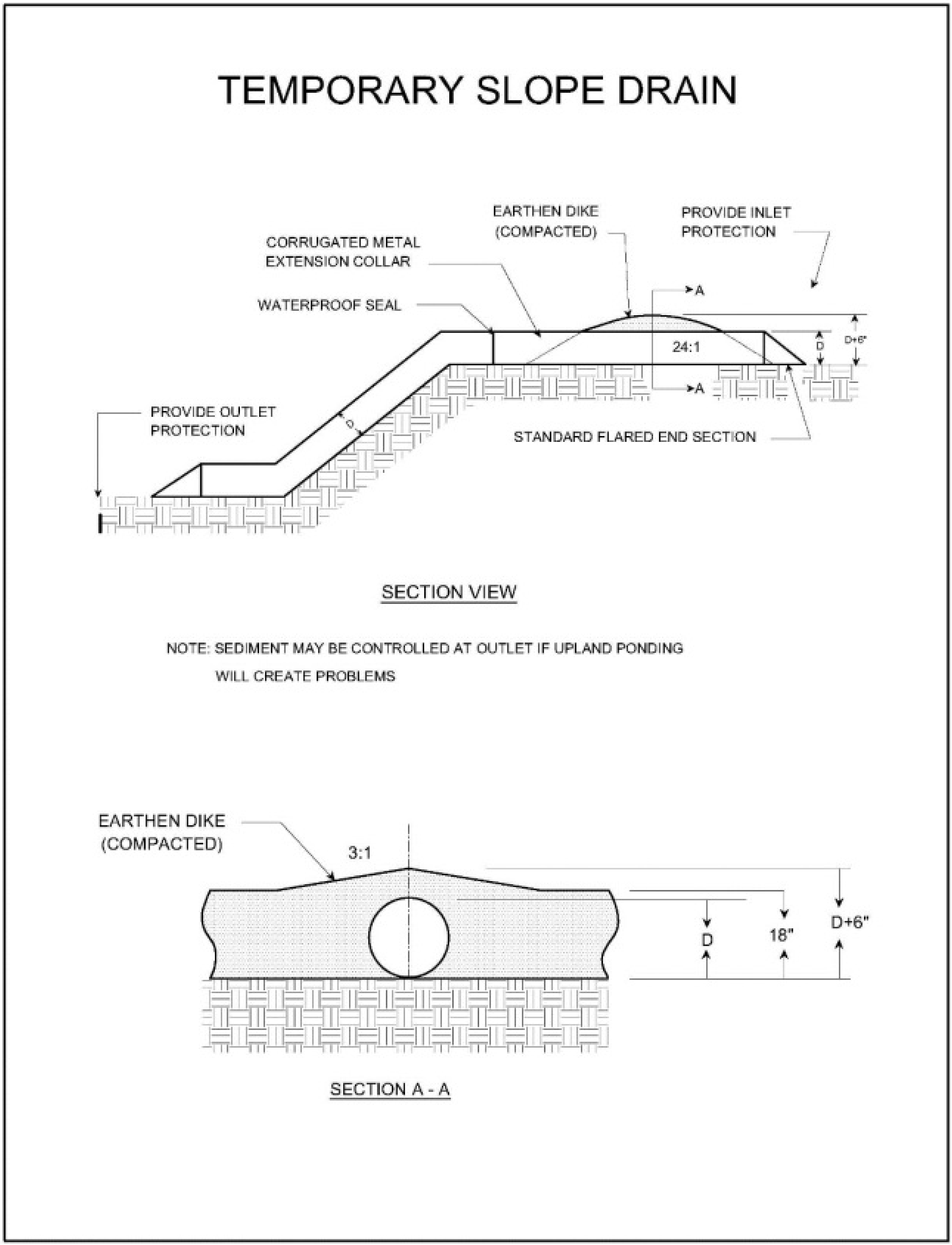
1. Place the slope drain pipe on undisturbed soil or well-compacted fill.
2. Slope the entrance section toward the slope drain at the minimum rate of 0.5 inch per foot.
3. Hand-tamp the soil around and under the entrance section in 8-inch lifts to the top of the dike to prevent piping failure around the inlet.
4. Securely stake the slope drain pipe to the slope using reinforced hold-down grommets spaced at 10-foot intervals.

5. Ensure the slope drain sections are securely fastened together and have watertight fittings.
6. Install culvert inlet protection and outlet protection in accordance with BMP C-SCM-05 and BMP C-ECM-15.

## 7.0 Operations and Maintenance Considerations

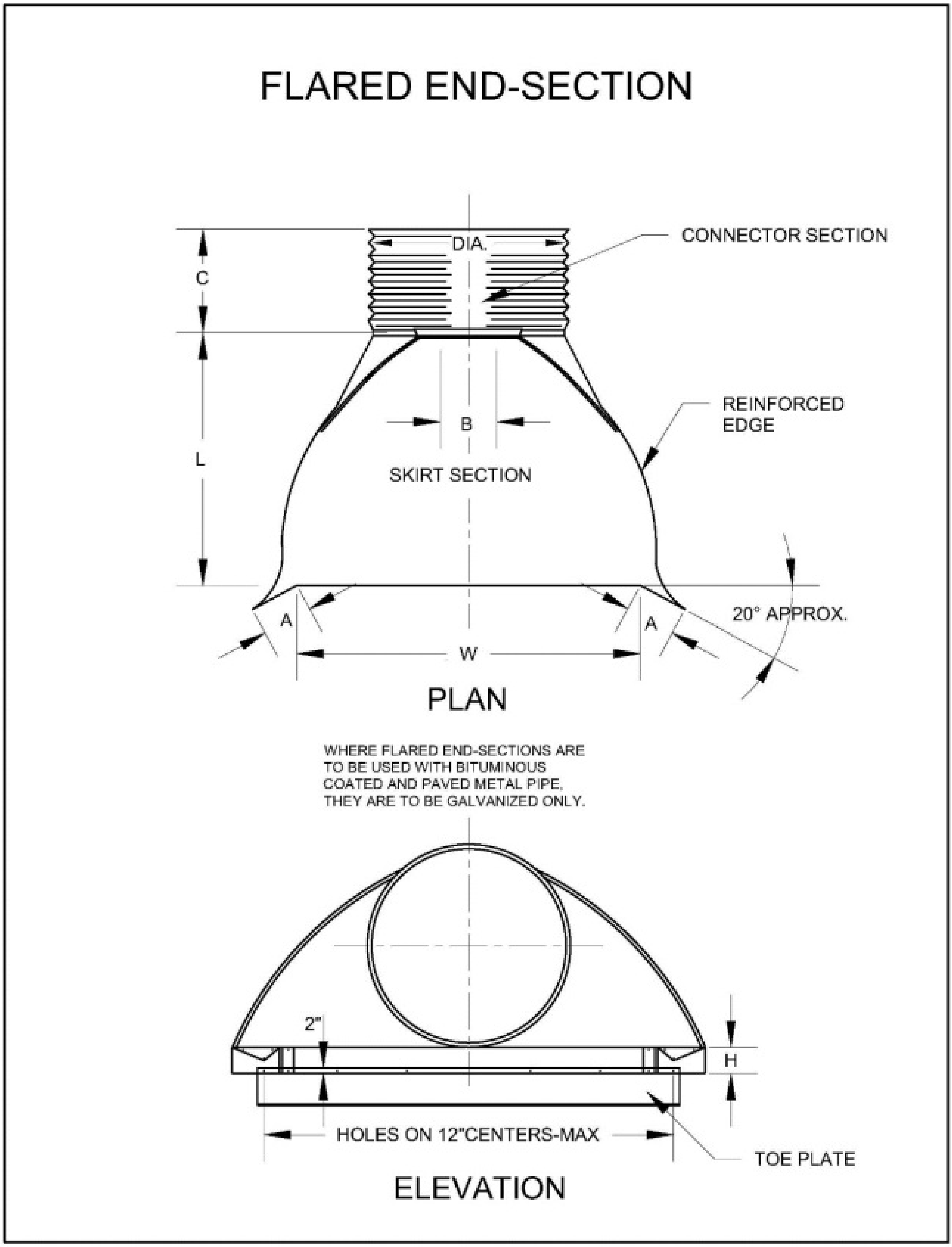
Inspect the slope drain structure weekly and after every storm and make repairs if necessary. Avoid the placement of any material on the slope drain and prevent construction traffic across the slope drain. When the protected area has been permanently stabilized, remove the temporary measures, properly dispose of materials, and appropriately stabilize all disturbed areas (North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service 2013).

**Figure C-ECM-12-1 Temporary Slope Drain**




SOURCE: VA. DSWC

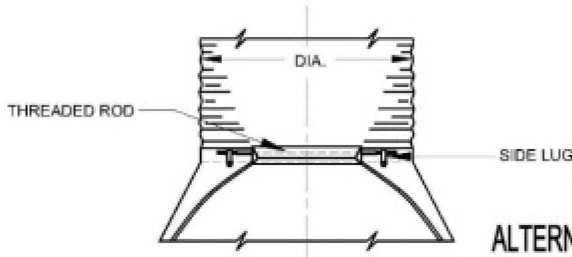
## *Figure C-ECM-12-2 Flared End Section*




SOURCE: VDOT ROAD AND BRIDGE STANDARDS

## *Figure C-ECM-12-3 Flared End Section 2*

# FLARED END-SECTION
(CONTINUED)




ALTERNATE CONNECTION

TOE PLATE, WHERE NEEDED, TO BE PUNCHED TO MATCH IN SKIRT LIP. 3/8" GALV. BOLTS TO BE FURNISHED. LENGTH OF TOE PLATE IS W + 10" FOR 12" TO 30" DIA. PIPE AND W + 22" FOR 36" TO 60" DIA. PIPE.

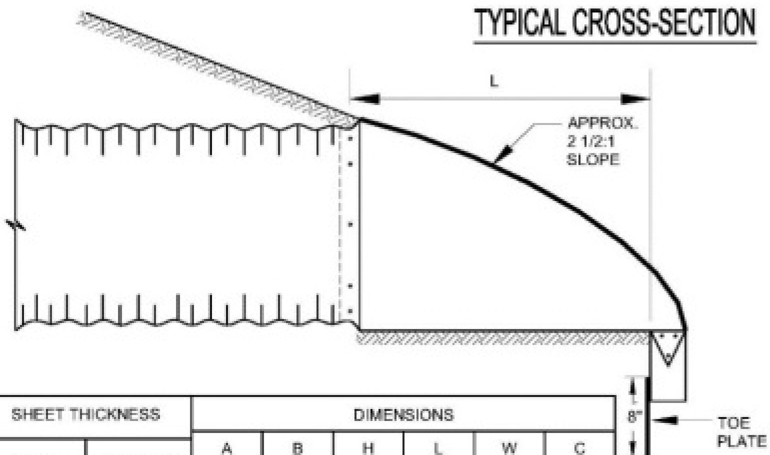
SKIRT SECTION FOR 12" TO 30" DIA. PIPE TO BE MADE IN ONE PIECE.

SKIRT SECTION FOR 36" TO 54" DIA. PIPE MAY BE MADE FROM TWO SHEETS JOINED BY RIVETING OR BOLTING ON CENTER LINE, 60" MAY BE CONSTRUCTED IN 3 PIECES.

CONNECTOR SECTION, CORNER PLATE AND TOE PLATE TO BE SAME SHEET THICKNESS AS SKIRT.

END-SECTIONS AND FITTINGS ARE TO BE GALVANIZED STEEL OR ALUMINUM ALLOY FOR USE WITH LIKE PIPE.

TYPICAL CROSS-SECTION




| PIPE DIA. | SHEET THICKNESS | | DIMENSIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| | STEEL | ALUMINUM | A 1"TOL. | B MAX. | H 1"TOL. | L 1 1/2" TOL. | W 2"TOL. | C |
| 12" | .064" | .060" | 6" | 6" | 6" | 21" | 24" | 24" |
| 15" | .064" | .060" | 7" | 8" | 6" | 26" | 30" | 24" |
| 18" | .064" | .060" | 8" | 10" | 6" | 31" | 36" | 24" |
| 21" | .064" | .060" | 10" | 12" | 6" | 36" | 42" | 24" |
| 24" | .064" | .060" | 10" | 13" | 6" | 41" | 48" | 24" |
| 27"/30" | .064" | .075" | 12" | 16" | 8" | 51" | 60" | 24" |
| 36" | .064" | .075" | 14" | 19" | 9" | 60" | 72" | 36" |
| 42" | .064" | .105" | 16" | 22" | 11" | 69" | 84" | 36" |
| 48" | .064" | .105" | 18" | 27" | 12" | 78" | 90" | 24" |
| 54" | .064"/.079" | .105" | 18" | 30" | 12" | 84" | 102" | 36" |
| 60" | .064"/.079" | .105"/.135" | 18" | 33" | 12" | 87" | 114" | 36" |

SOURCE: VDOT ROAD AND BRIDGE STANDARDS

***Figure C-ECM-12-3 Flared End Section 2***

*Source: VDOT 2008*

## 8.0 References

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

VDCR. 2004. The Virginia Stream Restoration and Stabilization Best Management Practices Guide. Virginia Department of Environmental Quality. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

VDOT. 2008. Road and Bridge Standards, Section 100: Drainage Items. Available online at: https://vdot.virginia.gov/business/locdes/Standards_CompleteSections.asp.

# C-ECM-13 Riprap

## 1.0 Definition

Riprap is a permanent, erosion-resistant ground cover of large, loose, angular stone installed with filter fabric or granular underlining.

– CAD C-ECM-13-1 Toe Requirements for Bank Stabilization

– CAD C-ECM-13-2 Recommended Freeboard and Height of Bank of Lined Channels

## 2.0 Purpose and Applicability of Best Management Practice

The purposes of riprap are:

1. To protect the soil from the erosive forces of concentrated runoff;
2. To slow the velocity of concentrated runoff while enhancing the potential for infiltration; and
3. To stabilize slopes with seepage problems and/or non-cohesive soils.

Source: Flickr, 2011

Use of riprap applies where soil and water interface and the soil conditions, water turbulence and velocity, expected vegetative cover, and other conditions are such that the soil may erode under the design flow conditions. Riprap may be used, as appropriate, at storm drain outlets, on channel banks and/or bottoms, roadside ditches, drop structures, at the toes of slopes, as transition from concrete channels to vegetated channels, diversion channels for utility line crossings, temporary culvert crossings, at temporary right-of-way diversion outlets, rock check dams, rock filter outlets, temporary sediment trap outlets, and temporary sediment basin emergency spillways.

**Planning and Considerations**

| Table C-ECM-13-1 Riprap Design Considerations | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Sequence of Construction | Because riprap is used where erosion potential is high, sequence construction so that the riprap is placed with the minimum possible delay.<br><br>Areas in which riprap is to be placed should be disturbed only when final preparation and placement of the riprap can follow immediately behind the initial disturbance.<br>Where riprap is used for outlet protection, place the riprap before or in conjunction with the construction of the pipe or channel so that the riprap is in place when the pipe or channel begins to operate; see Outlet Protection (BMP C-ECM-15). |
| Graded vs. Uniform Riprap | Riprap is classified as either graded or uniform. A sample of graded riprap would contain a mixture of stones that vary in size from small to large. A sample of uniform riprap would contain stones that are all consistent in size.<br><br>For most applications, graded riprap is preferred to uniform riprap. Graded riprap forms a flexible self-healing cover, while uniform riprap is more rigid and cannot withstand movement of the stones.<br><br>Graded riprap is cheaper to install, requiring only that the stones be dumped so that they remain in a well-graded mass. Hand or mechanical placement of individual stones is limited to that necessary to achieve the proper thickness and line. Uniform riprap requires placement in a uniform pattern, requiring more hand or mechanical labor.<br><br>Riprap sizes can be designed by either the diameter or the weight of the stones. It is often misleading to think of riprap in terms of diameter because the stones are angular instead of spherical. However, it is simpler to specify the diameter of an equivalent size of spherical stone. Table C-ECM-13-2 lists some typical stones by weight, spherical diameter, and the corresponding rectangular dimensions. These stone sizes are based on an assumed specific weight of 165 pounds per cubic foot ($lb/ft^3$).<br><br>Because graded riprap consists of a variety of stone sizes, a method is needed to specify the size range of the mixture of stone. This is accomplished by specifying a diameter of stone in the mixture for which some percentage, by weight, will be smaller. For example, d85 refers to a mixture of stones in which 85% of the stone by weight would be smaller than the diameter specified. Most designs are based on d50. In other words, the design is based on the nominal size of stone in the mixture. Table C-ECM- 12-3 lists Virginia Department of Transportation (VDOT) standard graded riprap sizes by diameter and weight of the stone.<br><br>To ensure use of stone of substantial weight when installing riprap structures, follow the specified weight ranges for individual stones and composition requirements. Such guidelines will help to prevent inadequate stone from being used when constructing the measures and will promote more consistent stone classification statewide. Table C-ECM-13-4 notes these requirements. |

| Table C-ECM-13-2 Size of Riprap Stones | | | |
|---|---|---|---|
| Weight (lbs.) | Mean Spherical Diameter (ft.) | Rectangle Length (ft.) | Rectangle Height/Width (ft.) |
| 25 | 0.7 | 1.1 | 0.4 |
| 50 | 0.8 | 1.4 | 0.5 |
| 75 | 1.0 | 1.6 | 0.5 |
| 100 | 1.1 | 1.75 | 0.6 |
| 150 | 1.3 | 2.0 | 0.67 |
| 300 | 1.6 | 2.6 | 0.9 |
| 500 | 1.9 | 3.0 | 1.0 |
| 1,000 | 2.2 | 3.7 | 1.25 |
| 1,500 | 2.6 | 4.7 | 1.5 |
| 2,000 | 2.75 | 5.4 | 1.8 |
| 4,000 | 3.6 | 6.0 | 2.0 |
| 6,000 | 4.0 | 6.9 | 2.3 |
| 8,000 | 4.5 | 7.6 | 2.5 |
| 20,000 | 6.1 | 10.0 | 3.3 |
| Source: VDOT 2017 | | | |

| Table C-ECM-13-3 Graded Riprap Design Values | | | |
|---|---|---|---|
| Riprap Class | D15 Weight (lbs.) | D15 Spherical Diameter (ft.) | D50 Spherical Diameter (ft.) |
| Class AI | 25 | 0.7 | 0.9 |
| Class I | 50 | 0.8 | 1.1 |
| Class II | 150 | 1.3 | 1.6 |
| Class III | 500 | 1.9 | 2.2 |
| Type I | 1,500 | 2.6 | 2.8 |
| Type II | 6,000 | 4.0 | 4.5 |
| Source: VDOT 2017 | | | |

| Table C-ECM-13-4 Graded Riprap Weight Analysis | | |
|---|---|---|
| Riprap Class/Type | Weight Range* (lbs.) | Requirements for Stone Mixture |
| Class AI | 25 – 75 | Max. 10% > 75 lbs. |
| Class I | 50 – 150 | 60% > 100 lbs. |
| Class II | 150 – 500 | 50% > 300 lbs. |
| Class III | 500 – 1,500 | 50% > 900 lbs. |
| Type I | 1,500 – 4,000 | Average weight = 2,000 lbs. |
| Type II | 6,000 – 20,000 | Average weight = 8,000 lbs. |

* In all classes/types of riprap, a maximum 10% of the stone in the mixture may weigh less than the lower end of the range.

Source: Adapted from VDOT 2020.

## 3.0 Stormwater Performance Summary

**MS-11: OUTLET PROTECTION** – Before any newly constructed stormwater conveyance channel can be made operational, adequate outlet protection and any required temporary or permanent channel lining will be installed in both the conveyance channel and receiving channel.

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: MODERATE**

## 4.0 Design Criteria

| Table C-ECM-13-5 Design Criteria for Riprap | |
|---|---|
| Parameter | Notes on Proper Use |
| Gradation | Use riprap composed of a well-graded mixture down to the 1-inch size particle such that 50% of the mixture by weight is larger than the d50 size as determined from the design procedure.<br><br>A well-graded mixture, as used herein, is defined as a mixture composed primarily of the larger stone sizes but with a sufficient mixture of other sizes to fill the progressively smaller voids between the stones. Design the diameter of the largest stone size in such a mixture to be 1.5 times the d50 size.<br><br>After determining the riprap size that will be stable under the flow conditions, consider that size to be a minimum size. Based on riprap gradations available in the area, select the size or sizes that equal or exceed the minimum size. Consider the possibility of damage in selecting a riprap size. |
| Thickness | Design the minimum thickness of the riprap layer to be two times the maximum stone diameter but not less than 6 inches. |

| Table C-ECM-13-5 Design Criteria for Riprap | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Quality of Stone | Use stone for riprap that consists of field stone or rough unhewn quarry stone of approximately rectangular shape. Ensure the stone is hard, angular, and of such quality that it will not disintegrate on exposure to water or weathering. Use stone that is suitable in all respects for the purpose intended. Ensure the specific gravity of the individual stones is at least 2.5.<br>Rubble concrete may be used provided it has a density of at least 150 pounds per cubic foot and otherwise meets the requirement of this standard and specification. |
| Filter Fabric Underlining | Place a lining of engineering filter fabric (geotextile) between the riprap and the underlying soil surface to prevent soil movement into or through the riprap. Table C-ECM-13-5 notes the minimum physical properties of the filter fabric.<br>Do not use filter fabric on slopes greater than 1.5H:1V, as slippage may occur. Use filter fabric in conjunction with a layer of coarse aggregate (granular filter blanket is described in the next row) when the riprap to be placed is Class II or larger. |
| Granular Filter | Although the filter fabric underlining or bedding is the preferred method of installation, a granular (stone) bedding is a viable option when the following relationships exist: $\frac{d_{15filter}}{d_{85base}} < 5 < \frac{d_{15filter}}{d_{15base}} < 40$ and $\frac{d_{50filter}}{d_{50base}} < 40$<br>In these relationships, "filter" refers to the overlying material, and "base" refers to the underlying material. Continue the relationships between the filter material and the base material and between the riprap and the filter material. More than one layer of base material may be needed. Design each layer of filter material to be approximately 6 inches thick. |
| Riprap at Outlets | Design criteria for sizing the stone and determining the dimensions of riprap pads used at the outlets of drainage structures are contained in Outlet Protection (BMP C-ECM-15). Install a filter fabric underlining for riprap used as outlet protection. |
| Riprap for Channel Stabilization | Design riprap for channel stabilization to be stable for the condition of bank-full flow in the reach of the channel being stabilized. Use the design procedure in Appendix A - Riprap Design in Channel, which is extracted from the Federal Highway Administration's Design of Stable Channels with Flexible Linings. This method establishes the stability of the rock material relative to the forces exerted upon it.<br>Extend riprap up the banks of the channel to a height equal to the maximum depth of flow or to a point where vegetation can be established to adequately protect the channel. Riprap should extend down the bank and across the bottom of the channel a distance equal to the thickness of the blanket. |

| Table C-ECM-13-5 Design Criteria for Riprap | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Freeboard and Height of Bank | For riprap and other lined channels, design the height of channel lining above the water surface based on the size of the channel, flow velocity, curvature, inflows, wind action, and flow regulation.<br>The height of the bank above the water surface varies similarly depending on the previously identified factors plus the type of soil.<br>Plate 2 is based on information developed by the U.S. Bureau of Reclamation for average freeboard and bank height in relation to channel capacity. Use this chart to calculate a minimum freeboard for placement of riprap and top of bank. |
| Riprap for Slope Stabilization | Design riprap for slope stabilization so that the natural angle of repose of the stone mixture is greater than the gradient of the slope being stabilized (see Plate 3). |
| Riprap for Lakes and Ponds Subject to Wave Action | Riprap used for shoreline protection on lakes and ponds may be subject to wave action. The waves affecting the shoreline may be wind-driven or created by boat wakes. Consult the latest edition of the VDOT Drainage Manual (Design of Slope Protection to Resist Wave Action) for specific design criteria in determining the required size of stones and the design wave height for such an installation. Use the equations in Appendix B - Riprap Design Equations for Lakes and Ponds Subject to Wave Action to calculate other pertinent design parameters. For more in-depth design criteria concerning these installations, see the U.S. Army Corps of Engineers' Shore Protection Manual. |
| Riprap for Abrupt Channel Contractions | Refer to latest edition of the VDOT Drainage Manual for design criteria. |
| Riprap for Installations Subject to Tidal and Wave Action | The design of riprap structures for tidal areas is beyond the scope of the Virginia Erosion and Sediment Control Law and Virginia Erosion and Sediment Control Regulations. Notably, a riprap design for shoreline protection in tidal areas must meet all applicable state and federal requirements and be carried out by a qualified professional. |

| Table C-ECM-13-6 Requirements for Filter Fabric Used with Riprap | | |
|---|---|---|
| **Physical Property** | **Test Method** | **Requirements** |
| Grab Tensile | ASTM D4632 | 250 lbs. |
| Grab Elongation | ASTM D4632 | 15% |
| Trapezoid Tear | ASTM D4533 | 90 lbs. |
| CBR Puncture Resistance | ASTM D6241 | 900 lbs. |
| Apparent Opening Size | ASTM D4751 | 40 U.S. Sieve |

Only use fabrics not meeting these specifications when design procedure and supporting documentation are supplied to determine fabric strength.

CBR = California bearing ratio

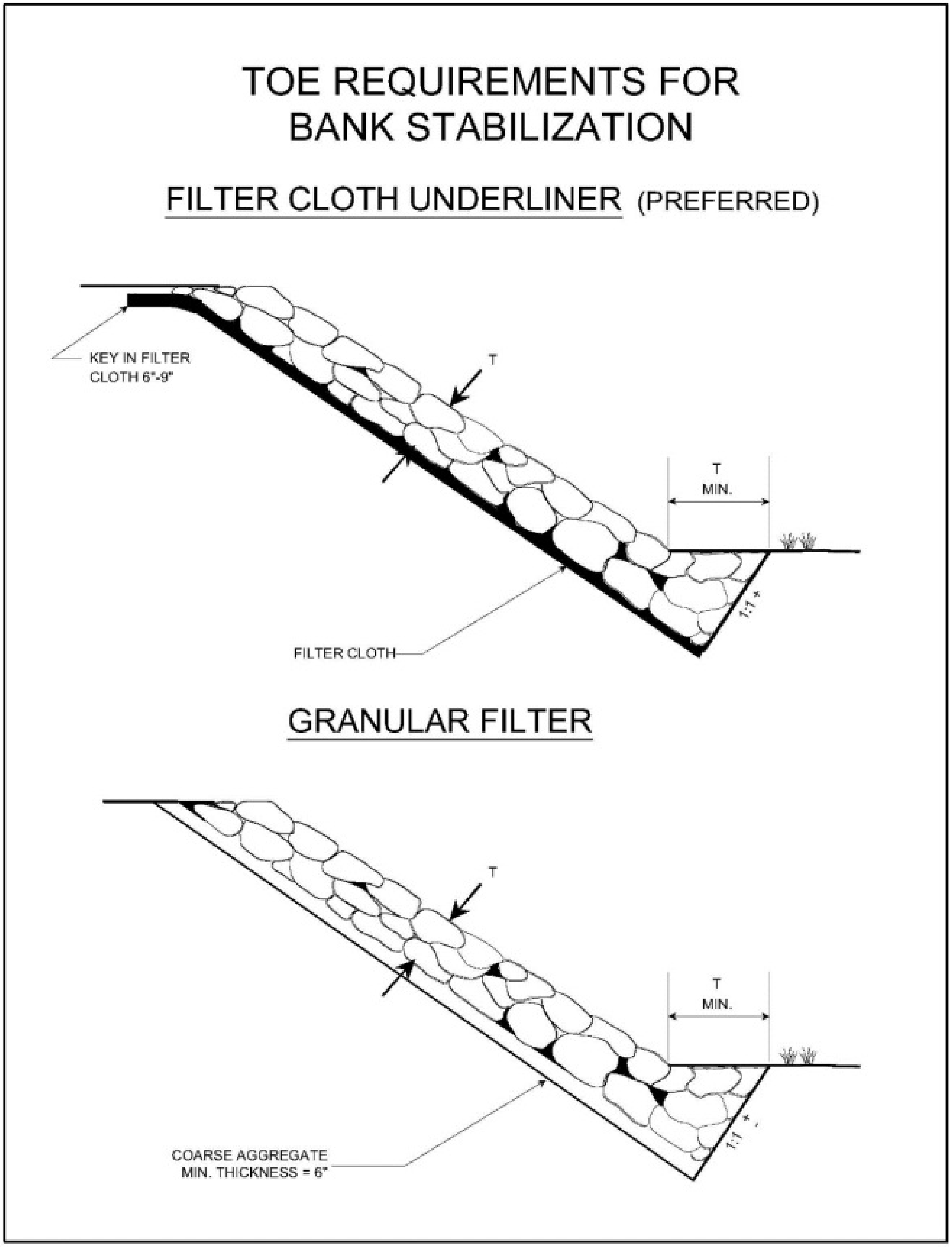
## 5.0 Construction Specifications

| Table C-ECM-13-7 Material Specifications for Riprap | |
|---|---|
| **Material** | **Notes on Proper Use** |
| Subgrade Preparation | Prepare the subgrade for the riprap or filter to the required lines and grades. Compact any fill required in the subgrade to a density approximately equal to that of the surrounding undisturbed material. Remove brush, trees, stumps, and other objectionable material. |
| Filter Fabric or Granular Filter | Place filter fabric immediately after slope preparation. For granular filters, spread the stone in a uniform layer to the specified depth (normally 6 inches). Where more than one layer of filter material is used, spread the layer so that there is minimal mixing of the layers.<br><br>When installing filter fabric, place the cloth directly on the prepared slope. Overlap the edges of the sheets by at least 12 inches, ensuring upstream cloth overlaps downstream cloth. Install anchor pins, 15 inches long, spaced every 3 feet along the overlap. Bury the upper and lower ends of the cloth at least 12 inches. Take care not to damage the cloth when placing the riprap. If damage occurs, remove and replace the damaged sheet.<br><br>For large stone (Class II or greater), install a 6-inch layer of granular filter over the cloth to prevent damage to the cloth. |
| Stone Placement | Immediately follow placement of the filter with placement of riprap. Place the riprap so that it produces a dense, well-graded mass of stone with few voids. The desired distribution of stones throughout the mass may be attained by selective loading at the quarry, controlled dumping of successive loads during final placing, or by a combination of these methods. Place the riprap to its full thickness in one operation. Do not place the riprap in layers. Do not place the riprap by dumping into chutes or similar methods that are likely to segregate the stone sizes. Take care not to dislodge the underlying material when placing the stones.<br><br>Ensure the finished slope is free of pockets of small stone or clusters of large stones. Hand placing may be necessary to achieve the required grades and a good distribution of stone sizes. Ensure the final thickness of the riprap blanket is within plus or minus one quarter of the specified thickness. |

## 6.0 Operations and Maintenance Considerations

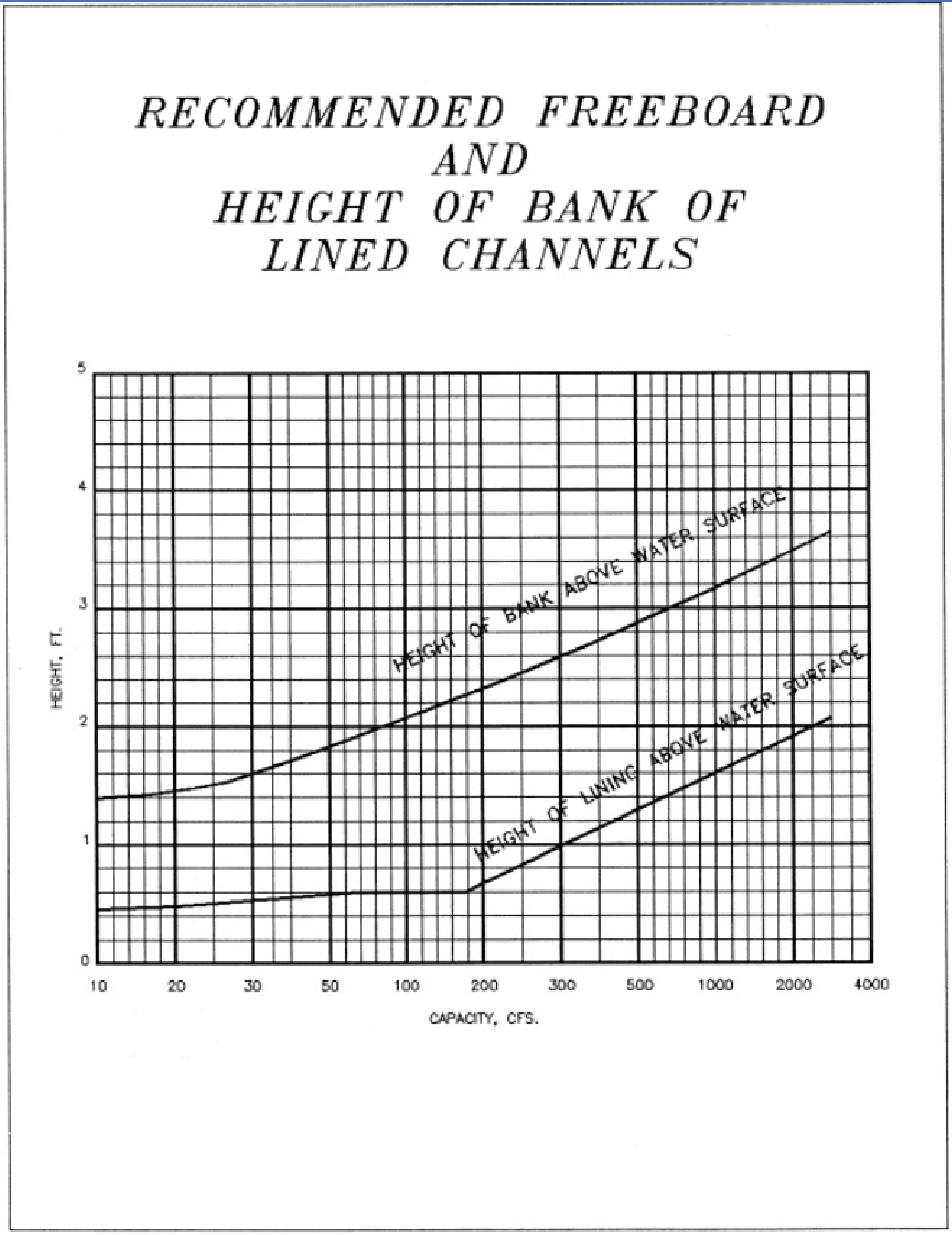
Periodically inspect the placed riprap to determine if high flows have caused scour beneath the riprap or filter fabric or dislodged any of the stone. Take care to properly control sediment-laden construction runoff, which may drain to the point of the new installation. Immediately perform any repairs needed.

### *Figure C-ECM-13-1 Toe Requirements for Riprap Bank Stabilization*




*Source: VDOT 2017*

*Figure C-ECM-13-2 Recommended Freeboard and Height of Bank of Lined Channels*




*Source: U.S. Bureau of Reclamation*

## 7.0 References

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## 8.0 Appendix A – Riprap Design in Channel

The design method described below is adapted from Hydraulic Engineering Circular No. 15 of the Federal Highway Administration (Kilgore and Cotton 2005). The method applies to both straight and curved sections of channel in which the flow is tangent to the bank of the channel.

**Tangent Flow – Federal Highway Administration Method**

This design method determines a stable rock size for straight and curved sections of channels. It is assumed that the shape, depth of flow, and slope of the channel are known. A stone size is chosen for the maximum depth of flow. If the sides of the channel are steeper than 3H:1V, the stone size must be modified accordingly. The final design size will be stable on both sides of the channel and the bottom.

1. Enter Plate 3 with the maximum depth of flow (feet) and channel slope (feet/foot). Where the two lines intersect, choose the d50 size of stone (Select the $d_{50}$ for the diagonal line above the point of intersection).
2. If channel sideslopes are steeper than 3H:1V, continue with Step 3; if not, the procedure is complete.
3. Enter Plate 4 with the sideslope and the base width to maximum depth ratio (B/d). Where the two lines intersect, move horizontally left to read $K_1$.
4. Determine from Plate 5 the angle of repose for the d50 size of stone and the sideslope of the channel (Use 42° for $d_{50}$ greater than 1.0. Do not use riprap on slopes steeper than the angle of repose for the size of stone).
5. Enter Plate 6 with the sideslope of the channel and the angle of repose for the $d_{50}$ size of stone. Where the two lines intersect, move vertically down to read $K_2$.
6. Compute $d_{50}$ x $K_1/K_2$ = $d'_{50}$ to determine the correct size stone for the bottom and sideslopes of straight sections of channel.

**For Curved Sections of Channel**

1. Compute the radius of the curve ($R_o$) measured at the outside edge of the bottom.
2. Compute the ratio of the top width of the water surface (Bs) to the radius of the curve ($R_o$), $B_s/R_o$.
3. Enter Plate 7 with the ratio $B_s/R_o$. Move vertically until the curve is intersected. Move horizontally left to read $K_3$.
4. Compute $d'_{50}$ x $K_3$ = $d_{50c}$ to determine the correct size stone for bottom and sideslopes of the curved sections of channel.

**Example Problem**

**Given:**

A trapezoidal channel 3 feet deep, 8 feet wide at the bottom, 2H:1V sideslopes, and a 2% slope.


**Calculate**:

A stable riprap size for the bottom and sideslopes of the channel.

**Solution**:

1. From Plate 3, for a 3-foot-deep channel on a 2% grade, $d_{50}$ = 0.75 foot or 9 inches.
2. Because the sideslopes are steeper than 3H:1V, continue with step 3.
3. From Plate 4, B/d = 8/3 = 2.67, Z = 2, K1 = 0.82.
4. From Plate 5, for $d_{50}$ = 9 inches, = 41°.
5. From Plate 6, for Z = 2 and = 41°, $K_2$ = 0.73.
6. $d_{50}$ x $K_1/K_2$ = $d'_{50}$ = 0.75 x 0.82/0.73 = 0.84 foot.

   0.84 foot x 12 inches/1 foot = 10.08. Use $d'_{50}$ = 10 inches.

**Given**:

The preceding channel has a curved section with a radius of 50 feet.

**Calculate**:

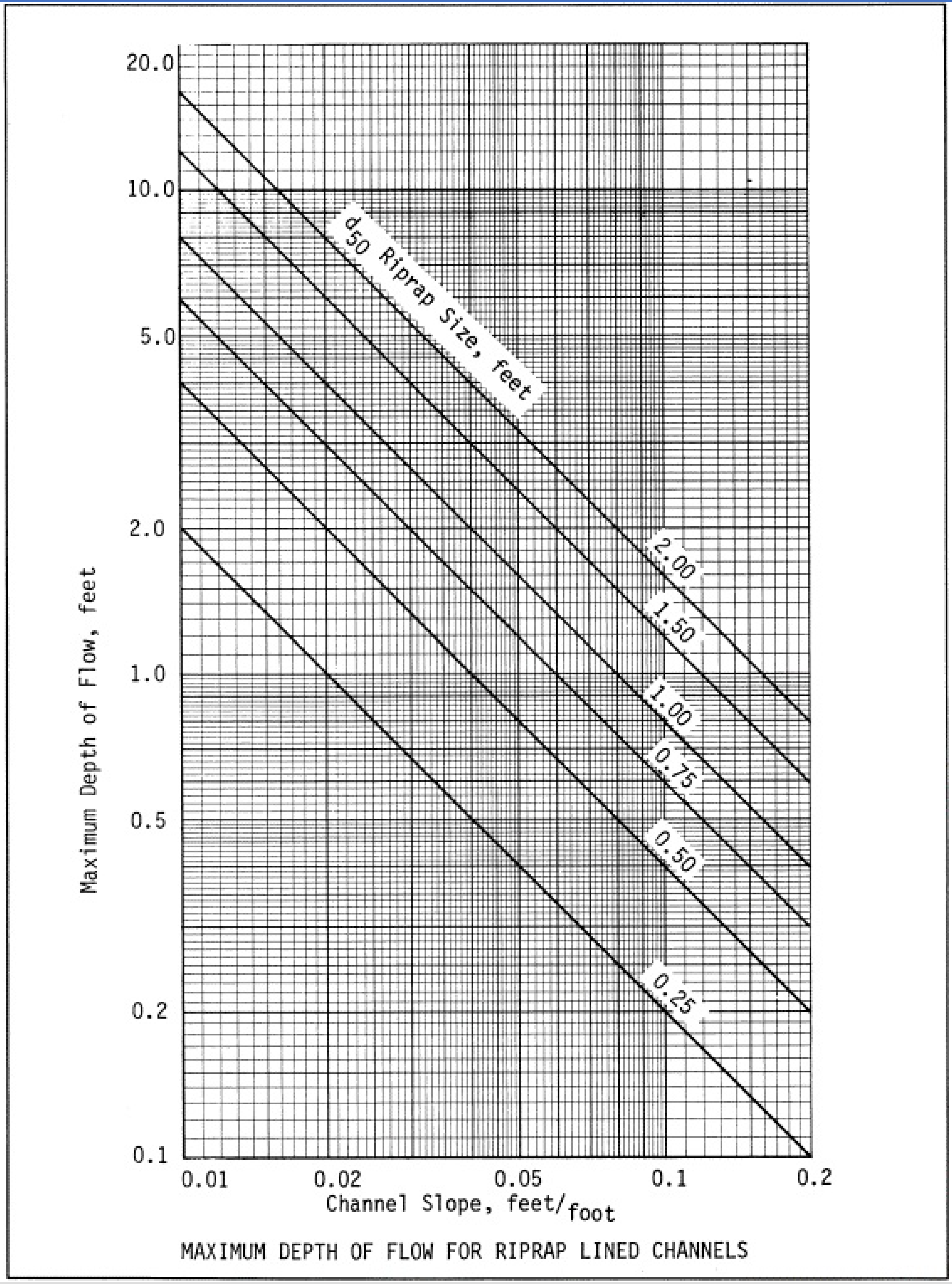
A stable riprap size for the bottom and sideslopes of the curved section of channel.

**Solution**:

1. $R_o$ = 50 feet
2. $B_s/R_o$ = 20/50 = 0.40
3. From Plate 7, for $B_s/R_o$ = 0.40, $K_3$ = 1.1
4. $d'_{50}$ x $K_3$ = 0.84 x 1.1 = 0.92 foot

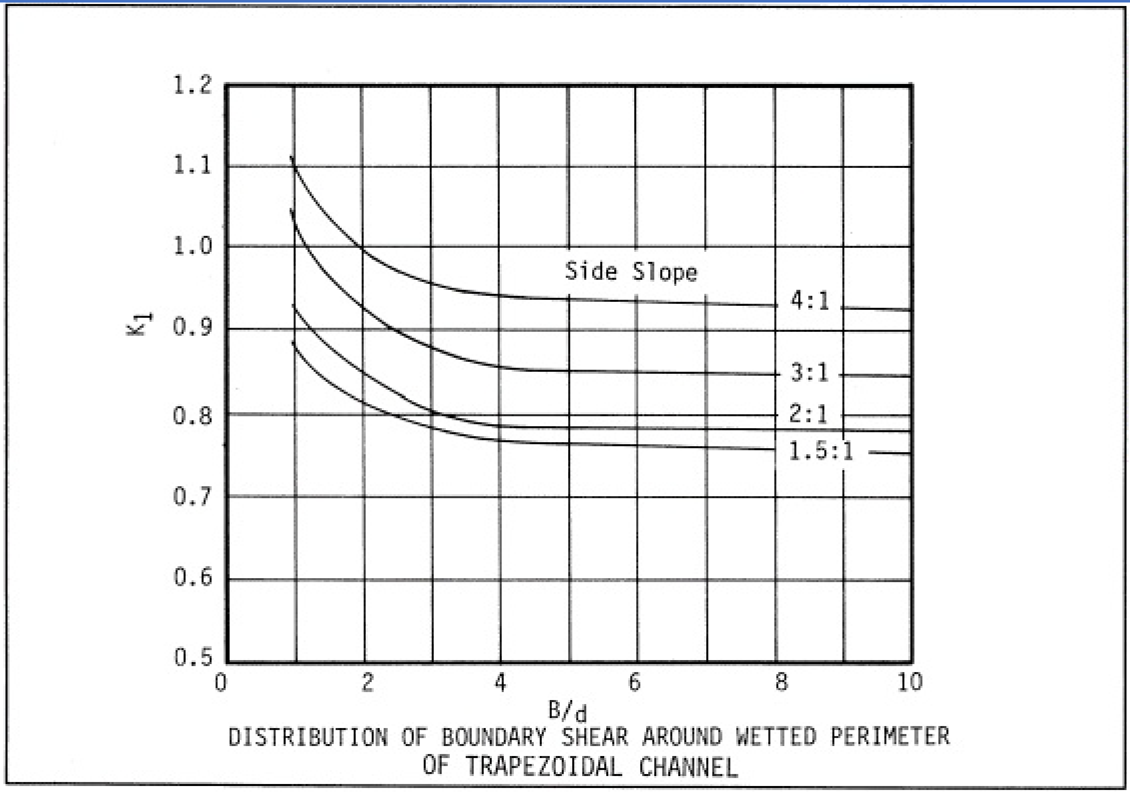
   0.92 foot x 12 inches/1 foot = 11.0.

## Figure C-ECM-13-3 Maximum Depth of Flow for Riprap Lined Channels



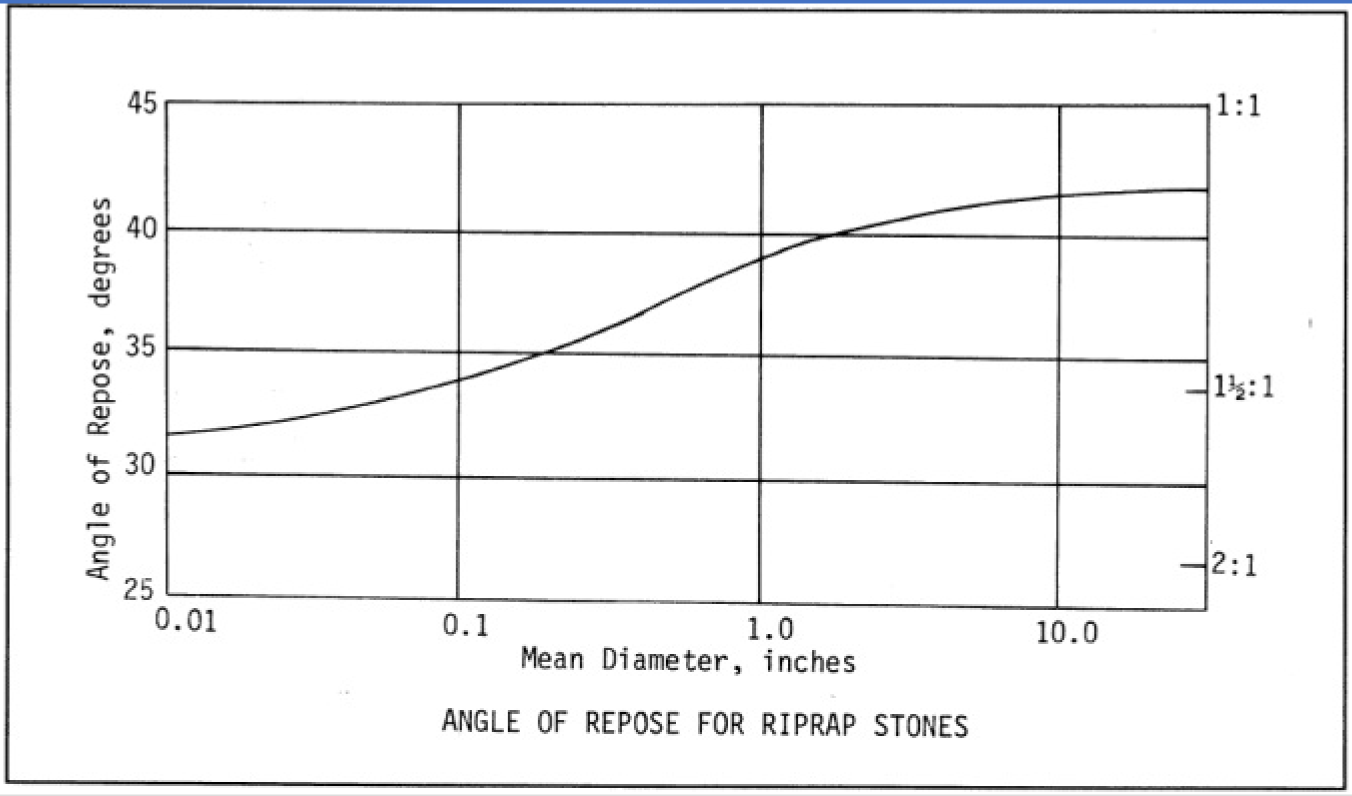

Source: VDOT 2017

**Figure C-ECM-13-4 Distribution of Boundary Shear Around Wetted Perimeter of Trapezoidal Channel**



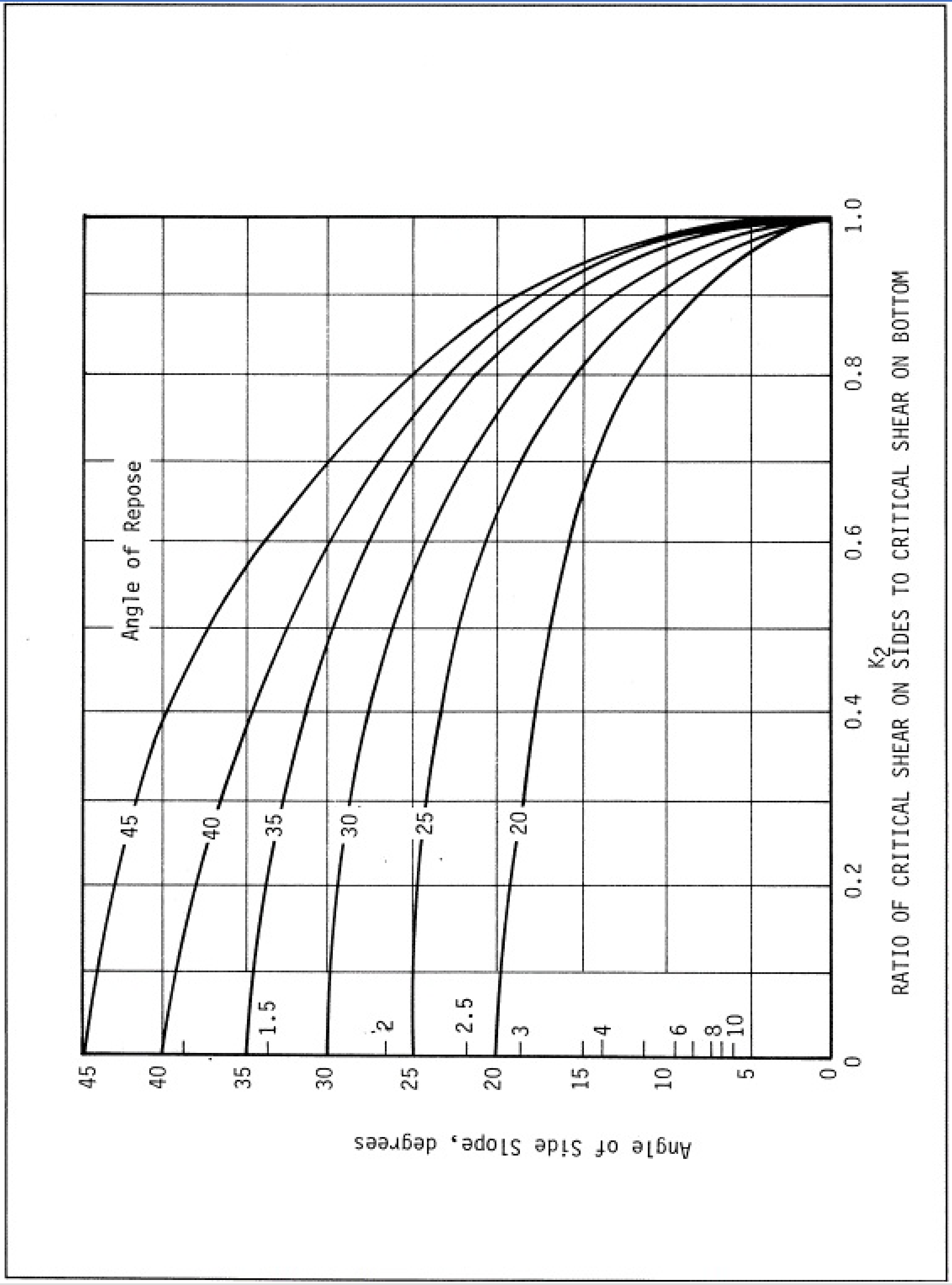

*Source: VDOT 2017*

**Figure C-ECM-13-5 Angle of Repose for Riprap Stones**



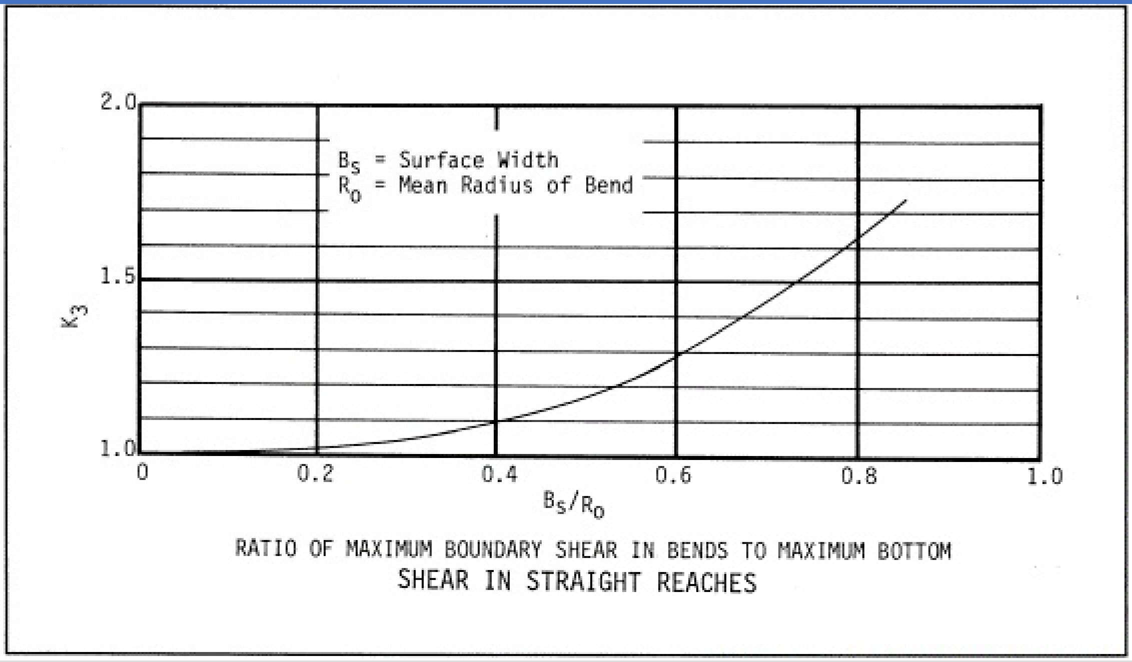

*Source: VDOT 2017*

**Figure C-ECM-13-6 Ratio of Critical Shear on Sides to Critical Shear on Bottom**




Source: VDOT 2017

***Figure C-ECM-13-7 Ratio of Maximum Boundary Shear in Bends to Maximum Bottom Shear in Straight Reaches***




*Source: VDOT 2017*

## 9.0 Appendix B – Riprap Design Equations for Lakes and Ponds Subject to Wave Action

In many instances, riprap is installed along the shoreline of non-tidal ponds and lakes to protect them from the continual scour of wind-driven waves. The following methods/equations will produce minimum design parameters for size of stone, depth of buried toe (or width of riprap apron), and height of structure above average water level.

I. **Size of Riprap Required** – See VDOT Drainage Manual ("Design of Slope Protection to Resist Wave Action").

II. **DWH (Design Wave Height)** – See VDOT Drainage Manual ("Design of Slope Protection to Resist Wave Action") or U.S. Army Corps of Engineers' Shore Protection Manual.

III. **Depth of Buried Toe** = DWH at design wind speed.

IV. **Width of Riprap Apron (Alternative to Buried Toe)** = DWH x 2.

V. **Height of Structure (Above the Average Water Level)** = DWH x 1.5.

# C-ECM-14 Temporary Level Spreader

## 1.0 Definition

A temporary level spreader is a flow control measure that receives concentrated, potentially erosive inflow, and converts to a sheet flow condition by discharging across a horizontal level weir onto areas of undisturbed soil that is stabilized by existing vegetation.

## 2.0 Purpose and Applicability of Best Management Practice

A level spreader is used to intercept concentrated sediment-free runoff from stabilized areas and convert it to sheet flow where it can be released to a well-vegetated stabilized area in a non-erosive manner.

Use a temporary level spreader where there is a need to divert stormwater away from disturbed areas to avoid overstressing erosion control measures, and where sediment-free stormwater runoff can be released in sheet flow down a stabilized slope without causing erosion. The level spreader should provide a stable outlet for measures including diversions, dikes, or right-of-way diversions.

If a level spreader is to be used with higher design flows, use a rigid spreader lip as discussed below. If a level spreader is proposed for use in Virginia Department of Transportation (VDOT) rights-of-way, refer to the appropriate VDOT standards and specifications for specific regulations. For other permanent installations, refer to P-SUP-08 for more information.

## 3.0 Planning and Considerations

Temporary diversion dikes (BMP C-ECM-04) and temporary right-of-way diversions (BMP C-ECM-07) each call for a stable outlet for concentrated stormwater flows. The level spreader is a relatively low-cost structure to convert smaller volumes of concentrated flow to sheet flow for release without causing erosion downstream where conditions are suitable (see Figure C-ECM-14-1).

Construct the level spreader prior to site prep in previously undisturbed soil where the outlet area below the level lip is uniform with a maximum slope of 10% and is stabilized by existing vegetation.

Ensure that the outlet lip is constructed to be completely level in a stable, undisturbed soil. Any depressions in the lip will concentrate the flow, resulting in erosion.

Under higher design flow conditions, use a rigid outlet lip design to create the desired sheet flow conditions. Treat runoff water containing high sediment loads in a sediment-trapping device before releasing the runoff to a level spreader.

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF** – Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

**MS-11: OUTLET PROTECTION** – Before newly constructed stormwater conveyance channels or pipes are made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and receiving channel.

9VAC25-875-560

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: Low**

## 5.0 Design Criteria

Use of the level spreader applies only where the spreader can be constructed on undisturbed soil and the area below the level lip is uniform with a slope of 10% or less and is stabilized by natural vegetation (Virginia Department of Environmental Quality [VDEQ] 1992).

| Table C-ECM-14-1 Design Criteria Parameters | |
|---|---|
| **Topic** | **Requirement** |
| Capacity | Determine the capacity of the spreader by estimating peak flow from the 10-year storm. Restrict the drainage area so that maximum flows into the spreader will not exceed 30 cubic feet per second (cfs).<br>See Appendix A – Hydrologic and Hydraulic Methods and Computations. |
| Spreader Dimensions | When water enters the spreader from one end, as from a diversion, select the appropriate length, width, and depth of the spreader from Table C-ECM-14-2.<br>Construct the level spreader with a minimum depth of 6 inches, as measured from the lip. Increase the depth to expand temporary storage capacity, improve trapping of debris, and enhance settling of any suspended solids.<br>Construct a 20-foot transition section in the diversion channel so the width of the diversion will smoothly meet the width of the spreader to ensure uniform outflow. |
| Grade | Provide a smooth transition grade, less than or equal to 1%, for the last 20 feet of the diversion channel entering the level spreader .<br>Grade the level spreader channel to 0% grade.<br>The side slopes of the spreader should be 2H:1V or flatter and should be tied into higher ground to prevent flow around the spreader. |
| Spreader Lip | *Vegetated spreader lips should have a maximum design flow of 4 cfs.*<br>Use a rigid lip of non-erodible material, such as pressure-treated timbers or concrete curbing, for higher design flows. *Rigid spreader lips should have a maximum design flow of 30 cfs.*<br>Note: Refer to Table C-ECM-13-2 to determine the length of the spreader lip based on design flow. |
| Outlet Area | Discharge the runoff from level spreader on a generally smooth area to preserve sheet flow and prevent concentration. This area should be well-vegetated with a maximum slope of 10%. |
| Vegetation | Seed and mulch all disturbed areas immediately after construction. |
| Sources: Henrico Department of Public Works 2022; VDEQ 1992; North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service (NCDEQ) 2013 | |

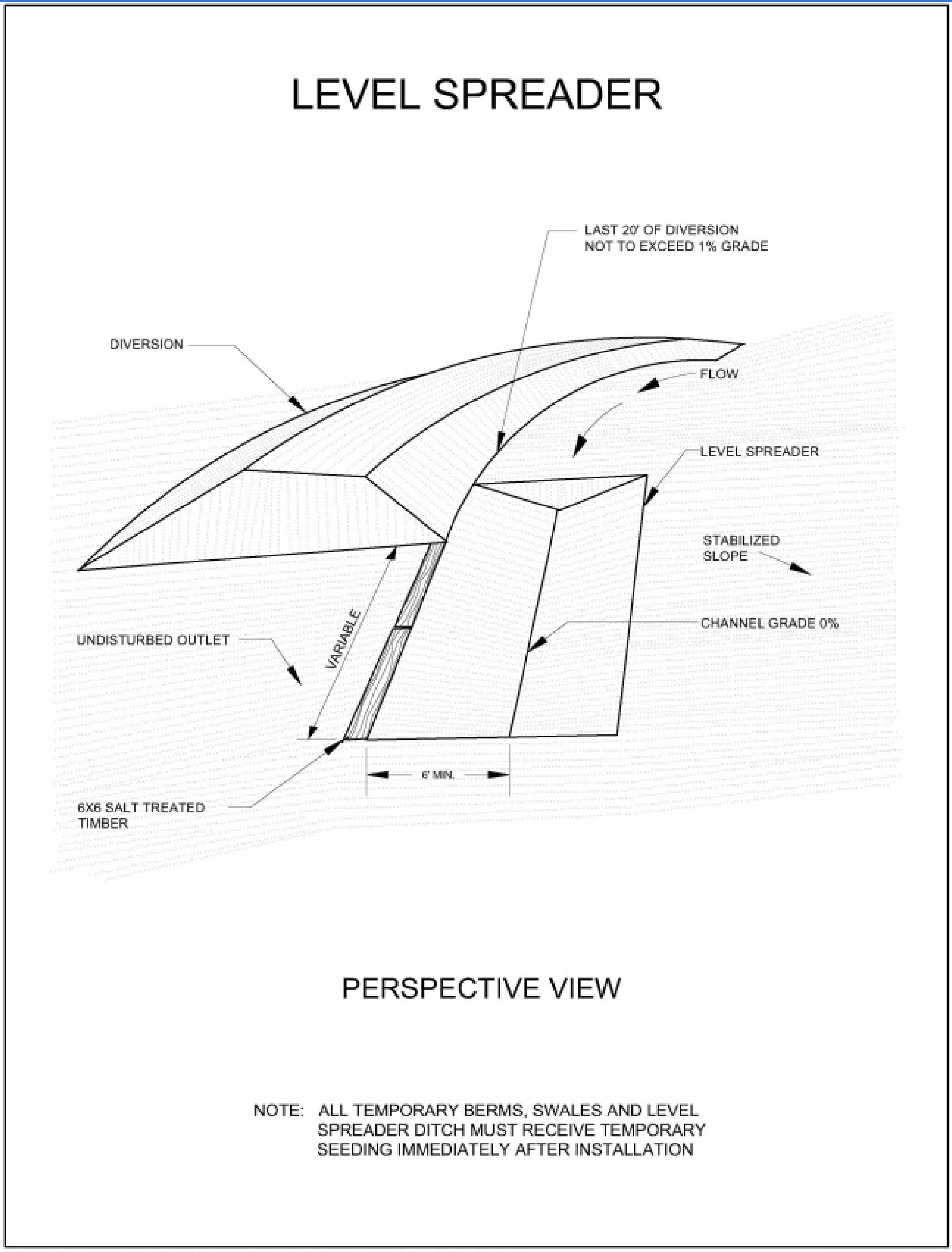
Table C-ECM-14-2 below provides the (1) minimum width of the level spreader, (2) the minimum depth of the level spreader along the entire length of the spreader, and (3) the minimum length of the level spreader based upon design flow to the level spreader from the vegetated diversion.

| Table C-ECM-14-2 Level Spreader Sizing | | | |
|---|---|---|---|
| Minimum Dimensions for Level Spreader | | | |
| **Design Flow (cfs)** | **Spreader Width (feet)** | **Depth (feet)** | **Length (feet)** |
| 0 – 10 | 6 | 0.5 | 10 |

| Table C-ECM-14-2 Level Spreader Sizing | | | |
|---|---|---|---|
| Minimum Dimensions for Level Spreader | | | |
| 10 – 20 | 6 | 0.6 | 20 |
| 20 – 30 | 6 | 0.7 | 30 |

Source: NCDEQ 2013

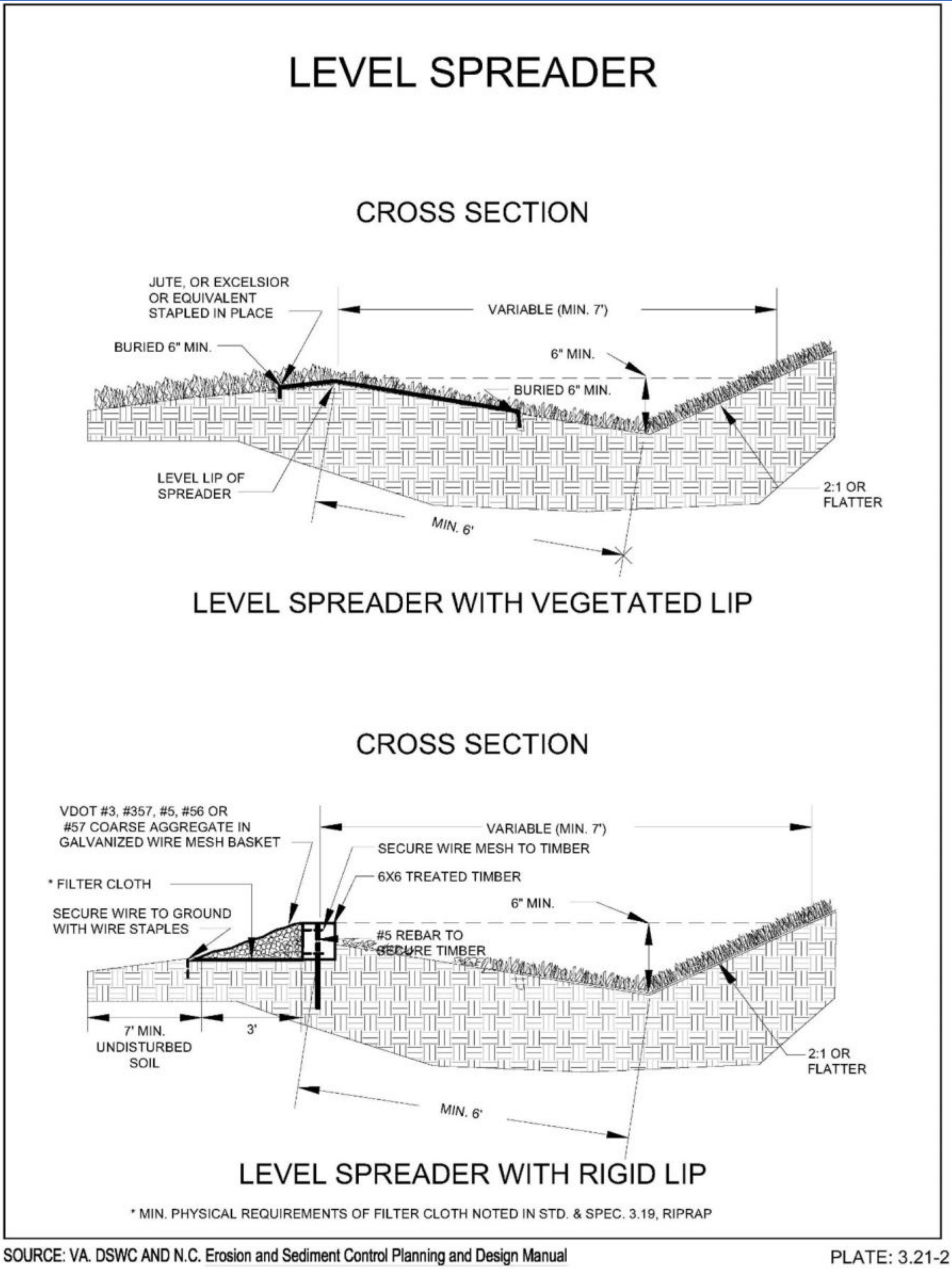
**Figure C-ECM-14-1 Level Spreader Perspective View**




SOURCE: ADAPTED FROM N.C. Erosion and Sediment Control Planning and Design Manual PLATE: 3.21-1

Source: NCDEQ 2013

### Figure C-ECM-14-2 Level Spreader Cross-Sections




Source: Virginia Department of Conservation and Recreation 2004; NCDEQ 2013

## 6.0 Construction Specifications

1. Construct level spreaders on undisturbed soil (not fill material).
2. Shape the entrance to the spreader so that runoff enters directly onto the 0% channel.
3. Construct a 20-foot transition section from the diversion channel to blend smoothly to the width and depth of the spreader.
4. Construct the spreader lip at 0% grade to ensure uniform spreading of stormwater runoff.
5. Vegetated Lip Only – Construct the spreader lip on undisturbed soil to uniform height and 0% grade over the length of the spreader. Protect the lip of an earthen level spreader with an erosion-resistant material, such as a reinforced erosion control blanket or turf reinforcement mat, to prevent erosion and enable establishment of vegetation.

   For a vegetated lip, install erosion control matting a minimum of 4 feet wide that extends 6 inches over the level lip. Bury the upstream edge at least 6 inches deep in a vertical trench. Secure the downstream edge in place with closely spaced, heavy-duty staples, at least 12 inches long. Install the protective covering for vegetated lip a minimum of 4 feet wide extending 6 inches over the lip and buried 6 inches deep in a vertical trench on the lower edge. Butt the upper edge against smoothly cut sod and securely hold in place with closely spaced heavy-duty wire staples (see Figure C-ECM-14-2).
6. Rigid Lip Only – Provide a smooth transition between the level spreader and the native ground downslope.

   Entrench the rigid level lip at least 2 inches below existing ground and securely anchor to prevent displacement. Install an apron of VDOT #1, #2, or #3 coarse aggregate to the top of the level lip and extended downslope at least 3 feet. Place filter fabric under stone and use galvanized wire mesh to hold stone securely in place (see Figure C-ECM-14-2).
7. Discharge the released runoff onto undisturbed stabilized areas with slope not exceeding 10%. Slope should be sufficiently smooth to preserve sheet flow and prevent flow from concentrating.
8. Immediately after construction, appropriately seed and mulch the entire disturbed area of the spreader.
9. Ensure that the end of the level spreader is constructed high enough to prevent water conveyance at this location and fulfill the proper intent of the best management practice.

## 7.0 Operations and Maintenance Considerations

Inspect the level spreader at least once a year and after every measurable rainfall event (i.e., 0.1 inch per 24 hours) and make repairs immediately as needed.

Maintain the level spreader lip at zero grade to allow proper function of the measure. Avoid the placement of any material on the level spreader and prevent construction traffic across the structure.

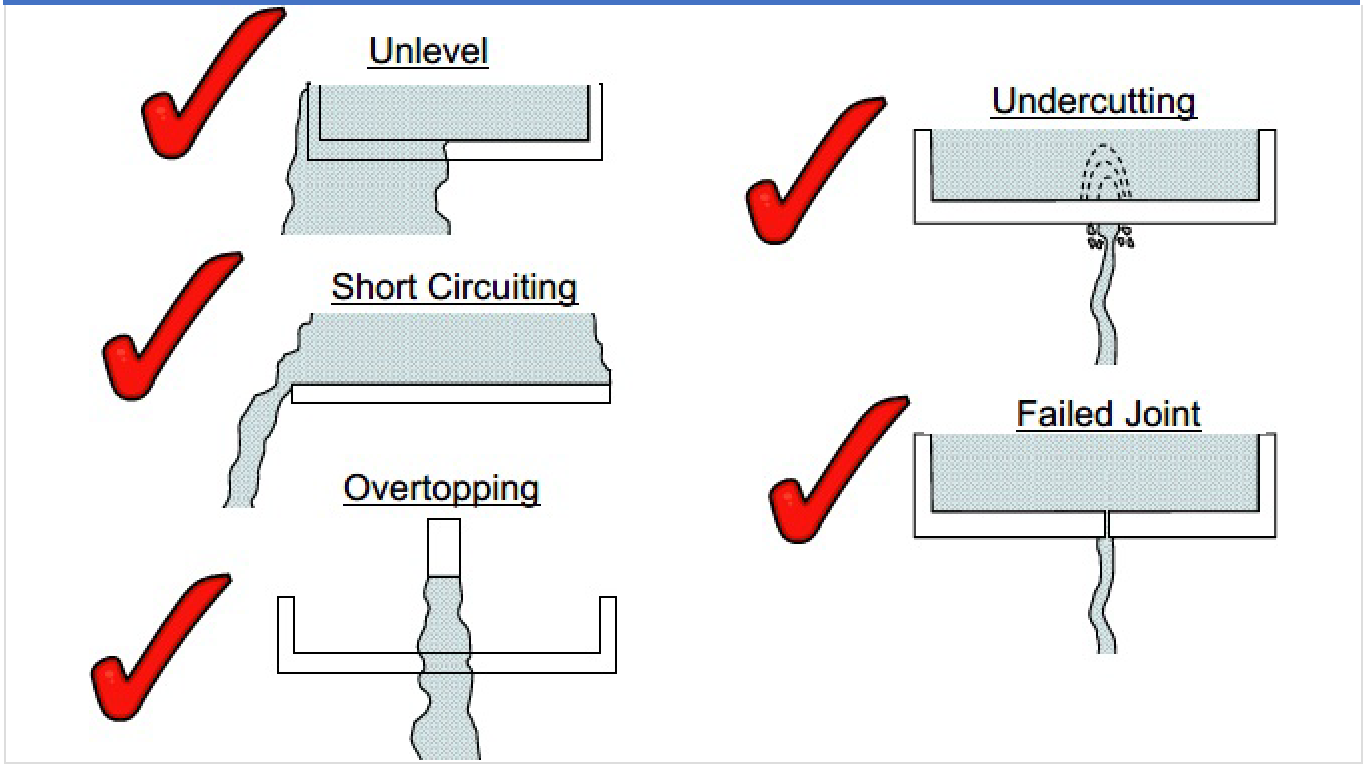
Immediately repair any damage to the level spreader. Inspect the level spreader in the same conditions for subsidence along the perimeter of the measure.

Inspect for low points, sags, cracks, breaks, etc. in the level spreader that would result in concentrated flow discharging over the spreader. Any identified alterations to the grade of the level spreader must be repaired immediately.

Debris buildup within the channel should be removed when it has accumulated to 20% of channel capacity.

### 7.1 Common Level Spreader Failures

*Figure C-ECM-14-4 Common Level Spreader Failures*




*Source: Rocco 2007*

Inspect the downstream area of the level spreader for any development of water channelization or subsidence.

Inspect the upstream diversion channel after every rainfall. If any changes in soil morphology are observed within the undisturbed soil and are seen to be forming a sinkhole or soil intrusion, carefully monitor that location. If an existing sinkhole is discovered where runoff is found to be diverting, that sinkhole may be transitioned and classified into a United States Environmental Protection Agency (USEPA) Class V injection well. More information on Class V injection wells is provided at the following USEPA website: https://www.epa.gov/uic/basic-information-about-class-v-injection-wells#:~:text=A%20Class%20V%20well%20is%20used%20to%20inject,simple%20shallow%20wells%20to%20complex%20experimental%20injection%20technologies (USEPA 2023).

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# C-ECM-15 Outlet Protection

## 1.0 Definition

Outlet protection takes the form of structurally lined aprons or other forms of energy-dissipating devices placed at the outlets of pipes, curb openings, ditch turnouts, or paved channel sections to slow discharge velocity from the outlet to prevent an erosive condition.

## 2.0 Purpose and Applicability of Best Management Practice

Outlet protection prevents scouring at stormwater outlets, protects the outlet structure, and minimizes the potential for downstream erosion by reducing the velocity and energy of concentrated stormwater flows. Outlet protection applies to the outlets of all pipes and engineered channel sections. Discharge velocities from pipe outfalls, outlet channels, or similar structures should not cause erosion in downstream channels.

## 3.0 Planning and Considerations

The outlets of pipes and structurally lined channels are points of critical erosion potential. Stormwater transported through man-made conveyance systems at design capacity generally reaches a velocity that exceeds the capacity of the receiving channel or area to resist erosion. To prevent scour at stormwater outlets, a flow transition structure is needed, which will absorb the initial impact of the flow and reduce the flow velocity to a level that will not erode the receiving channel or area.

The most used device for outlet protection is a rock  lined apron. These aprons are generally lined with riprap, grouted riprap, or concrete and are constructed at a zero grade for a distance that is related to the outlet flowrate and the tailwater level. Criteria for designing such an apron are contained in this practice. The site grading plan and drainage structure profiles must accommodate and show the full length of the outlet protection apron at zero grade.

Consider riprap stilling basins or plunge pools to reduce flow velocity rapidly in lieu of aprons where high flows would require excessive apron length. See the plunge pool design guidance in this specification. In karst areas, use an impermeable liner in lieu of a filter fabric to prevent infiltration of stormwater into groundwater at the site location.

Consider other energy dissipaters, such as concrete impact basins or paved outlet structures, where site conditions warrant. Alternative methods of energy dissipation are identified in Hydraulic Design of Energy Dissipaters for Culverts and Channels (Thompson and Kilgore 2006).

## 4.0 Stormwater Performance Summary

**MS-11: OUTLET PROTECTION** – Before any newly constructed stormwater conveyance channel can be made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and the receiving channel.

9VAC25-875-560

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: Low**

## 5.0 Design Criteria

***For outlet protection design standards within the Virginia Department of Transportation (VDOT) right-of-way, the designer should consult with the appropriate VDOT Drainage Manual.***

The design of structurally lined aprons at the outlets of pipes and paved channel sections applies to the immediate area or reach below the pipe or channel and does not apply to continuous rock linings of channels or streams; see Stormwater Conveyance Channel (C-ECM-09).

Do not protect the pipe or channel outlets at the tops of cut slopes or on slopes steeper than 10% using just outlet protection because of the reconcentration and large velocity of flow encountered as the flow leaves the structural apron.

Adequate outlet protection should be installed and stabilized before newly constructed stormwater conveyance channels or pipes are made operational.

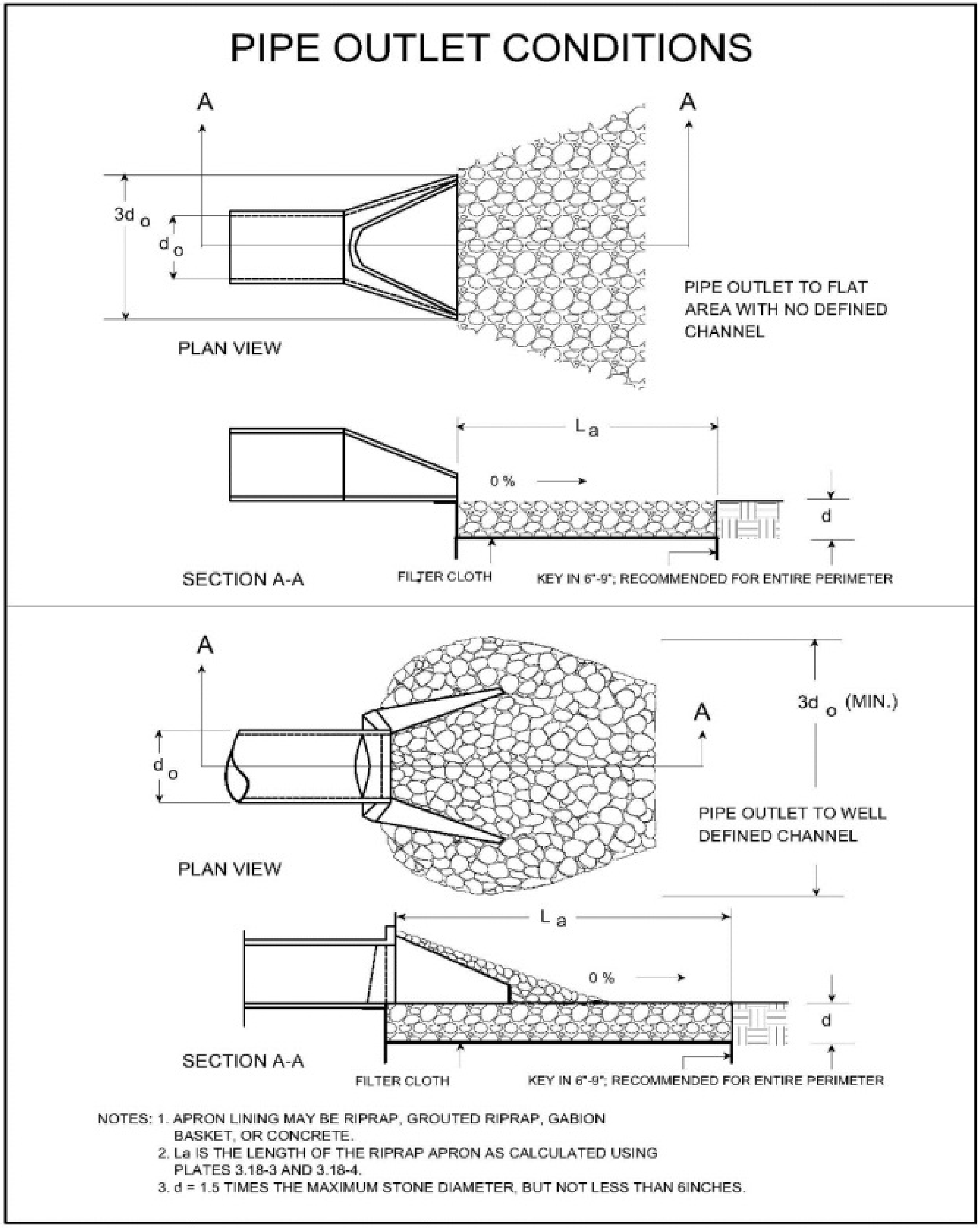
Design outlet protection according to the following criteria.

**Pipe Outlets**

| Table C-ECM-15-1 Outlet Protection Design Criteria Specifications | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Tailwater Depth | Determine the depth of tailwater immediately below the pipe outlet for the design capacity of the pipe. Manning's Equation may be used to determine tailwater depth (see Appendix A, Hydraulic and Hydrologic Calculations). *If the tailwater depth is less than half the diameter of the outlet pipe, classify it as a* **Minimum Tailwater Condition**. *If the tailwater depth is greater than half the pipe diameter, classify it as a* **Maximum Tailwater Condition**. Pipes that outlet onto flat areas with no defined channel may be assumed to have a **Minimum Tailwater Condition**. Notably, in most cases where post- development stormwater runoff has been concentrated or increased, Minimum Standard MS-19 will be satisfied only by outfall into a defined channel. |
| Apron Length | Determine the apron length from the curves according to the tailwater condition: Minimum Tailwater (see Figure C-ECM-15-3) and Maximum Tailwater (see Figure C-ECM-15-4) |
| Apron Width | When the pipe discharges directly into a well-defined channel, the apron should extend across the channel bottom and up the channel banks to an elevation 1 foot above the maximum tailwater depth or to the top of the bank (whichever is less).<br>If the pipe discharges onto a flat area with no defined channel, the width of the apron should be determined as follows:<br>1. The upstream end of the apron, adjacent to the pipe, should be three times as wide as the inner diameter of the outlet pipe.<br>2. For a **Minimum Tailwater Condition**, the downstream end of the apron should be as wide as three times the outlet pipe inner diameter plus the length of the apron.<br>For a **Maximum Tailwater Condition**, design the downstream end to be as wide as three times the pipe diameter plus 0.4 time the length of the apron. |
| Thickness | Design the minimum thickness of riprap to be 1.5 times the diameter of the maximum stone size but not less than 6 inches. |
| Bottom Grade | Design and construct the apron with no slope along its length (0% grade).<br>Design and construct structurally lined aprons at the outlets of pipes and paved channels to be at a 0% grade for a distance related to the outlet flowrate and the tailwater depth. |
| Sideslopes | If the pipe discharges into a well-defined channel, ensure the sideslopes of the channel are not steeper than 2H:1V. |
| Alignment | Locate the apron so there are no bends in the horizontal alignment. |
| Materials | The apron may be lined with riprap, grouted riprap, concrete, or gabion baskets. Determine the median sized stone (d50) for riprap from the curves on Figure C-ECM-15-3 and Figure C-ECM-15-4 according to the tailwater condition. Ensure the gradation, quality, and placement of riprap conform to Riprap (C-ECM-13). |

| Table C-ECM-15-1 Outlet Protection Design Criteria Specifications | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Filter Fabric | In all cases, place filter fabric between the riprap and the underlying soil to prevent soil movement into and through the riprap. Use a material that meets or exceeds the physical properties for filter fabric identified in Riprap (C-ECM-13). Use AASHTO M-288, Class II Woven Filter Cloth or approved equivalent. See Figure C-ECM-15-1 for orientation details. In karst areas, use an impermeable liner, in lieu of a filter fabric, that meets field strength requirements to be able to withstand tearing, breaking, and other challenges during heavy storm events. |

## Figure C-ECM-15-1 Pipe Outlet Conditions




Source: Va. DSWC

### Outlet Protection Design

When designing outlet protection for a channel or swale, use the guidance for a pipe having an equivalent cross-sectional area and design discharge to the channel or swale.

**When a pipe is flowing full**, the anticipated velocity can be calculated from the continuity equation:

$$V = \frac{Q}{A}$$

where:

V = Velocity (feet per second [fps])

Q = Design Discharge (cubic feet per second [cfs])

A = Cross-sectional Area of the Pipe (square feet [ft2])

**When a pipe is not flowing full**, a different procedure should be used to determine the velocity. Due to the increased friction that occurs along the wetted perimeter, full flow does not represent the greatest flow capacity of a pipe. For circular pipes, peak flow occurs at 93% of the total inside diameter. Likewise, the average velocity of a pipe flowing half full is equal to that for one flowing full. Therefore, the anticipated velocity should be determined either using Manning's equation (for circular channels), standard design nomographs, or Figure C-ECM-15-5**, limited to pipes with gradients <0.05 ft/ft.**

To use Figure C-ECM-15-5, the full flow capacity of the pipe should be determined from the following equation.

$$Q_f = \frac{0.464}{n} D^{\frac{8}{3}} S^{\frac{1}{2}}$$

Use the Continuity Equation to determine the full flow velocity:

$$V_f = \frac{Q_f}{A}$$

Calculate the ratio of partial to full flow discharge:

$$\frac{d}{D} = \frac{Q_d}{Q_f}$$

where:

d/D = Ratio of Part Full to Full Flow Discharge

$Q_d$ = Design Discharge (cfs)

$Q_f$ = Full-Flow Discharge (cfs)

D = Diameter (ft)

S = Slope of pipe

Using Figure C-ECM-15-5, find the value for the d/D ratio. Project a vertical line from the d/D ratio upward to the FLOW curve, then a horizontal line to the VELOCITY curve, and then follow a vertical line downward to determine the velocity ratio. Multiply the velocity ratio by the velocity calculated from the Continuity Equation to determine the less-than-full velocity.

**For pipes with slopes equal to or greater than 0.05 ft/ft, use the Manning's equation.** The velocity is calculated for full flow conditions even though the pipe is typically flowing only partially full. Partial flows will be very close to the full-flow velocity for depths of flow between 30% and 100% of the pipe diameter in steep slope conditions. Manning's equation for full pipe flow is as follows:

$$V = \frac{1.486}{n}\left[\frac{D}{4}\right]^{\frac{2}{3}}\sqrt{S}$$

where:

V = Velocity (feet per second [ft/s])

D = Pipe diameter (ft)

S = Pipe slope (feet per foot [ft/ft])

For pipes with high anticipated velocities (>13.0 ft/s), drop structures or other energy reducing structures are recommended to reduce velocity before discharge.

**Paved Channel Outlets**

1. The flow velocity at the outlets of paved channels flowing at design capacity should not exceed the permissible velocity of the receiving channel (see Table C-ECM-15-2 and Table C-ECM-15-3).
2. The end of the paved channel should merge smoothly with the receiving channel section. There should be no flooding at the end of the paved section. Where the bottom width of the paved channel is narrower than the bottom width of the receiving channel, a transition section, typically of riprap, should be provided. The maximum side divergence of the transition should be 1 in 3F where:

$$F = \frac{V}{\sqrt{gd}}$$

where:

F = Froude number

V = Velocity at beginning of transition (ft/s)

d = depth of flow at beginning of transition (ft)

g = 32.2 feet per second squared (ft/s2)

3. Bends or curves in the horizontal alignment at the transition are not allowed unless the Froude number (F) is 1.0 or less, or the section is specifically designed for turbulent flow. The transition from supercritical flow (F > 1) to a subcritical flow (F < 1) should occur within the riprap apron and should be calculated before installation of a riprap outlet protection device to ensure accuracy and quality of the measure.

**Example:**

For a paved channel transitioning into a grass-lined channel, with a grassed channel slope of 8% vegetated with Bermudagrass, the permissible velocity of the grass-lined channel in erosion-resistant soils should be no greater than 5 fps. If the depth of the water in the grass-lined channel is 6 inches, and the depth of the water in the paved channel is 12 inches, the following velocity comparison/equivalency can be used:

$$\frac{V_{PC}}{\sqrt{gd_{PC}}} = \frac{V_{GC}}{\sqrt{gd_{GC}}}$$

where:

PC = Paved Channel

GC = Grass Channel

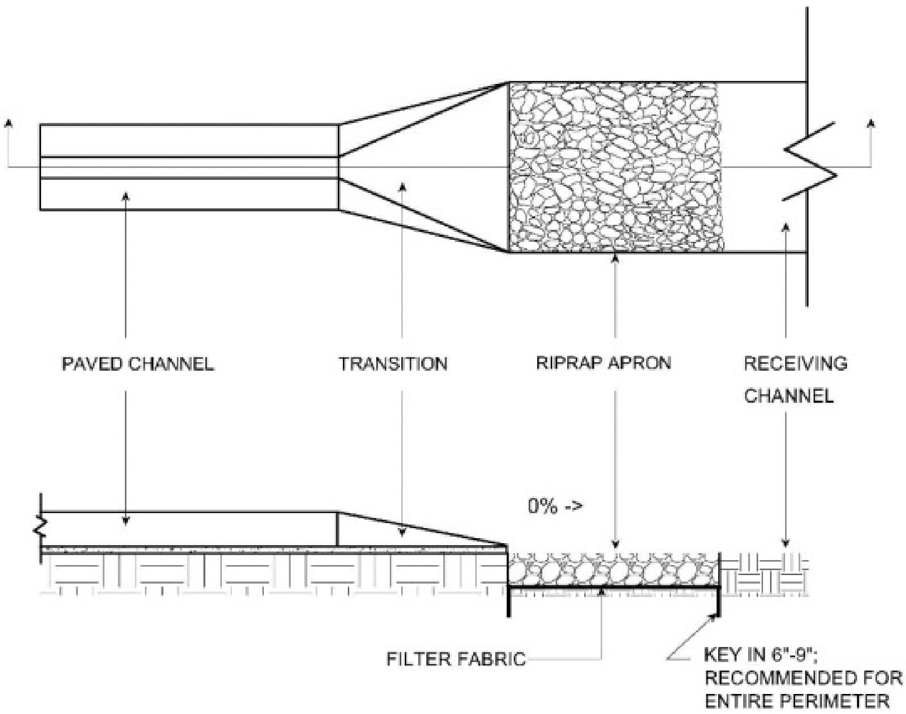
Therefore:

$$V_{PC} = \frac{V_{GC}}{\sqrt{gd_{GC}}}\sqrt{gd_{PC}}$$

$$V_{PC} = \frac{5}{\sqrt{32.2*0.5}}\frac{5}{\sqrt{32.2*0.5}}\sqrt{32.2*1} = 7.07 \text{ ft/s}$$

## *Figure C-ECM-15-2 Paved Channel Outlet Specifications*

# PAVED CHANNEL OUTLET




<u>NOTES:</u>

1. RIPRAP APRON REDUCES THE FLOW VELOCITY BELOW THE PERMISSIBLE VELOCITY OF THE NATURAL RECEIVING CHANNEL.
2. TRANSITION SIDE DIVERGENCE IS 1 IN 3F, WHERE

$$F = \text{FROUDE NUMBER} = \frac{V}{\sqrt{gd}}\text{, WHERE}$$

V = VELOCITY AT THE BEGINING OF THE TRANSITION

d = DEPTH OF FLOW AT THE BEGINING OF THE TRANSITION

g = 32.2 ft./sec$^2$

*Source: Va. DSWC*

| Table C-ECM-15-2 Permissible Velocities for Grass-Lined Channels | | | |
|---|---|---|---|
| Channel Slope | Lining | Erosion-Resistant Soil Velocity (ft/s) | Easily Eroded Soil Velocity (ft/s) |
| 0 – 5% | Bermudagrass | 6 | 4.5 |
| | Reed canarygrass<br>Tall fescue<br>Kentucky bluegrass | 5 | 3.75 |
| | Grass-legume mixture | 4 | 3 |
| | Red fescue<br>Redtop<br>Annual Lespedeza<br>Small grains<br>Temporary vegetation | 2.5 | 1.875 |
| 5 – 10% | Bermudagrass | 5 | 3.75 |
| | Reed canarygrass<br>Tall fescue<br>Kentucky bluegrass | 4 | 3 |
| | Grass-legume mixture | 3 | 2.25 |
| >10% | Bermudagrass | 4 | 3 |
| | Reed canarygrass<br>Tall fescue<br>Kentucky bluegrass | 3 | 2.25 |

Source: Schwab, G., et al., 1966

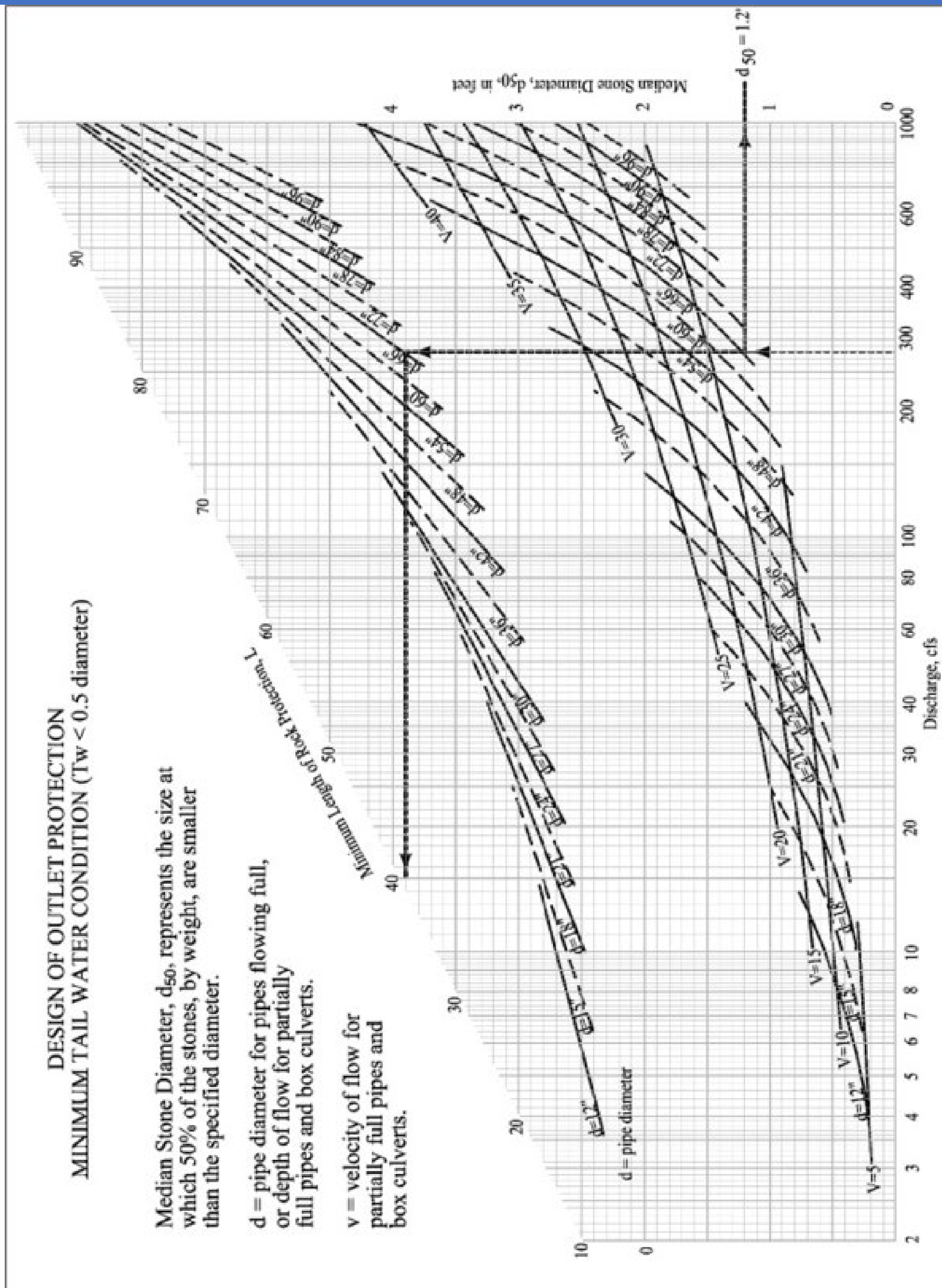
1. A velocity of 3 ft/s should be the maximum if only a sparse cover can be established or maintained because of shade, soils, or climate.
2. A velocity of 3 to 4 ft/s should be used under normal conditions if the vegetation is to be established by seeding.
3. A velocity of 4 to 5 ft/s should be used only if a dense, vigorous sod is obtained quickly or if water can be diverted out of the waterway while vegetation is establishing.
4. A velocity of 5 to 6 ft/s may be used on well established, good quality sod. Special maintenance may be required.
5. A velocity of 6 to 7 ft/s may be used only on established, excellent quality sod and only under special circumstances in which flow cannot be handled at a lower velocity. Under these conditions, special maintenance and appurtenant structures will be required.
6. If stone centers or other erosion-resistant materials supplement the vegetative lining, the velocities in the Table C-ECM-15-2 may be increased by 2 ft/s.
7. When base flow exists, a rock-lined low-flow channel should be designed and incorporated into the vegetative lined channel section.

| Table C-ECM-15-3 Permissible Velocities for Earth Linings | |
|---|---|
| Soil Types | Permissible Velocities (ft/s) |
| Fine Sand (non-colloidal) | 2.5 |

| Table C-ECM-15-3 Permissible Velocities for Earth Linings | |
|---|---|
| Sandy Loam (non-colloidal) | 2.5 |
| Silt Loam (non-colloidal) | 3.0 |
| Ordinary Firm Loam | 3.5 |
| Fine Gravel | 5.0 |
| Stiff Clay (very colloidal) | 5.0 |
| Graded, Loam to Cobbles (non-colloidal) | 5.0 |
| Graded, Silt to Cobbles (colloidal) | 5.5 |
| Alluvial Silts (non-colloidal) | 3.5 |
| Alluvial Silts (colloidal) | 5.0 |
| Coarse Gravel (non-colloidal) | 6.0 |
| Cobbles and Shingles | 5.5 |
| Shales and Hard Plans | 6.0 |

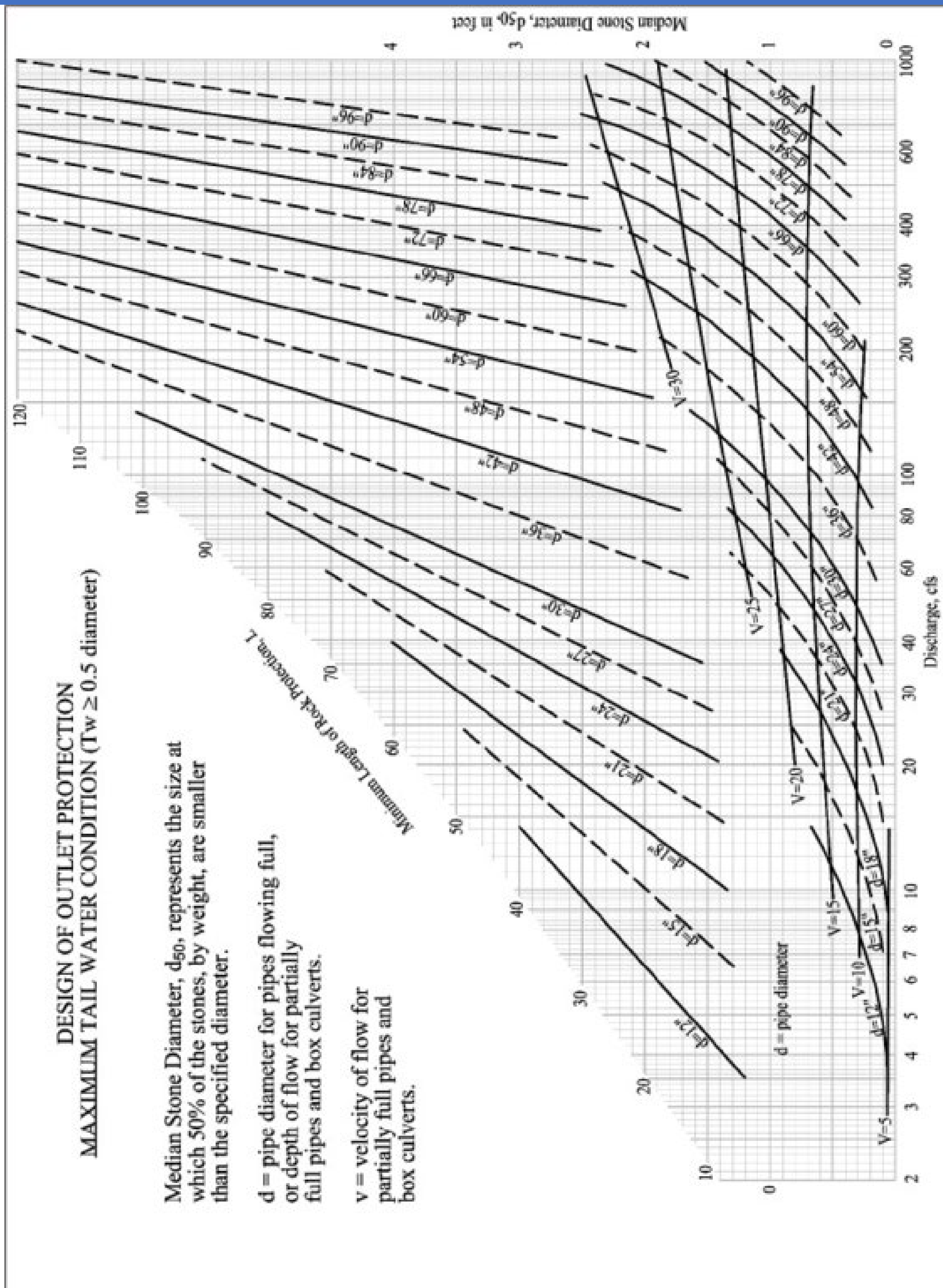
Source: Schwab, G., et al, 1966

## Figure C-ECM-15-3 Minimum Tailwater Condition Tw < 0.5*d




Source: USDA NRCS, 2004

## Figure C-ECM-15-4 Maximum Tailwater Condition Tw >= 0.5*d




Source: USDA NRCS, 2004

**Nomograph Use Process**

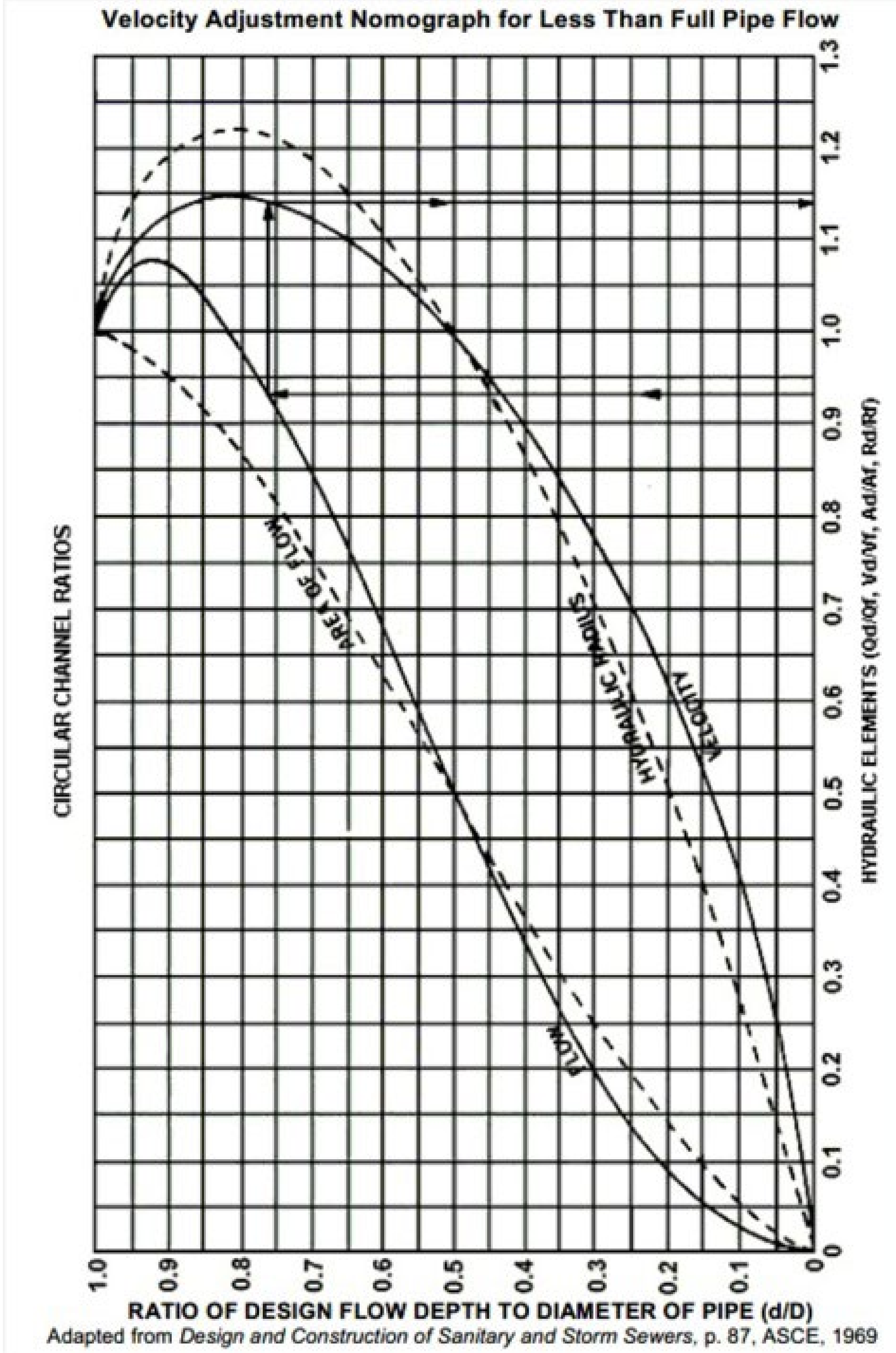
Step1. Find design flow (Q) or velocity (V); this is the flows that directly travels into the outlet protection apron as seen in the outlet protection design equations.

Step2. Find median stone size (D50); this corresponds to the intersection of the flow/velocity and the lower curved line of the proposed influent pipe size to the outlet protection apron. Take the intersection point and draw a line perpendicular to the RIGHT SIDE of the nomograph, indicating the appropriate median stone size (D50).

Step3. Find the apron length (L); this corresponds to the intersection of the flow/velocity and the upper curved line of the proposed influent pipe size to the outlet protection apron. Take the intersection point and draw a line to the LEFT SIDE of the nomograph, indicating the appropriate apron length (L).

*These two parameters allow the design engineer to properly size the outlet protection apron and propose an appropriate location for the measure.

## Figure C-ECM-15-5 Circular Channel Ratios




*Source: ASCE 1969*

**Plunge Pool (see Figure C-ECM-15-6 – Plunge Pool Design**

Where discharge velocity and energy at a pipe outlet are sufficient to erode the downstream channel reach, pipe outlets are cantilevered, or high flows require excessive apron length, a plunge pool is a means of reducing velocity before traditional outlet protection.

This practice applies to outlets of all types such as road culverts, sediment basins, and stormwater management facilities. Plunge pools are an alternative to rock outlet protection and are preferable where space is constrained. A plunge pool may be temporary or permanent based on design. The designer should note that traditional outlet protection, such as an apron, may be required downstream of the plunge pool. Base the plunge pool location on land use and feasibility; intended use is limited to the proposed or existing channel. For calculations of scouring, refer to Chapter 10 of HEC-14 (Riprap Basin and Aprons).

**Plunge Pool Design**

1. Select type of plunge pool (larger stone required for Type 1):

   Type I: Plunge pool is depressed half the size of the culvert rise.

   Type II: Plunge pool is depressed the full height of the culvert rise.

2. Determine the riprap (d50) stone size for the plunge pool type and design storm flow.

   Type I: d50 = (0.0125d2/Tw) x (Q/d2.5)4/3

   Type II: d50 = (0.0082d2/Tw) x (Q/d2.5)4/3

3. Determine plunge pool dimensions.

   C = (3 x d) + (6 x F)

   B = (2 x d) + (6 x F)

   where:

   $d_{50}$ = the median stone size (feet), refer to Riprap (C-ECM-12)

   d = the culvert diameter or span (feet)

   $T_w$ = the tailwater depth (feet)

   Q = the design flow for the culvert, minimum 10-year, 24-hour storm (cfs)

   B = the plunge pool width (feet)

   C = the plunge pool length (feet)

   D = 2 x $d_{50}$ = riprap thickness (feet)

   E = the culvert diameter or span (feet) equal to d

   3E = the plunge pool bottom length in feet

   2E = the plunge pool bottom width (feet)

   F = plunge pool depth (feet) = d (for Type II) or 0.5 d (for Type I)

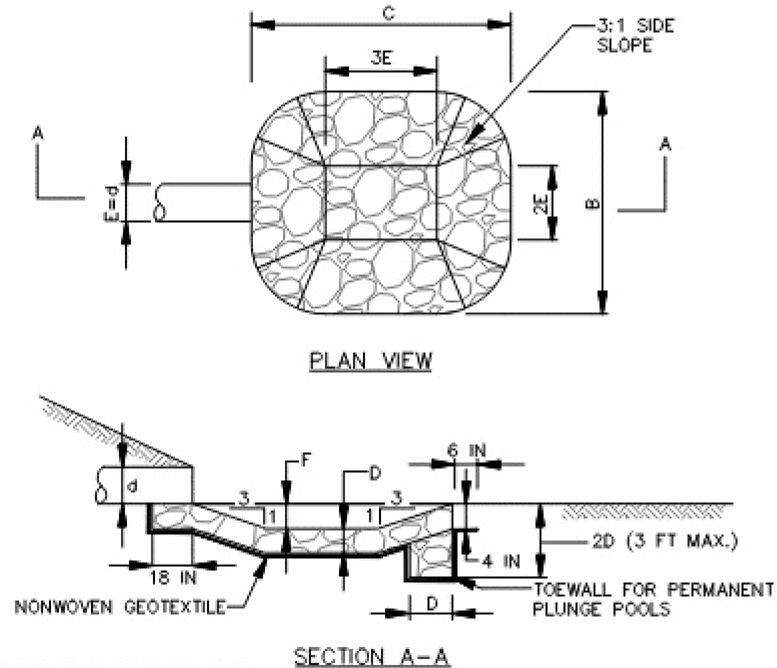
4. For permanent uses, provide a toe wall at the downstream end at a depth twice the (D) dimension and at a width equal to the (D) dimension on non-woven geotextile. Extend the riprap a minimum of 18 inches under the outlet pipe if the outlet does not have a footer or headwall.
5. Provide an underdrain to a suitable outfall if standing water in the plunge pool is an issue or as required by the certified plan reviewer.
6. Provide the design values on the plans for the following dimensions indicated on Figure C-ECM-15-6: B, C, D, E, and F.

**Figure C-ECM-15-6 Plunge Pool Design**

**DETAIL D-4-2 PLUNGE POOL**

STANDARD SYMBOL

PP




CONSTRUCTION SPECIFICATIONS

1. USE SPECIFIED CLASS OF RIPRAP.
2. USE NONWOVEN GEOTEXTILE AS SPECIFIED IN SECTION H-1 MATERIALS, AND PROTECT FROM PUNCHING, CUTTING, OR TEARING. REPAIR ANY DAMAGE OTHER THAN AN OCCASIONAL SMALL HOLE BY PLACING ANOTHER PIECE OF GEOTEXTILE OVER THE DAMAGED PART OR BY COMPLETELY REPLACING THE GEOTEXTILE. PROVIDE A MINIMUM OF ONE FOOT OVERLAP FOR ALL REPAIRS AND FOR JOINING TWO PIECES OF GEOTEXTILE.
3. PREPARE THE SUBGRADE FOR THE PLUNGE POOL TO THE REQUIRED LINES AND GRADES. COMPACT ANY FILL REQUIRED IN THE SUBGRADE TO A DENSITY OF APPROXIMATELY THAT OF THE SURROUNDING UNDISTURBED MATERIAL.
4. EMBED THE GEOTEXTILE A MINIMUM OF 4 INCHES AND EXTEND THE GEOTEXTILE A MINIMUM OF 6 INCHES BEYOND THE EDGE OF THE SCOUR HOLE.
5. STONE FOR THE PLUNGE POOL MAY BE PLACED BY EQUIPMENT. CONSTRUCT TO THE FULL COURSE THICKNESS IN ONE OPERATION AND IN SUCH A MANNER AS TO AVOID DISPLACEMENT OF UNDERLYING MATERIALS. DELIVER AND PLACE THE STONE FOR THE PLUNGE POOL IN A MANNER THAT WILL ENSURE THAT IT IS REASONABLY HOMOGENEOUS WITH THE SMALLER STONES AND SPALLS FILLING THE VOIDS BETWEEN THE LARGER STONES. PLACE STONE FOR THE PLUNGE POOL IN A MANNER TO PREVENT DAMAGE TO THE GEOTEXTILE. HAND PLACE TO THE EXTENT NECESSARY.
6. AT THE PLUNGE POOL OUTLET, PLACE THE STONE SO THAT IT MEETS THE EXISTING GRADE.
7. MAINTAIN LINE, GRADE, AND CROSS SECTION. KEEP OUTLET FREE OF EROSION. REMOVE ACCUMULATED SEDIMENT AND DEBRIS. AFTER HIGH FLOWS INSPECT FOR SCOUR AND DISLODGED RIPRAP. MAKE NECESSARY REPAIRS IMMEDIATELY.

MARYLAND STANDARDS AND SPECIFICATIONS FOR SOIL EROSION AND SEDIMENT CONTROL

| U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE | 2011 | MARYLAND DEPARTMENT OF ENVIRONMENT WATER MANAGEMENT ADMINISTRATION |
|---|---|---|

*Source: Maryland Department of the Environment 2011.*

## 6.0 Construction Specifications

1. Install and stabilize adequate outlet protection before newly constructed stormwater conveyance channels or pipes are made operational.

2. Ensure that the subgrade for the filter and riprap follows the required lines and grades shown in the plan. Compact any fill required in the subgrade to the density of the surrounding undisturbed material. Low areas in the subgrade on undisturbed soil may also be filled by increasing the riprap thickness.
3. Construct the riprap and gravel filter to conform to the specified grading limits shown on the plans.
4. Use filter fabric, when applicable, that meets the design requirements, and properly protect from punching or tearing during installation. Repair any damage by removing the riprap and placing another piece of filter fabric over the damaged area. Overlap all connecting joints so the top layer is above the downstream layer a minimum of 1 foot. If the damage is extensive, replace the entire filter fabric.
5. Riprap may be placed by equipment; but take care to avoid damaging the filter.
6. Riprap may be field stone or rough quarry stone. Use riprap that is hard, angular, highly weather-resistant, free of fines, and well graded.
7. Construct the apron on zero grade with no overfall at the end. Make the top of the riprap at the downstream end level with the receiving area or slightly below it.
8. Ensure that the apron is properly aligned with the receiving stream and preferably straight throughout its length. If a curve is needed to fit site conditions, place it in the upper section of the apron.
9. Immediately after construction, stabilize all disturbed areas with vegetation.

Where riprap is grouted, apply the following construction specifications:

1. Take precautions to prevent uncured concrete from coming into contact with any surface waters.
2. Place grout in a layer at a thickness equivalent to the d50 stone size over the entire extent of the apron before rock placement.
3. After rock placement, fill void spaces with grout.

## 7.0 Operations and Maintenance Considerations

Inspect riprap outlet structures weekly and after significant (0.5-inch or greater) rainfall events to identify any erosion around or below the riprap or if stones have been dislodged.

Immediately do all needed repairs to prevent further damage. Accumulated sediment and debris must be removed.

## 8.0 References

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# C-ECM-16 Flexible Transition Mat

## 1.0 Definition

A flexible scour-protection system that is used as a synthetic alternative to riprap outlet protection.

## 2.0 Purpose and Applicability of Best Management Practice

A transition mat is a high-density polyethylene (HDPE), ultraviolet (UV) stabilized, plastic sheet approximately 4 feet by 4 feet by 0.5 inch thick that contains multiple voids that allow vegetation to grow through or small gravel and pebbles to accumulate and stabilize the area. The mat protects the area at pipe outlets from scour until the water spreading out in the channel diminishes the turbulent forces. The channel downstream of the outlet, where flow becomes uniform, should still be evaluated to ensure that the channel lining can withstand the anticipated shear stress and/or velocity.

Transition mats may also be used for other applications (e.g., curb outfalls, spillways, overflow structures, stream banks, slopes) if manufacturer's recommendations are followed.

## 3.0 Planning and Considerations

- Install flow transition mats on a smooth, level, side-to-side (across the width of the flow area) surface to avoid water concentration; refer to Outlet Protection (BMP C-ECM-15).
- Grade the surface where necessary to remove any unevenness.
- Where a change in slope is greater than 25% (e.g., slope changes from 1% to greater than 26%), transition mats are not recommended.
- Transition mats are not appropriate for high-velocity discharges greater than 16 feet per second (fps).
- Locate the finish elevation of the tops of the mats at or slightly below (3-inch maximum) the pipe outlet.
- The width of the mat should be equal to the full width of the downstream channel across the channel bottom and side slopes. Allow for as much expansion of flow width as possible in the design when discharging directly into surface water to reduce velocities and promote infiltration.
- Ensure the downstream slope is as flat as possible to avoid increasing the velocity.
- Install a seeded turf reinforcement mat (TRM) underlayment where thick sod is not present. Use a high-performance TRM for slopes greater than 10H:1V, with the TRMs capable of withstanding velocities of at least 5.5 fps.
- If the following conditions are present, use a double layer of mats, with the open area of the second layer offset from those of the first layer.
    - The installation is located on erodible soils or subsidence-prone soils characteristic of karst terra~~ne~~in.
    - The installation is in an environmentally sensitive area.
    - The anticipated discharge velocity exceeds 7 fps.
    - The slope on which the mat is placed is 10H:1V or steeper.
- Anchor transition mats to achieve consistent contact with the underlying surface and prevent seepage underneath the mat.

- Locate the outlet and transition mat where adequate sunlight is available to promote healthy vegetation.

## 4.0 Stormwater Performance Summary

**MS-11: OUTLET PROTECTION** – Before newly constructed stormwater conveyance channels or pipes are made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and receiving channel.

9VAC25-875-560

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: Low**

## 5.0 Design Criteria

Design the outlet protection to withstand the 10-year storm event. Table C-ECM-16-1 lists the recommended dimensions for transition mat and TRM (if used) installations based on pipe diameter.

| Table C-ECM-16-1 Design Criteria Specifications | | | | |
|---|---|---|---|---|
| Flexible Transition Mat Application | | | | |
| Pipe Diameter (inches) | Discharge[a,b,c] (cfs) | Transition Mats | | TRM |
| | | Width (feet) x Length (feet) | Quantity | Width (feet) x Length (feet) |
| 12 | 8 | 4 x 4 | 1 | 6 x 8 |
| 24 | 30 | 4 x 8 | 2 | 11 x 12 |
| 36 | 75 | 8 x 12 | 6 | 17 x 16 |
| 48 | 100 | 12 x 16 | 12 | 23 x 20 |

Notes:

cfs = cubic feet per second

a. a Provide alternative methods of outlet protection if the design discharge exceeds that for the diameter shown.
b. b Verify discharge rates based on pipe diameters and pipe slopes using the 10-year storm to ensure that discharge quantities coincide with those in the table.
c. c Do not exceed the manufacturer's specification for maximum discharge to the transition mat regardless of the discharge shown in the table above.

## 6.0 Construction Specifications

1. Continue soil cover beyond the outlet apron area to properly protect the downstream channel and prevent head cutting.
2. Install a soil cover (seeded TRM, sod, or both) across the full width of channel, including the bottom and up both side slopes.
3. Install transition mats at a maximum of 1 to 3 inches below the flowline of the culvert or culvert apron. Install so that there are no waterfall impacts onto the transition mats.
4. Install anchors per manufacturer's installation guidelines.

## 7.0 Operations and Maintenance Considerations

Failure of a transition mat has occurred when a rill forms under the mat. If rills form under the mat, remove the mat, grade the rill, and provide a higher form of protection. Transition mats are generally permanent installations, and maintenance should not be necessary.

Used in a temporary installation, the transition mats and TRMs can be picked up and moved when appropriate.

Mowing over a vegetated transition mat is allowed; a minimum height of 4 inches is recommended. Mowing is not recommended where soft, saturated soils exist.

Inspect transition mats for underlying subsidence in karst areas.

## 8.0 References

Iowa Department of Natural Resources. 2006. Iowa Construction Site Erosion Control Manual. Available online at: https://publications.iowa.gov/8127/.

Pennsylvania Department of Environmental Protection. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

# C-ENV-01 Vegetative Streambank Stabilization

## 1.0 Definition

Vegetative streambank stabilization is the use of vegetation to stabilize streambanks.

## 2.0 Purpose and Applicability of Best Management Practice

Vegetative streambank stabilization is used to protect streambanks from the erosive forces of flowing water along banks in creeks, streams, and rivers subject to erosion from excess runoff.

Vegetative streambank stabilization is generally applicable where bankfull flow velocity does not exceed 5 feet per second (ft/s) and soils are erosion-resistant. At flows higher than 5 ft/s, structural measures are generally required to stabilize bank soils.

Vegetative streambank stabilization does not apply to the banks of streams subject to tidal influence.

## 3.0 Planning and Considerations

A primary cause of stream channel erosion is the increased frequency of bankfull flows, which can result from upstream development and changing weather patterns.

Most natural stream channels are formed with a bankfull capacity to pass the runoff from a storm with a 1.5- to 2-year recurrence interval. However, in a typical urbanizing watershed, stream channels are subject to a 3- to 5-fold increase in the frequency of bankfull flows. As a result, stream channels that were once parabolic in shape and covered with vegetation are often transformed into wide, rectangular channels with barren banks.

The use of living plants instead of, or in conjunction with, structural measures offers many advantages. The degree of protection, which may be low to start with, increases as the plants grow and spread. The repair and maintenance of structures is unnecessary where self-maintaining streambank plants are established. The protection provided by natural vegetation is more reliable and effective where the cover consists of natural plant communities that are native to the site. Planting vegetation is less damaging to the environment than installing structures. Vegetation also provides habitat for fish and wildlife and is aesthetically pleasing. Plants protect streambanks from erosion by reducing stream velocity, binding soil in place with a root mat, and covering the soil surface when high flows tend to flatten vegetation against the banks. For these reasons, always consider vegetation first.

The addition of vegetation to the streambank will lower the carrying capacity of the stream. The designer should analyze all impacts of this project with the proper hydrologic and hydraulic models. Evaluate the erosion potential for the stream to determine the best solutions. Consider the following items in the evaluation:

1. The frequency of bankfull flow based on anticipated watershed development;
2. The channel slope and flow velocity by design reaches;
3. The antecedent soil conditions;
4. Present and anticipated channel roughness (Manning's n) values;
5. The locations of channel bends along with bank conditions; and
6. The locations of unstable areas and trouble spots. Steep channel reaches, high erosive banks, and sharp bends may require structural stabilization measures such as riprap, while the remainder of the streambank may require only vegetation.

Table C-ENV-01-1 provides a comprehensive list of design considerations for vegetative streambank stabilization.

Where streambank stabilization is required and velocities appear too high for the use of vegetation, consider structural measures (see Structural Streambank Stabilization BMP C-ENV-02) or the use of permanent erosion control matting (see Soil Stabilization Blankets and Matting BMP C-SSM-05). Notably, obtain any applicable approval or permits from other state or federal agencies before working in such areas. The design engineer should ensure that all necessary permitting work is coordinated with the US Army Corps of Engineers (USACE) and/or the Virginia Department of Environmental Quality (VDEQ) as applicable.

For permanent streambank stabilization, refer to the Virginia Stream Restoration and Stabilization Best Management Practice (BMP) Guide.

| Table C-ENV-01-1 Vegetative Streambank Stabilization Design Considerations | |
|---|---|
| **Area to be Stabilized** | **Notes on Proper Use** |
| Vegetation Zones Along Watercourses | At the edges of all natural watercourses, plant communities exist in a characteristic succession of vegetative zones, the boundaries of which depend on site conditions, such as the steepness and shape of the bank, and the seasonal and local variations in water depth and flowrate. Streambanks commonly exhibit the following zonation (see Figure C-ENV-01-1).Aquatic Plant Zone: This zone is normally permanently submerged. In Virginia, this zone is inhabited by plants, such as pondweeds and water lilies, which reduce the water's flowrate by friction. The roots of these plants help to bind the soil, and they further protect the channel from erosion because the water flow tends to flatten them against the banks and bed of the stream. Reed-Bank Zone: The lower part of this zone is normally submerged for only about half the year. In Virginia, this zone is inhabited by rushes, reed grasses, cattails, and other plants that bind the soil with their roots, rhizomes, and shoots and slow the water's flowrate by friction. |
| Vegetation Zones Along Watercourses | Shrub Zone: This zone is flooded only during periods of average high water. In Virginia, the shrub zone is inhabited by trees and shrubs, such as willow, alder, dogwood, and viburnum, with a high regenerative capacity. These plants hold the soil with their root systems and slow water speed by friction. The plants also protect tree trunks from damage caused by breaking ice and help to prevent the formation of strong eddies around large trees during flood flows. Shrub zone vegetation is particularly beneficial along the impact bank of a stream meander, where maximum scouring tends to occur.<br><br>Infringement of shrub vegetation into the channel tends to reduce the channel width, increasing probability of floods. However, brief flooding of riverside woods and undeveloped bottomlands does no significant damage, and the silt deposits in these wooded areas are less of a problem than they are on failed banks. Tree Zone: This zone is flooded only during periods of very high water (i.e., the 2-year bankfull flow or greater flows). Typical plants in Virginia that inhabit this zone are trees in the ash-elm, alder-ash, and oak-hornbeam associations. These trees hold soil in place with their root systems. |

## 4.0 Stormwater Performance Summary

**MS-15: BED AND BANK STABILIZATION** – The bed and banks of a watercourse shall be stabilized immediately after work in the watercourse is completed.

9VAC25-875-560

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

Table C-ENV-01-2 provides general guidelines for maximum allowable velocities in streams to be protected by vegetation.

1. Ensure that channel bottoms are stable before stabilizing channel banks.
2. Keep velocities at bankfull flow non-erosive for the site conditions.
3. Provide mechanical protection, such as riprap, on the outside of channel bends if bankfull stream velocities approach the maximum allowable for site conditions.
4. Be sure that requirements of other state or federal agencies are met in the design when other approvals or permits are necessary.

**Table C-ENV-01-2 Conditions in which Vegetative Streambank Stabilization is Acceptable**

| Frequency of Bankfull Flow (times/year) | Maximum Allowable Velocity for Highly Erodible Soil (ft/s) k>0.37 | Maximum Allowable Velocity for Erosion Resistant Soil (ft/s) k<0.37 |
|---|---|---|
| > 4 | 4 | 5 |
| 1 to 4 | 5 | 6 |
| < 1 | 6 | 6 |

If permanent design is proposed from streambank stabilization, the Virginia Stream Restoration and Stabilization BMP Guide should be referenced.

## 6.0 Construction Specifications

### 6.1 Planting Guidelines

Guidelines will be presented only for the reed-bank and shrub zones. The aquatic plant zone is difficult to implant and establish naturally when reed-bank vegetation is present. There are presently many experts in this field at the federal, state, and private sector levels who can be consulted concerning successful establishment of plants in the aquatic zone. The tree zone is least significant in terms of protecting banks from more frequent erosion-force flows because this zone is seldom flooded. Also, shade from trees in this zone can prevent adequate establishment of vegetation in other zones. Planting specifications are detailed further in Table C-ENV-01-3.

| Table C-ENV-01-3 Planting Specifications | |
|---|---|
| **Planting Activity** | **Notes on Proper Execution** |
| Establishing Reed-Bank Vegetation | There are various methods of planting reed-bank vegetation. The following plants are considered suitable:<br><br>Reed canary grass (*Phalaris arundinacae*); Great bulrush (*Scirpus lacustris*); and Common cattail (*Typha latifolia*).<br>Planting in Clumps: The oldest and most common method of planting reeds is planting in clumps (see Figure C-ENV-01-2). The stems of the reed colony are scythed, then square clumps are cut out of the ground and placed in pits prepared in advance on the chosen site. The clumps are planted at a depth at which the clumps will be submerged to a maximum of two thirds of their height.<br><br>Planting Rhizomes and Shoots: Less material is needed for the planting of rhizomes and shoots, a procedure that can be used to establish reed grass, bulrush, cattail, and other plants. Slips are taken from existing beds during the dormant season, after the stems have been cut. Rhizomes and shoots are carefully removed from the earth without bruising the buds or the tips of the sprouts. The rhizomes and shoots are placed in holes or narrow trenches along the line of the average summer water level so that only the stem sprouts show above the soil.<br>Planting Stem Slips: It is possible to plant stem slips along slow-moving streams (see Figure C-ENV-01-2). Usually, three slips are set in a pit 12 to 20 inches deep. If the soil is packed or strong, make the holes with a dibble bar or some other metal planting tool. Locate the pits approximately 1 foot apart. |

| Table C-ENV-01-3 Planting Specifications | |
|---|---|
| **Planting Activity** | **Notes on Proper Execution** |
| Establishing Reed-Bank Vegetation | Reed Rolls: In many cases, the previously described methods do not consolidate the banks sufficiently during the period immediately after planting. Combined structures have therefore been designed, in which protection of the bank is at first ensured by structural materials. Along slow to fast streams, the most effective method of establishing reed-bank vegetation has been found to be the use of reed rolls (see Figure C-ENV-01-2).<br><br>A trench 18 inches wide and deep is dug behind a row of stakes. Wire netting, such as 0.5-inch hardware cloth, is then stretched from both sides of the trench between upright planks. Onto this netting is dumped fill material such as coarse gravel, sod, or soil and other organic material. This material is then covered by reed clumps until the two edges of the wire netting can just be held together with wire. Ensure the upper edge of the roll is no more than 2 inches above the level of the water. Finally, the planks are taken out, and any gaps along the sides of the roll are filled in with earth. This method provides greater protection from the possibility of a heavy flow washing away the vegetative materials before they have a chance to become established.<br><br>Seeding: Reed canary grass can be sown 0.5 inch deep on very damp bank soil, provided that the seeded surface is not covered by water for 6 months after sowing. Seed at a rate of 12 to 15 pounds per acre. Reed canary grass is a cool season grass and should not be seeded in the summer.<br><br>Vegetation and Stone Facing: Reed-bank and other types of vegetation can be planted in conjunction with riprap or other stone facing by planting clumps, rhizomes, or shoots in the crevices and gaps along the line of the average summer water level. |
| Establishing Shrub Zone Vegetation | Stands of full-grown trees are of little use for protecting streambanks apart from the binding of soil with their roots. Shrub wood provides much better protection; and in fact, riverside stands of willow trees are often replaced naturally by colonies of shrub-like willows. Use plants that can easily adapt to the stream and site conditions. Seeding and Sodding: Frequently, if the stream is small and a good seedbed can be prepared, grasses can be used alone to stabilize the streambanks. To seed the shrub zone, first grade eroded or steep streambanks to a maximum slope of 2H:1V (3H:1V preferred). Retain existing trees greater than 4 inches in diameter whenever possible. Conserve topsoil for reuse in an upland stockpile area with perimeter controls (silt fence or compost filter sock). Select seeding mixtures and perform operations according to Permanent Seeding (BMP C-SSM-10). Install some type of erosion control blanket, such as jute netting, excelsior blankets, or equivalent according to Soil Stabilization Blankets and Matting (BMP C-SSM-05). Sod can also be placed where grass is suitable. Select and install sod according to Sodding (BMP C-SSM-06). Use turf only where the grass will provide adequate protection, necessary maintenance can be provided, and establishment of other streambank vegetation is not practical or possible. |

| Table C-ENV-01-3 Planting Specifications | |
|---|---|
| **Planting Activity** | **Notes on Proper Execution** |
| Establishing Shrub Zone Vegetation | Planting Cuttings and Seedlings: Shrub willows, shrub dogwoods, and alders can be put into the soil as cuttings, slips, or stems. In dense shade, shrubs such as the blue arctic willow (*Salix purpurea nana*) and the silky dogwood (*Cornus amomum*) or evergreen ground covers such as lily turf (*Liriope Muscari*) or Hall's honeysuckle (*Linicera hallsiana*) are appropriate. The silky dogwood also works well in sunny areas. On larger streams, "Streamco" purpleosier willow (*Salix purpurea "Streamco"*) and Bankers' dwarf willow (*Salix x Cotteti*) have been widely used with success. Two native river alders (*Alnus serrulata* and *Alnus rugosa*), which occur throughout the northeast, also show great promise for streambank stabilization, although they have not been fully tested. Again, the first step in the planting process is to grade eroded or steep slopes to a maximum slope of 2H:1V (3H:1V preferred), removing overhanging bank edges.<br>Willows can be planted as 1-year-old, nursery-grown, rooted cuttings or as fresh hardwood cuttings gathered from local mother-stock plantings. Use silky dogwood and alders that are nursery-grown seedlings 1 or 2 years old. Use fresh cuttings that are<br>0.375 to 0.5 inch thick and 12 to 18 inches long and are kept moist. If not used at once, store the cuttings in cool moist sand.<br><br>Streambanks are often difficult to plant, even when the banks are well sloped. This is especially true in gravelly or strong banks. Where mattocks or shovels are unsatisfactory tools, a stiff steel bar, such as a crowbar, is better. The best tool for this purpose is a dibble bar: a heavy metal tool with a blade and a foot pedal that is thrust into the ground to make a hole for the plant (see Figure C-ENV-01-3).<br><br>Plant rooted cuttings vertically in the bank with 1 or 2 inches of wood protruding above the ground surface. Stick the rooted cuttings in a hole large enough to accommodate the root system when well spread. Maneuver the plant roots into the bottom of the hole so the roots will grow down instead of up. Do not twist the roots or expose the roots above the ground surface. After the plant is placed, install the dibble bar a few inches away from the plant to close the hole. Apply slow-release fertilizer on the surface, not in the hole. Tamp the soil adequately to provide complete contact between the soil and the cutting. Plant cuttings 1 foot on center in at least three rows located at the top, middle, and bottom of the shrub zone.<br><br>Plant seedlings of the river alders vertically in the bank to the depth at which the seedings were growing in the nursery. Use the same procedure described previously.<br><br>Plant one row of alders at 2-foot intervals at the base of the shrub zone, not more than<br>1.5 to 3 feet from the average summer water level or from the reeds. A greater distance is of no use unless a belt of tall perennial herb colonies is established between the reeds and the alders. Plant the next row 2 feet up the slope, with a third row 4 feet up the slope. Plant at least three rows. Locate the plants in a diamond pattern.<br><br>Because these plants are generally not effective for the first 2 years, grasses can be seeded immediately following their planting to provide initial streambank protection. The seed mixtures noted in Table C-ENV-01-4 are appropriate plantings. |

| Table C-ENV-01-3 Planting Specifications | |
|---|---|
| **Planting Activity** | **Notes on Proper Execution** |
| Establishing Shrub Zone Vegetation | Roughen the seedbed with rakes and fertilize with 500 to 1,000 pounds per acre of 10- 10-10 fertilizer adjusted to meet the needs of the site. Take special care when fertilizing next to water sources to avoid any unnecessary introduction of nitrogen/phosphorus into the water.<br><br>Broadcast seed, cover lightly, and mulch with 2 tons of straw per acre (two to three bales per 1,000 square feet) or a minimum of 1,500 pounds of wood fiber mulch per acre (2,000 pounds per acre preferred). If straw is used, properly anchor the straw with netting or an effective tackifier. Erosion control blankets/mats are often effective aids in the establishment of grasses or plant material along streambanks; see Soil Stabilization Blankets and Matting (BMP C-SSM-05). Willows and other softwoods can also be bound together in various ways to ensure immediate protection of the streambank.<br><br>Fascine Rolls: Fascine rolls are bundles of brushwood and sticks, without branches, if possible, that are filled with coarse gravel and rubble and wired tightly around the outside. The fascine rolls are 4 to 20 yards long and 4 to 16 inches in diameter. The fascine rolls are set against the bank so that the parts intended to take root touch the ground above the water level and can access sufficient moisture. Covering with earth improves the contact with the ground and retards the loss of moisture from the wood (See Figure C-ENV-01-4).<br><br>Willow Mattresses: The degree of streambank protection can be increased using willow mattresses or packed fascine work. Willow mattresses consist of 4- to 8-inch-thick layers of growing branches set perpendicular to the direction of the current or sloping downstream, with the broad ends of the branches oriented downwards.<br><br>The branches are held together with interweaving wire or other branches at intervals of 24 to 32 inches, set parallel to the direction of the current or at an angle of 30 degrees. If several layers of mattress are necessary, the tops of the lower layers should cover the bases of the upper layers. The bottom layer is fixed at the base in a trench previously dug at the base of the softwood zone. The whole mattress structure should be covered with 2 to 10 inches of earth or fine gravel (See Figure C-ENV-01-4).<br><br>Packed Fascine Work: Packed fascine work (see Figure C-ENV-01-4) consists essentially of layers of branches laid one across the other to a depth of 8 to 12 inches and covered with fascine rolls. The spaces between the fascine rolls are filled with gravel, stones, and soil so that no gaps remain; and a layer of soil and gravel 8 to 12 inches thick is added on top. Packed fascine work is particularly suitable for repairing large breaches in the banks of streams with high water levels.<br><br>Combination with Stone Facing: In many places, the bank is not adequately protected by vegetation until the roots are fully developed, and temporary protection must be provided by inanimate materials. There is a wide choice of methods including the planting of woody plants in the crevices of stone facing (See Figure C-ENV-01-4). For structural protection measures, see Structural Streambank Stabilization (BMP C-SSM-02). |

| Table C-ENV-01-4 – Initial Streambank Plantings: Seed Mixtures by Region* and Application Rates | |
|---|---|
| **Species** | **Application Rate (lbs/acre)** |
| Kentucky-31 Tall Fescue[a] | 65 |
| Creeping Red Fescue[a] | 15 |
| Redtop Grass[a] | 5 |
| Kentucky-31 Tall Fescue[b] | 80 |
| Redtop Grass[b] | 5 |
| Kentucky-31 Tall Fescue[c] | 65 |
| Bermudagrass[c] | 15 |
| Redtop Grass[c] | 5 |

*Physiographic Regions are described in Permanent Seeding (BMP C-SSM-10).

a. Appalachian Region
b. Piedmont Region
c. Coastal Plain

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Coir Fascines | This is a manufactured product also known as coir logs or coconut fiber rolls. Coir fascines consist of coconut husk fibers bound together in a cylindrical bundle by natural or synthetic netting and are manufactured in a variety of standard lengths, diameters, and fill densities for environments of different energy. Coir fascines are flexible and can be fitted to the existing curvature of a streambank. They provide immediate toe protection and bank stabilization while trapping sediment within the coir fascine, which encourages plant growth. Coir fascines are well suited for establishing herbaceous materials, and they can be pre-vegetated before installation. A key advantage of this method is the modularization and standardization of the materials that result in relatively predictable and reliable performance. A disadvantage of coir fascines is that they are expensive to purchase and ship. They require additional anchoring systems, which increases the initial costs and installation time.<br><br>Material:<br><br>Fascines fabricated from and filled with 100 percent coir (coconut husk) are preferred for streambank stabilization work because they serve as a stable growing medium on which seeds and young plants can become established. This material provides some resistance to damage from ice flows, floating debris, and other impacts and provides a reinforcing framework for vegetation until the coir filling decays, at which point the plants should be able to protect the banks.<br><br>For most settings, high tensile strength (minimum 200 lb tensile strength) synthetic mesh is desirable for the knotted or braided mesh exterior of the coir fascine. Although coir mesh versions are available, the mesh frequently loses its strength before vegetation can become fully established, making the material vulnerable to failure. Therefore, coir mesh versions are typically used on sites with low stress levels. The most sturdy and resistant coir fascines are manufactured with a density of 9 pounds per cubic foot. Where ice, debris, steep banks, and other stress factors are not a problem, lower density materials may offer a more cost-effective alternative. The most used size is 12-inch-diameter, although they are available in both larger and smaller sizes. Coir fascines are typically anchored with wooden stakes or earth anchors with cable assemblies. |

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Coir Fascines | Installation:<br><br>Coir fascines may be installed during any season, provided that the ground can be worked adequately for placement and anchoring. Planting into the coir fascine may be planned for a more desirable season, as needed.<br>Coir fascines can either be placed so that they help position the toe of a bank, where it was located before an erosion event, or in direct contact with the current bank profile. Position the coir fascine so that the top is located at the mean water level during the summer growing season. In most cases, this zone best supports herbaceous vegetation. Due to the distance from the plant to the soil, it is imperative that the coir fascine remain wet.<br><br>Coir fascines are frequently planted with 2-inch-diameter plugs of herbaceous species that have been rooted in a coir fiber matrix to provide good frictional contact.<br>Protect coir fascines against scouring and flanking in the design. Ensure the anchoring system is adequate to seat the coir fascine securely in contact with the adjacent soil. Use a pair of stakes placed every 2 feet along the coir fascine, one on each side. In cold climates, earth anchors or rope tie-downs are necessary to prevent lifting of the coir fascine as ice forms. Always place wooden stakes between the cable or rope and the coir to keep the cable or rope from cutting clear through the coir fascine.<br><br>Avoid piercing a high-density coir fascine with stakes. Drive the stakes alongside the coir fascine. Secure the coir fascine by either tightly sandwiching it between the stakes or using ropes or cables to tie around the coir fascine.<br><br>Tie the coir fascines together end to end to form a continuous unit. This is most convenient to do while they are still on dry land, laid out along the top of bank. Use strong synthetic rope to stitch the ends together, with knots tied at frequent intervals to ensure a reliable connection.<br><br>When coir fascines are stacked to provide coverage of a wider strip of bank, place the fascines together on the edges where they touch. One row of lacing is typically adequate to hold two tiers together, although two rows of lacing will result in a tighter contact between the tiers, which is useful at holding back cohesive soils. All tiers require appropriate staking or anchoring.<br><br>After anchoring is complete, coir fascines may be planted. Either live cuttings may be inserted through the coir fascine itself, or 2-inch-diameter plugs may be inserted 6 inches on center along the length of the coir fascine.<br>When the coir fascines are stacked, live poles, live cuttings, or rooted plants may be placed on the first (lower) coir fascine before placing the next one above it. |

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Fascines | A fascine is a long bundle of live cuttings bound together into a rope or sausage-like bundles. The structure provides immediate protection for the toe of the bank. Because this is a surface treatment, it is important to avoid sites that will be too wet or too dry. The live cuttings eventually root and provide permanent reinforcement. Materials:<br>Live cuttings: 0.75 to 2 inches in diameter, 5 to 15 feet long;<br><br>Cord; braided manila; sisal or pre-stretched cotton twine; or small-gauge, non-galvanized wire;<br><br>Dead stout stakes: wedge-shaped wooden stakes, 2 to 3 feet long depending on soil conditions;<br><br>Tools: machete, shovels, clippers, hammer, sledgehammer, saw, and chainsaw; and Fertilizer and other soil amendments. Installation:<br><br>Collect and soak live cuttings for 14 days or install them the day they are harvested and fabricated. Leave side branches intact.<br><br>Stagger the live cuttings in a uniform bundle built to a length of about 8 feet. Vary the orientation of the cuttings. Use 8- to 10-foot bundles for ease of handling and transport. The bundles can also be easily spliced together to create a fascine long enough to fit the project site.<br><br>Tie bundles with twine at approximately 2-foot intervals. The bundles should be 6 to 24 inches in diameter depending on their application.<br><br>Start installation from a stable point at the upstream end of the eroding bank.<br>Excavate a trench into the bed of the stream, where the bank meets the bed. Dig the trench to be about a half to three quarters the diameter of the bundle.<br><br>Align the fascine along the toe of the bank of the eroding section.<br><br>Place the bundle in the trench and stake (use wedge-shaped dead stout stakes) directly through the bundle 3 feet on center. Allow the stake to protrude 2 inches above the top of the bundle. To improve depth of reinforcement and rooting, install live stakes (2 to 3 feet in length) just below (downslope) and in between the previously installed dead stout stakes, leaving 3 inches protruding from the finished ground elevation. Cover the fascine with soil, ensuring good soil to stem contact. Wash it in with water to distribute the soil around the inner stems of the bundle. Ensure some of the bundle remains exposed to sunlight to promote sprouting. Use material from the next up-bank trench. It may be desirable to use erosion control fabric to hold the soil adjacent to and in between the fascine bundles, especially in wet climates. When using erosion control fabric between the fascine bundles, the fabric is first placed in the bottom of the trench, an inch of soil is placed on top and up the sides of the trench and erosion control fabric, and the fascine bundle is then placed in the trench and staked down. Note: Fascines can be oriented perpendicular to the streambank contours, which is called the vertical bundle method. The primary difference between the construction of a vertical bundle and a fascine is that all the cuttings in a vertical bundle are oriented so the cut ends are in the water. It is particularly applicable where there is uncertainty in determining the water table. |

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Live Pole Cuttings or Live Stakes | Live pole cuttings are dormant stems, branches, or trunks of live, woody plant material inserted into the ground with the purpose of getting them to grow. Live stakes are generally shorter material used as stakes to secure other soil bioengineering treatments such as fascines, brush mattresses, erosion control fabric, and coir fascines. However, the terms live stakes and live pole cuttings are often used interchangeably. Both live poles and live cuttings can be used as anchoring stakes. Pole cuttings and stakes are live material, so they will also root and sprout. These cuttings typically do not provide immediate reinforcement of soil layers, as they normally do not extend beyond a failure plane. Over time, they provide reinforcement to the soil mantle, as well as surface protection and roughness to the streambank and some control of internal seepage. They assist in quickly reestablishing riparian vegetation and cause sediment deposition in the treated area.<br><br>Materials:<br><br>Live cuttings: 0.75 to 3 inches in diameter, 3 to 20 feet long; and<br>Tools: machete, clippers, dead blow hammer, saw, chain saw, loppers, and rebar.<br><br>Installation:<br><br>Cleanly remove all side branches and top growth. Cut the basal (bottom) end to a 45- degree angle or sharpen into a pointed end. Cut the top end flat. Ensure at least two buds or bud scars are present above the ground in the final installation depending on the surrounding vegetation height. Ensure the live cuttings are taller than the surrounding vegetation so that they are not shaded.<br><br>Collect and soak the live cuttings for 14 days or install them on the day on which they are harvested and fabricated.<br><br>Use a punch bar or hand auger to create a pilot hole perpendicular to the slope. Ensure the depth of the hole is two thirds to three fourths the length of the live cutting. Make the hole diameter as close to the cutting's diameter as possible to obtain the best soil to stem contact. Ensure the hole is deep enough to intercept the lowest water table of the year or a minimum of 2 feet.<br><br>To achieve good soil to stem contact, fill the hole around the pole with a water and soil slurry mixture. Add soil around the cutting as the water percolates into the ground and the soil in suspension settles around the cutting. Another method is to tamp soil around the cutting with a rod. Throw a small amount of soil in the hole around the cutting and tamp it down to remove all air pockets, as if installing a wooden fence post.<br><br>Install the pole into the ground at a right angle to the slope face. Use a dead blow hammer to tap the cutting into the ground. Insert the cutting at a 90-degree angle to the face of the slope. Ensure that the sharpened basal end is installed first.<br><br>Place stakes on 2- to 4-foot spacing in either a random pattern or triangular grid for most shrub species. Spacing depends on species, moisture, aspect, and soil. |

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Joint Plantings | Joint plantings or vegetated riprap are cuttings of live, woody plant material inserted between the joints or voids of riprap and into the ground below. Typically, the live cuttings do not provide immediate reinforcement of soil layers, as they normally do not extend beyond the failure plane. The live cuttings are intended to root and develop top growth providing several adjunctive benefits to the riprap. These installations provide reinforcement to the soil on which the riprap has been placed, as well as providing roughness (top growth) that typically causes sediment deposition in the treated area.<br><br>Some control of internal seepage is also provided. These joint planting installations assist in quickly reestablishing riparian vegetation. Joint plantings are frequently used on the lower part of the bank. Materials:<br><br>Joint plantings: live cuttings 0.75 to 2 inches in diameter and 2.5 to 4 feet long or a length that extends at least 1 foot of the cutting will extend into the ground below the riprap.<br><br>Tools: machete, clippers, dead blow hammers, sledgehammer, saw, chainsaw, loppers, and rebar.<br><br>Installation:<br><br>Cleanly remove all side branches and the top growth from the cuttings. Cut the basal end to a 45-degree angle or sharpen to a point. Cut the top end flat. Ensure at least two buds or bud scars are present above the ground in the final installation, depending on the surrounding vegetation height. Ensure the live cuttings are taller than the surrounding vegetation so that they are not shaded.<br><br>Collect and soak the live cuttings for 14 days or install them on the day on which they are harvested and fabricated.<br><br>Make a pilot hole by hammering in a piece of rebar between the rock. A steel stinger can also be used. Carefully extrude the rebar and tamp in the joint planting stem. Insert the basal end first.<br><br>To achieve good soil to stem contact, fill the hole around the cutting with a water and soil slurry mixture.<br><br>Plant live cuttings on 1.5- to 2-foot spacing in a random pattern or triangular grid. Spacing depends on species, moisture, aspect, and soil characteristics. |

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Brush Mattress | A brush mattress is a layer of live cuttings placed flat against the sloped face of the bank. Dead stout stakes and string are used to anchor the cutting material to the bank. This measure is often constructed using a fascine, joint planting, or riprap at the toe of the bank, with live cuttings in the upper mattress area. The branches provide immediate protection from parallel streamflow. The cuttings are expected to root into the entire bank face and provide surface reinforcement to the soil. Materials:<br>Live cuttings: 0.75 to 1 inch in diameter that are approximately 2 feet taller than the bank face, which will allow the basal ends to be placed in or at the edge of the water. Up to 20 percent of the cuttings can be dead material to add bulk;<br>Dead stout stakes: wedge-shaped, 1.5 to 4 feet long, depending on soil texture; Ties: string, braided manila, sisal or pre-stretched cotton twine, or galvanized wire;<br>Tools: machete, shovels, clippers, hammer, sledgehammer, punch bar, saw, and machine to shape the bank; and<br>Fertilizer and other soil amendments. |

| Table C-ENV-01-5 Streambank Soil Bioengineering Techniques | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Brush Mattress | Installation:<br><br>Collect and soak the live cuttings for 14 days or install them om the day on which they are harvested. Leave side branches intact.<br><br>Cut a 2- by 4-inch board diagonally and at a desired length to create the dead stout stakes.<br><br>Excavate the bank to a slope of 1V:2H or flatter. The distance from the top of the slope to the bottom of the slope is typically 4 to 20 feet. Excavate a 1-foot-wide and 8- to 12-inch- deep trench along the toe of the bank.<br><br>Drive the dead stout stakes 1 to 3 feet into the ground up the face of the prepared bank. Space the installation of the dead stout stakes on a grid that is 1.5 to 3 foot square. Start the lowest row of dead stout stakes below bankfull width or a fourth of the height of the bank. Extend the tops of the dead stout stakes above the ground 6 to 9 inches. Live cuttings may also be mixed with the dead stout stakes and tamped in between to add deeper initial rooting. However, do not rely on the live cuttings solely for anchoring the brush mattress, as they generally cannot be driven in as securely as the dead stout stakes.<br><br>Lay the live cuttings up against the face of the bank. The basal ends of the cuttings are installed into the trench with the growing tips oriented up bank. Retain the live cuttings' side branches and overlap the side branches in a slight crisscross pattern. Depending on the sizes of the branches, approximately 8 to 15 branches are installed per linear foot of bank.<br><br>Use a fascine or some form of anchoring along the bottom portion of the brush mattress to ensure the basal ends of the live cuttings are pressed against the bank.<br><br>Stand on the live cuttings and secure them by tying string, cord, wire, braided manila, sisal, or pre-stretched cotton twine in a diamond pattern between the dead stout stakes. Short lengths of tying material are preferred over long lengths. In the event of a failure, only a small portion of the treatment would be compromised if short lengths are used.<br><br>Otherwise, there are risks of losing larger portions of the project if long lengths of tying material are used to anchor the cuttings to the dead stout stakes.<br><br>After tying the string to the stakes, drive the dead stout stakes 2 to 3 inches further into the bank to firmly secure the live cuttings to the bank face. This improves the soil to stem contact.<br><br>Wash loose soil into the mattress between and around the live cuttings so that the bottom halves of the cuttings are covered with a 3- to 4-inch layer of soil.<br><br>Backfill the trench with soil or a suitable toe protection such as rock.<br><br>Trim the terminal bud at the top of bank so that stem energy will be routed to the lateral buds for more rapid root and stem sprouting. |

## 7.0 Operations and Maintenance Considerations

Streambanks are always vulnerable to new damage. Repairs are needed periodically. Inspect streambanks after every high-water event is over. Fix gaps in the vegetative cover at once with new plants and mulch if necessary. Fresh cuttings from other plants on the bank can be used, or the cuttings can be taken from mother-stock plantings if they are available. Remove trees that become established on the bank at once.

*Streambank wasting in need of restoration.*
Photo Credit: NC Forest Service

While soil bioengineering projects tend to be self- renewing and grow stronger with time, project areas require periodic monitoring and maintenance, particularly during the establishment stage. Maintenance is especially important on highly erosive sites. Remove debris and eliminate invasive or undesirable species, and replant vegetation in spot areas. It is recommended that a comprehensive plan for the management of invasive species be developed.

The success of a soil bioengineering streambank stabilization project depends on the establishment and growth of the vegetative component. It is important to monitor soil bioengineering projects after project completion to ensure plant survival and development.

**Figure C-ENV-01-1 Typical Annual Curve of Water Correlated with Typical Vegetative Zones**

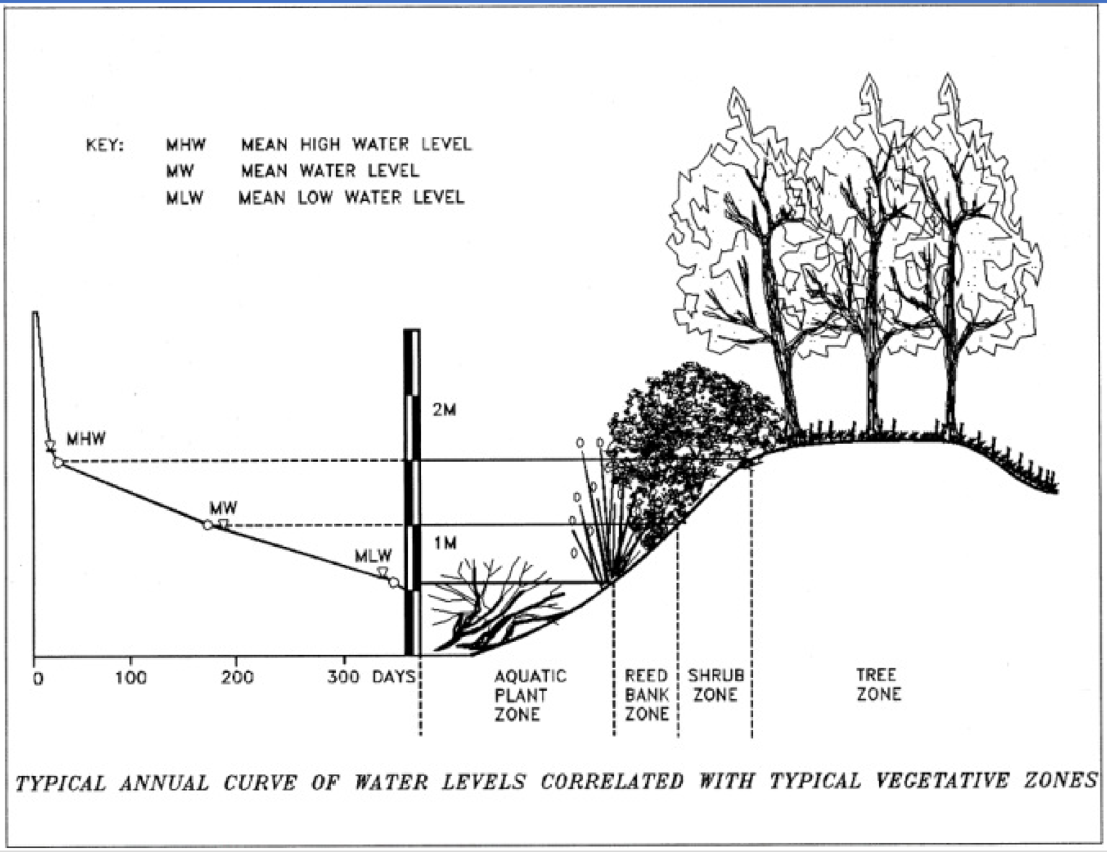


**Figure C-ENV-01-2 Methods of Establishing Reed Bank Vegetation**

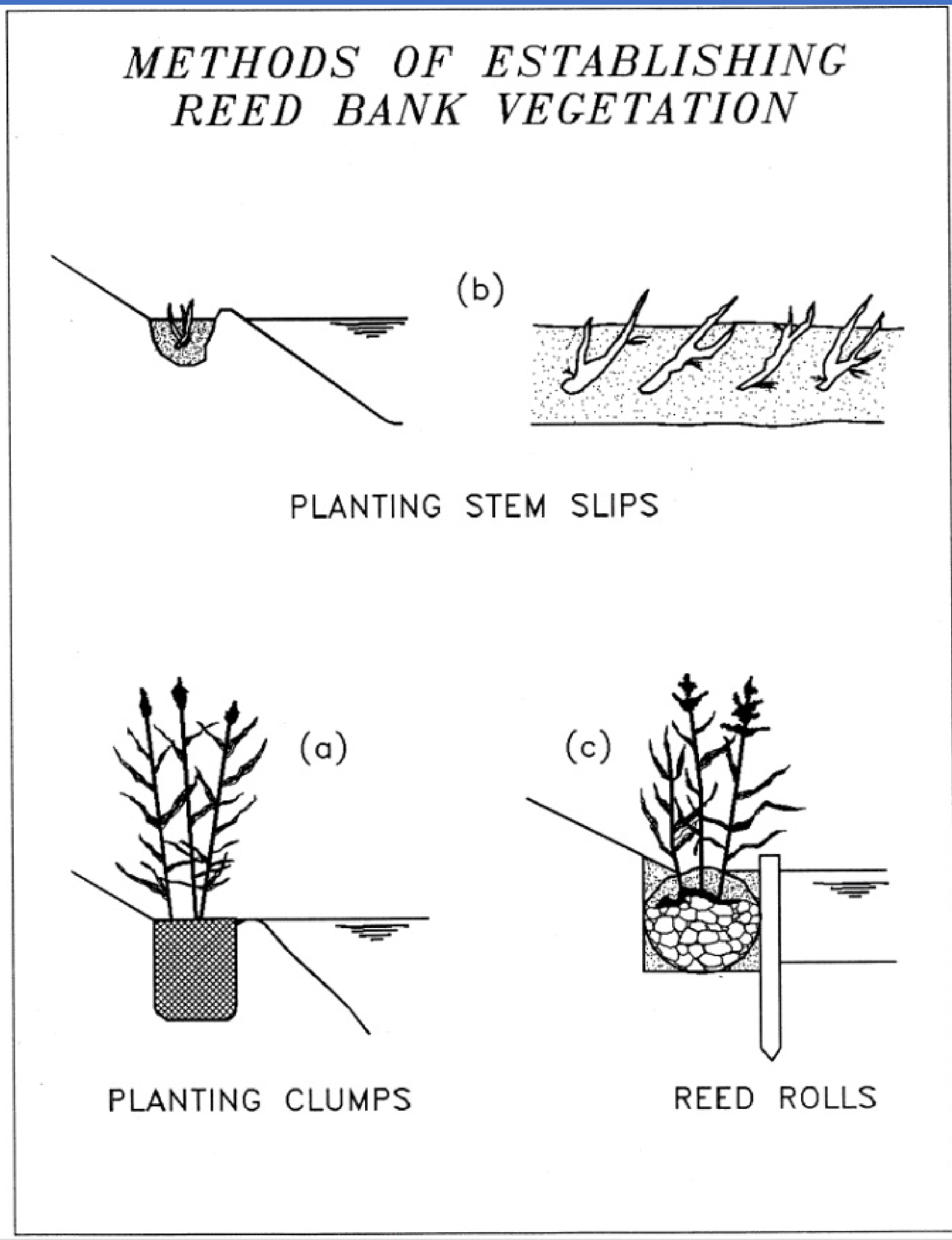


**Figure C-ENV-01-3 Dibble Planting**

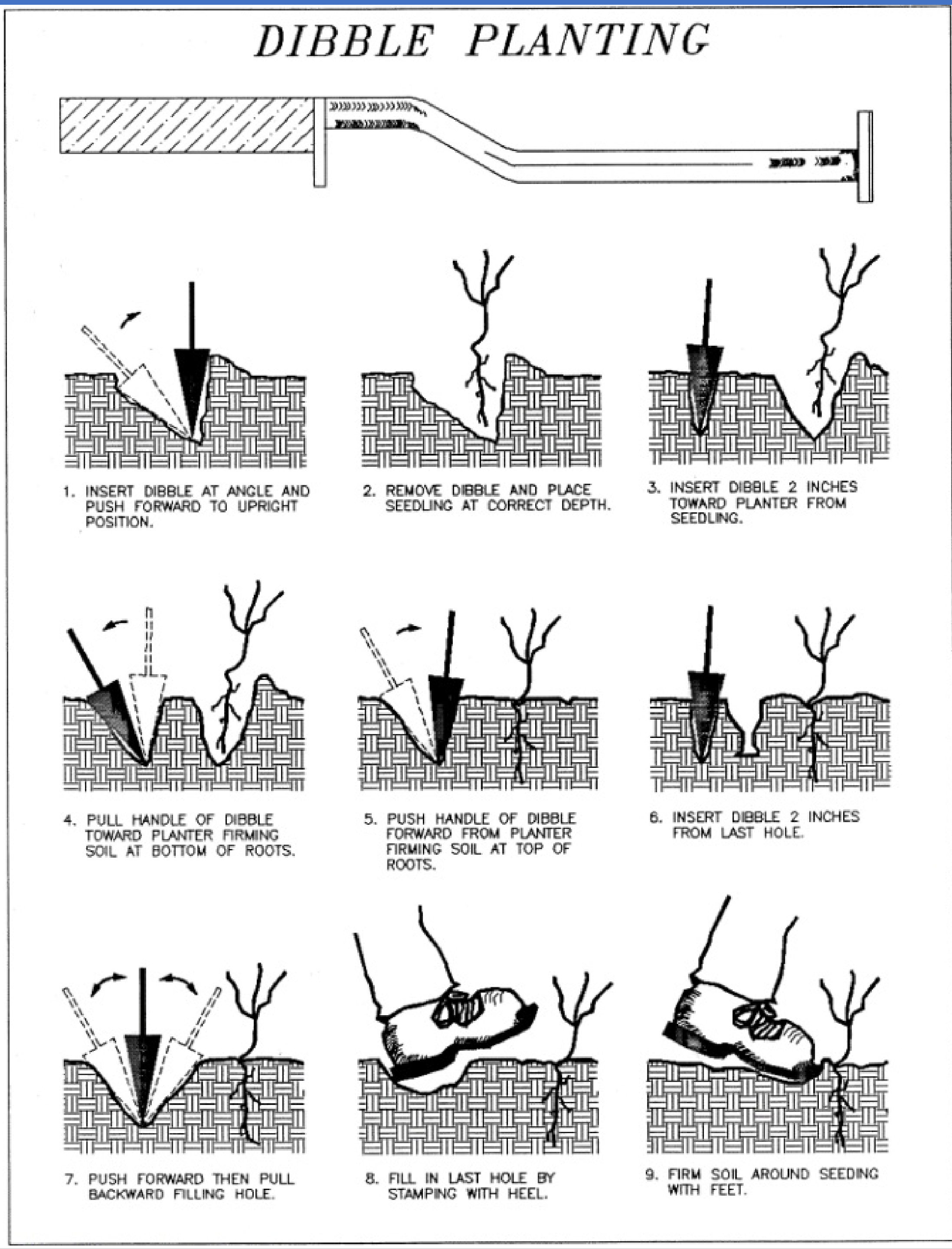
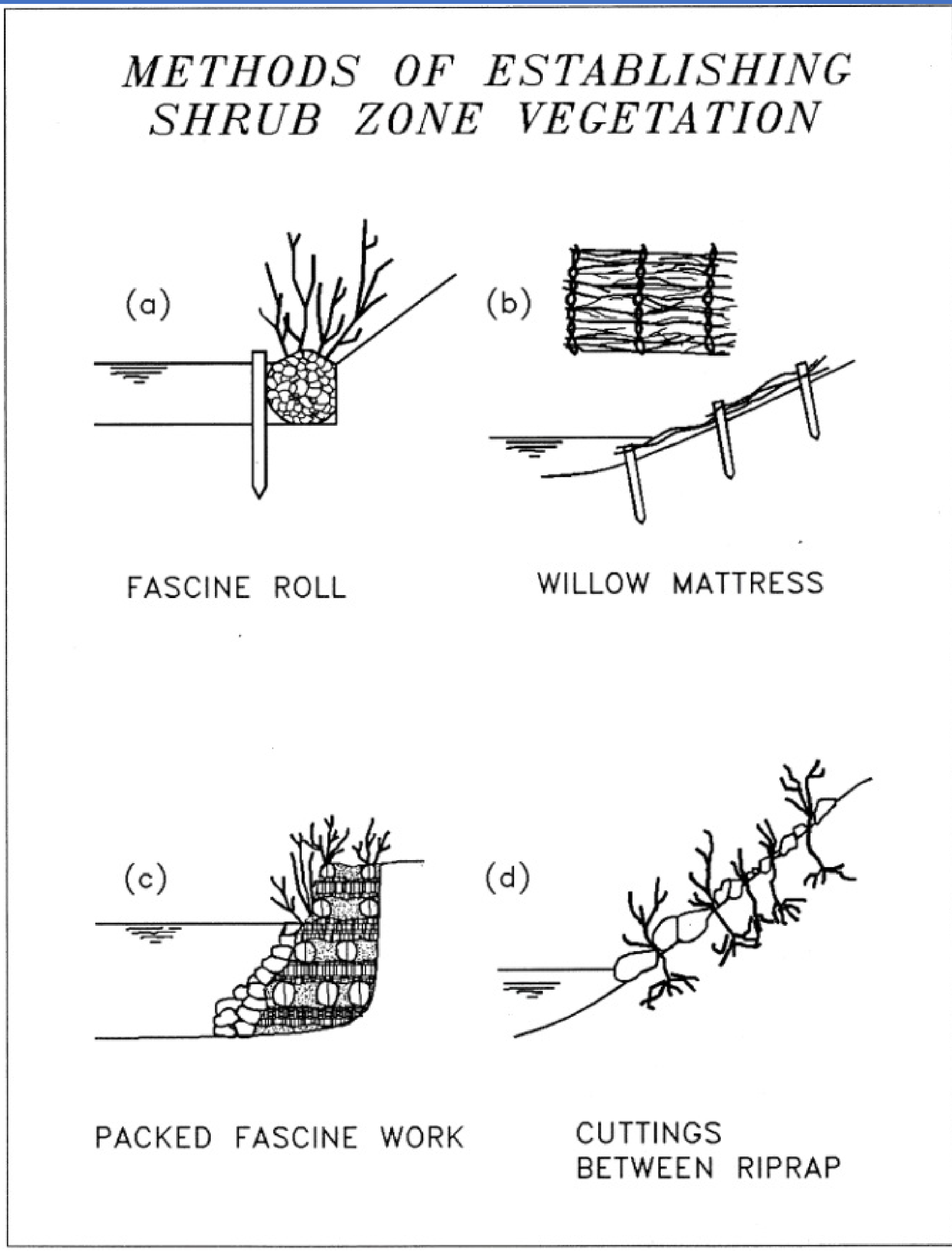


**Figure C-ENV-01-4 Methods of Establishing Shrub Zone Vegetation**




## 8.0 References

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-ENV-02 Structural Streambank Stabilization

## 1.0 Definition

Structural streambank stabilization constitutes methods of stabilizing the banks of live streams with permanent structural measures.

- CAD C-ENV-02-1 Gabions
- CAD C-ENV-02-2 Deflectors
- CAD C-ENV-02-3 Log Cribbing
- CAD C-ENV-02-4 Grid Pavers

## 2.0 Purpose and Applicability of Best Management Practice

Structural streambank stabilization is used to protect streambanks from the erosive forces of flowing water.

Structural streambank stabilization is applicable to streambank sections that are subject to excessive erosion due to increased flows or disturbance during construction and where flow velocities exceed 5 feet per second (ft/s) or where vegetative streambank protection is inappropriate.

## 3.0 Planning and Considerations

Stream channel erosion problems vary widely in type and scale, and many different structural stabilization techniques have been employed with varying degrees of effectiveness. The purpose of this specification is to identify some of the practices that are available and to establish some broad guidelines for their selection and design. Ensure such structures are planned and designed in advance by an engineer or other qualified individual with appropriate experience. Many of the referenced practices involve the use of manufactured products. Design and install manufactured products in accordance with the manufacturers' specifications.

Before selecting a structural stabilization technique, carefully evaluate the possibility of using vegetative stabilization (see Vegetative Streambank Stabilization [BMP C-ENV-01]), alone or in conjunction with structural measures, to achieve the desired protection. Vegetative techniques are generally less costly and more compatible with natural stream characteristics.

## 4.0 Stormwater Performance Summary

**MS-15: BED AND BANK STABILIZATION** – The bed and banks of a watercourse shall be stabilized immediately after work in the watercourse is completed.

9VAC25-875-560

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

| Table C-ENV-02-1 Structural Streambank Stabilization Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| General Guidelines | Because each reach of channel requiring protection is unique, install measures for streambank protection according to a plan and adapted to the specific site. Develop designs according to the following principles:<br>Ensure protective measures to be applied are compatible with improvements planned or being carried out by others.<br>Control the bottom scour, by either natural or artificial means, before any permanent type of bank protection can be considered feasible. This is not necessary if the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bottom scour.<br>Start and end streambank protection at a stabilized or controlled point on the stream.<br>Modify channel alignment only after evaluating the effect on land use, interdependent wastewater systems, hydraulic characteristics, and existing structures.<br>Give special attention to maintaining and improving habitat for fish and wildlife.<br>Calculate the design velocity based on the peak discharge of the 10-year, 24-hour storm event. Ensure structural measures are effective for this design flow and can withstand greater flows without serious damage.<br>Meet all requirements of state law and permit requirements of local, state, and federal agencies.<br>Stabilize all areas disturbed by construction as soon as the structural measures are complete. |

| Table C-ENV-02-1 Structural Streambank Stabilization Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Streambank Protection Measures | Riprap: Heavy angular stone placed (preferably) or dumped onto the streambank to provide armor protection against erosion. Design and install riprap according to specs and standards (Riprap [BMP C-ECM-13]). Where riprap is proposed for streambank protection, install the riprap as shown on Figure C-ECM-12-1. Provide provision for the passage of aquatic life through the stabilization area once the stone is in place. In most cases, the riprap need not extend more than 12 inches above the normal flow depth, often evidenced by a lack of vegetation or a strand line. If additional stream bank above that elevation has been disturbed, consider using a perennial vegetative cover. When possible, slope banks to 2H:1V or flatter, and place a gravel filter or filter fabric on the smoothed slopes before installing riprap. Place the toe of the riprap at least 1 foot below the stream channel bottom or below the anticipated depth of channel degradation. Where necessary, riprap the entire length between well-stabilized points of the stream channel.<br><br>Reinforced Concrete: May be used to armor eroding sections of the streambank by constructing concrete retaining walls or bulkheads. Positive drainage behind these structures must be provided. Reinforced concrete may also be used as a channel lining; see Stormwater Conveyance Channel (BMP C-ECM-09). |

| Table C-ENV-02-1 Structural Streambank Stabilization Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Streambank Protection Measures | Gabions: Rectangular, rock-filled wire baskets are pervious, semi-flexible building blocks that can be used to armor the beds and/or banks of channels or to divert flow away from eroding channel sections. Gabions offer important advantages for bank protection. Gabions can provide vertical protection in high-energy environments where construction area is restricted. Gabions can also be a more affordable alternative, especially where rock of the needed size for riprap is unavailable. Gabion wire mesh baskets can be used to stabilize streambank toes and entire slopes. Gabions can also be compatible with many soil bioengineering practices.<br><br>Gabions come in two basic types: woven wire mesh and welded wire mesh. Woven wire mesh is a double-twisted, hexagonal mesh consisting of two wires twisted together in two 180-degree turns. Welded wire mesh has a uniform square or rectangular pattern and a resistance weld at each intersection.<br><br>Between these two types there are two styles of gabions: gabion baskets and gabion mattresses. Baskets are 12 inches or more tall, while mattresses typically range from 5 to 12 inches tall. Gabion baskets can be particularly effective for toe stabilization on problem slopes. Gabion baskets provide the size and weight to stay in place, with the further advantage of being tied together as a unit. Baskets can be installed in multiple rows to increase stability and provide a foundation for other measures above them.<br>Gabion mattresses are best suited for revetment-type installations, channel linings, and waterways. Gabion mattresses may also be used for basket foundations and scour aprons.<br><br>Design and install gabions in accordance with manufacturer's standards and specifications (Figure C-ENV-02-1 – Gabions). At a minimum, construct gabions of a hexagonal triple-twist mesh of heavily galvanized steel wire (galvanized wire may also receive a poly-vinyl chloride coating). Ensure the design water velocity for channels using gabions does not exceed that specified in Table C-ENV-02-2.<br><br>Vegetated Gabion: In some locations, traditional gabions may be unacceptable from either an aesthetic or ecological perspective. A modification to traditional gabion protection that may satisfy these concerns is the vegetated gabion. A vegetated gabion incorporates topsoil into the void spaces of the gabion. The resulting gabion volume consists of 30 to 40 percent soil that allows root propagation between the stones. The resulting structure is interlocked with stone, wire, and roots.<br><br>Log Cribbing: A retaining structure built of logs backfilled with rock to protect streambanks from erosion. Log cribbing is normally built on the outside of stream bends to protect the streambank from the impinging flow of the stream (see Figure C-ENV-02-3 – Log Cribbing). The construction of a timber and rock crib requires considerable hand labor, and its useful life depends on the length of time the logs will hold the rock in place before rotting. As with gabions, the cribbing allows for the protection of unstable banks with stones that would be too small if used in a riprap revetment. While not exactly duplicating a riprap revetment, similar design characteristics are required for its design, such as scour, filtration, drainage, and length. |

| Table C-ENV-02-1 Structural Streambank Stabilization Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Streambank Protection Measures | Deflectors (groins or jetties): Structural barriers that project into the stream to divert flow away from eroding streambank sections. Figure C-ENV-02-2 – Deflectors contains general guidelines for designing and installing deflectors.<br><br>Grid Pavers: Modular concrete units with interspersed void areas that can be used to armor the streambank while maintaining porosity and allowing the establishment of vegetation. These structures may be obtained in pre-cast blocks or mats, or the grid pavers may be formed and poured in place. Design and install grid pavers in accordance with manufacturer's instructions (Figure C-ENV-02-4 – Grid Pavers).<br><br>Cellular Confinement Systems: May be used to stabilize streambanks when the manufacturer's recommendations are followed. Excavate the area of installation as necessary so that the top of the panel is flush with, or slightly lower than, the adjacent terrain or final grade. Level the surface of the slope and remove stones and debris. Fill and compact gullies. Replace unsuitable material, shape and compact the subgrade, and install an underlayment suitable for water bodies prior to stretching and anchoring the panel(s).<br><br>Miscellaneous Hard Armor Techniques: Other products on the market may be suitable for streambank stabilization. These include, but are not necessarily limited to, cable concrete, articulated concrete, and concrete jacks. Where such products are proposed, consider the specific site conditions, such as access by construction equipment, anticipated flows, soil limitations, site dimensions, public use, and aesthetics, which might make some products less desirable than others. Also consider the manufacturer's recommendations, product limitations, cost, and project life as other factors when choosing a suitable stabilization method.<br><br>Fluvial Geomorphology (FGM) Techniques: Stream channel stabilization using structures that mimic natural features (e.g., rock vanes, W rock weirs, J-hooks) have been shown to be quite effective when used correctly. They can also be very ineffective when the proper stream assessments, design, or construction practices have not been followed. Refer to Chapter 11, Rosgen Geomorphic Channel Design of Part 654 Stream Restoration Design of the National Engineering Handbook for information regarding FGM techniques. The advantage for many of the methods described in these references is that flow is directed to the center of the channel, away from erodible banks. |

| Table C-ENV-02-1 Structural Streambank Stabilization Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Installation of Structures Under Wave and/or Tidal Action | The installation of riprap, gabions, or deflectors under significant wave action or under tidal conditions requires special design considerations to ensure stability of the measure and the area it protects. The design/installation of these measures for tidal areas is beyond the scope of the Virginia Erosion and Sediment Control Law and Virginia Erosion and Sediment Control Regulations.<br>The Department of Stormwater Control's (DSWC's) Shoreline Programs Bureau can be consulted regarding minimum design parameters for tidal installations. Where there is significant wave action affecting the shoreline of a non-tidal lake or pond, use the design parameters presented in Riprap (BMP C-ECM-13). Notably, there are many other site-specific factors that should be incorporated into a design; hence, it is recommended that the design parameters presented only be used as minimum requirements and that a qualified professional be consulted when contemplating the installation of such a structure. |

| Table C-ENV-02-2 Gabion Thickness relative to Maximum Velocity | |
|---|---|
| **Gabion Thickness (feet)** | **Maximum Velocity (ft/s)** |
| 0.5 | 6 |
| 0.75 | 11 |
| 1 | 14 |

## 6.0 Construction Specifications

A key requirement at this phase is to correctly implement the proposed design, which involve the layout, construction supervision, and water quality controls during construction.

### 6.1 Layout

It is necessary to pre-stake the alignment of the channel and to provide for protection of existing vegetation outside of the construction alignment. The layout involves making necessary onsite adjustments to the design based on constraints that may have been previously overlooked. Terrain irregularities, vegetation, property boundaries, and channel changes since the field data were collected can all require local modifications to placement. Locate staging areas for the collection and temporary storage of materials. Flag stockpile areas, boundary references/facilities requiring special identification, and the locations of structure placement and type.

### 6.2 Construction Supervision (Oversight)

Perform daily site inspections and construction coordination. Check grades, dimensions, structure placement, slopes, angles, and footers as an ongoing requirement. Coordinate this work during construction rather than waiting and providing a post-construction inspection to find problems after the work is completed. The daily field review and documentation at this phase will facilitate the proper implementation of the design.

### 6.3 Water Quality Controls

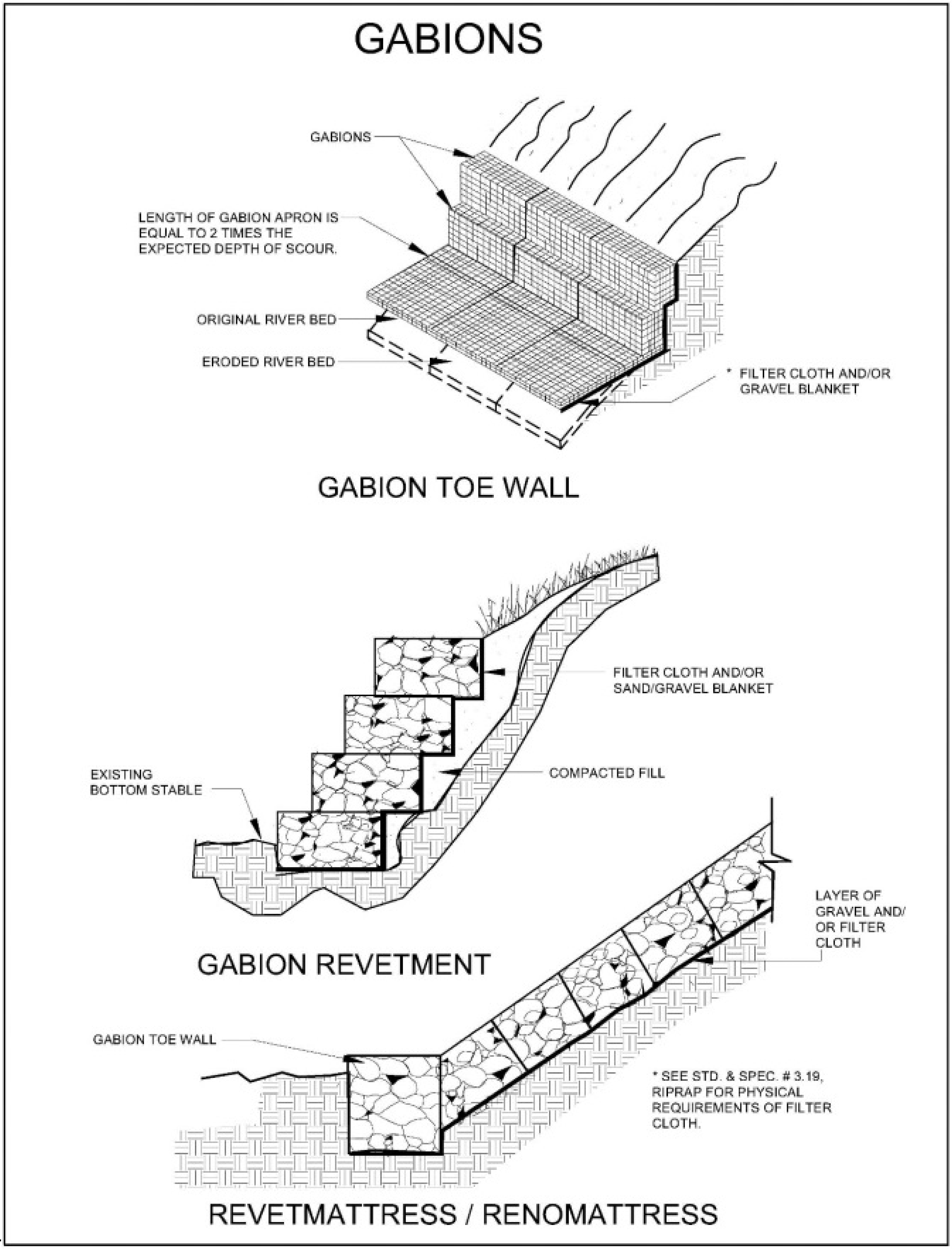
As part of the layout, locate sediment detention basins, diversions, silt fence or compost filter sock, and pump sites to prevent onsite and downstream sediment problems and as required by federal, state, and local ordinances. Stage construction to minimize sedimentation problems. Monitoring of water quality during construction may be required; thus, preventative measures will reduce future problems.

Special attention should be afforded to the original water quality of sinking or losing streams, or if the outfall of the stream consists of a cave, sinkhole, or other karst feature. In these instances, sedimentation trapping measures should be installed upstream of these features.

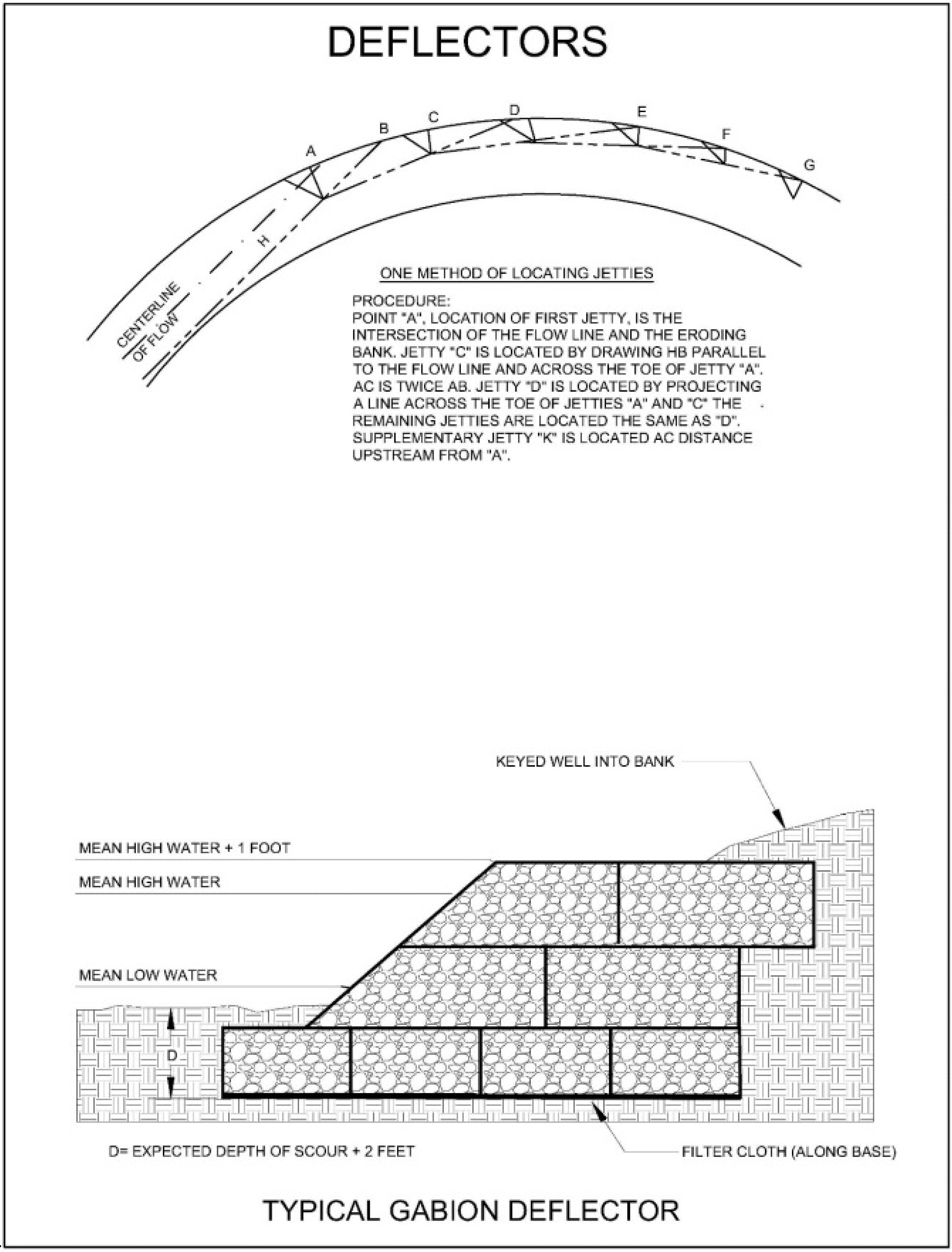
## 7.0 Operations and Maintenance Considerations

Maintain all structures in an "as built" condition. Repair structural damage caused by storm events as soon as possible to prevent further damage to the structure or erosion of the streambank.

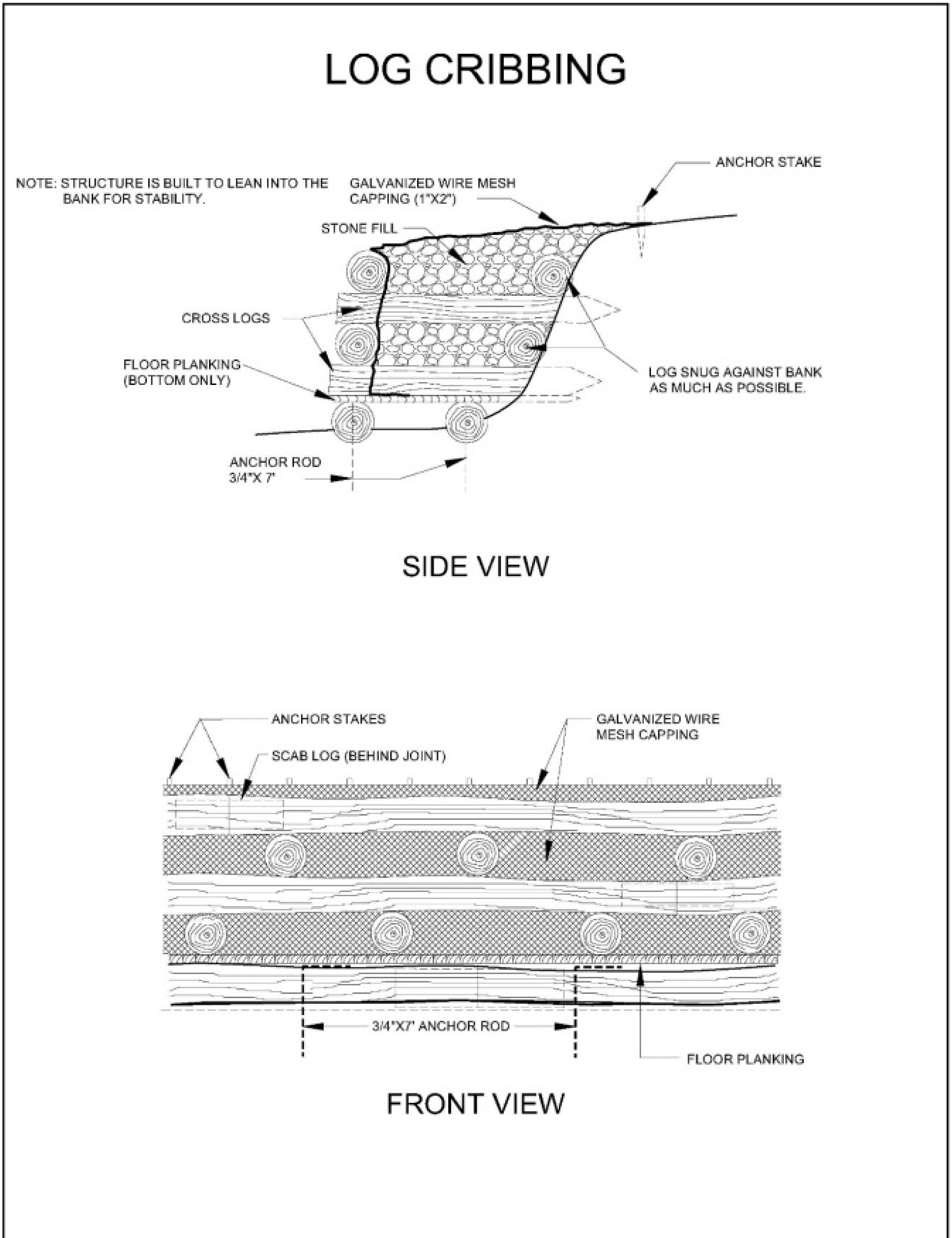
## *Figure C-ENV-02-1 Gabions*



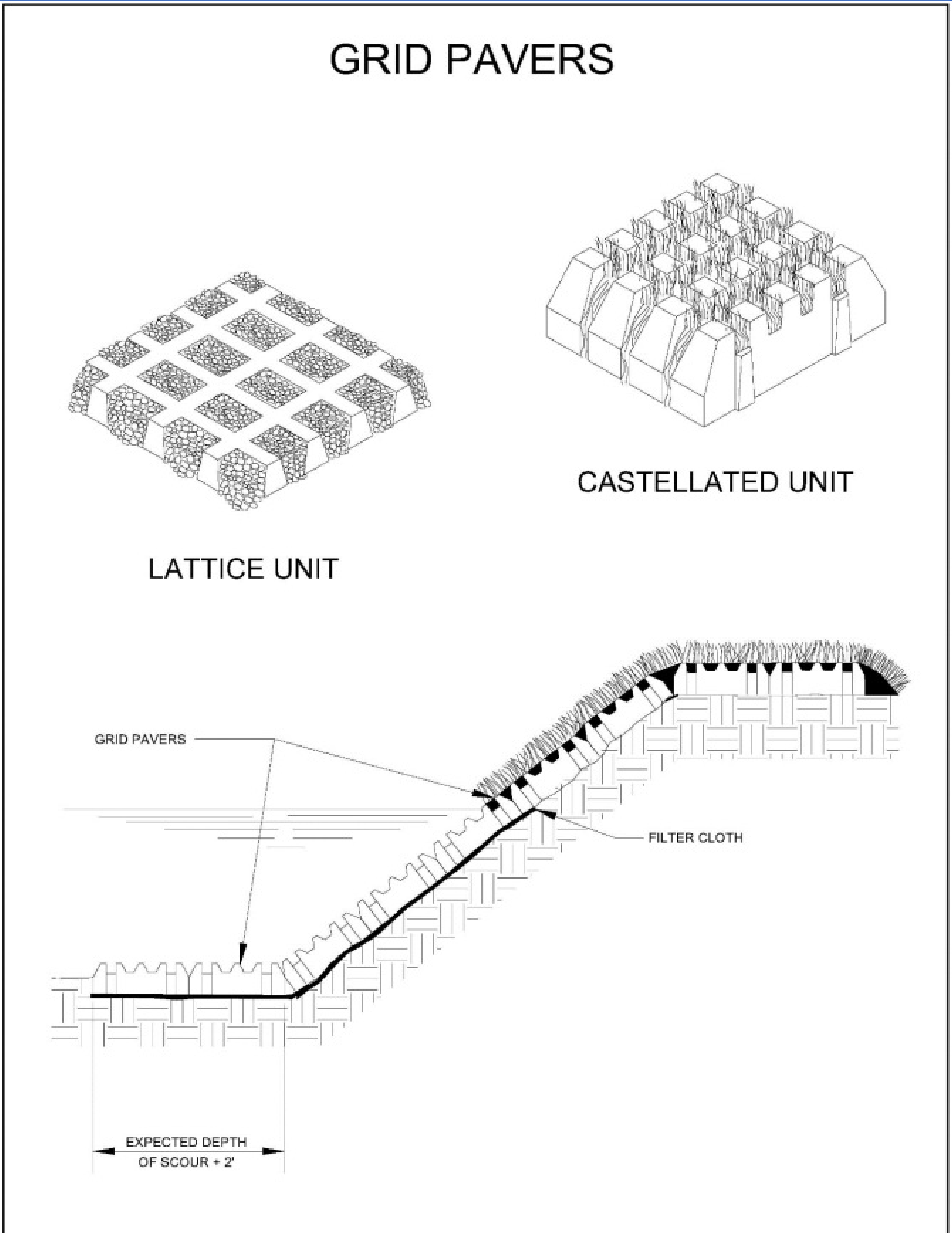
## *Figure C-ENV-02-2 Deflectors*



## *Figure C-ENV-02-3 Log Cribbing*



## *Figure C-ENV-02-4 Grid Pavers*




SOURCE: VA. DSWC

## 8.0 References

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

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United States Department of Agriculture. 2007. Natural Resources Conservation Service. National Engineering Handbook. Part 654, Stream Restoration Design.

# C-ENV-03 Temporary Vehicular Stream Crossing

## 1.0 Definition

A temporary vehicular stream crossing is a temporary structural span installed across a flowing watercourse for use by construction traffic. Structures may include bridges, round pipes, pipe arches, or oval pipes.

– CAD C-ENV-03-1 Temporary Bridge Crossing

– CAD C-ENV-03-2 Temporary Culvert Crossing

## 2.0 Purpose and Applicability of Best Management Practice

Temporary vehicular stream crossings provide a means for construction traffic to cross flowing streams without damaging the channel or banks and keep sediment generated by construction traffic out of the stream.

Temporary vehicular stream crossings are generally applicable to flowing streams with drainage areas less than 1 square mile. Design structures that must handle flow from larger drainage areas using methods that more accurately define the actual hydrologic and hydraulic parameters that will affect the functioning of the structure.

## 3.0 Planning and Considerations

Temporary stream crossings are necessary to prevent construction vehicles from damaging streambanks and continually tracking sediment and other pollutants into the flow regime. These structures also, however, represent a channel constriction, which can cause flow backups or washouts during periods of high flow. For this reason, the temporary nature of stream crossings is stressed. Plan for the temporary vehicular stream crossing to be in service for the shortest practical period and to be removed as soon as their function is completed.

The specifications contained in this section pertain primarily to flow capacity and resistance to washout of the structure. From a safety and utility standpoint, design the span to be capable of withstanding the expected loads from heavy construction equipment that will cross the structure. Ensure the design considers that such structures are subject to the rules and regulations of the U.S. Army Corps of Engineers for in-stream modifications.

A Section 401 State Certification of Water Quality, Section 404 dredge and fill permit, or state permit may be a requirement for a temporary stream crossing. Additionally, a permit with the U.S. Fish and Wildlife Service may be a requirement if authorities know endangered or threatened species or critical habitat to be present in the work area (USEPA 2021).

A temporary bridge crossing is a structure made of wood, metal, or other materials that provides access across a stream or waterway. The temporary bridge crossing is the preferred practice for temporary waterway crossings. Normally, bridge construction causes the least amount of disturbance to the stream bed and banks compared to the other types of crossings, and they can also be quickly removed and reused. In addition, temporary bridges pose the least chance for interference with fish migration when compared to the other temporary access waterway crossings.

A temporary culvert crossing is a structure consisting of stone and a section(s) of circular pipe, pipe arches, or oval pipes of reinforced concrete, corrugated metal, high-density polyethylene (HDPE), steel reinforced polyethylene (SRPE) pipe, polypropylene, or structural plate, which is used to convey flowing water through the crossings. Temporary culverts are used where the channel is too wide for normal bridge construction, or the anticipated loading of construction vehicles may prove unsafe for single-span bridges. There is some disturbance within the stream during construction and removal of the temporary culvert crossing. The stone, along with the temporary culverts, can be salvaged and reused.

## 4.0 Stormwater Performance Summary

**MS-13: TEMPORARY VEHICULAR STREAM CROSSING** – When a live watercourse must be crossed by construction vehicles more than twice in any 6-month period, a temporary vehicular stream crossing constructed of non-erodible material shall be provided.

**MS-15: BED AND BANK STABILIZATION** – The bed and banks of a watercourse shall be stabilized immediately after work in the watercourse has been completed.

9VAC25-875-560

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: N/A**

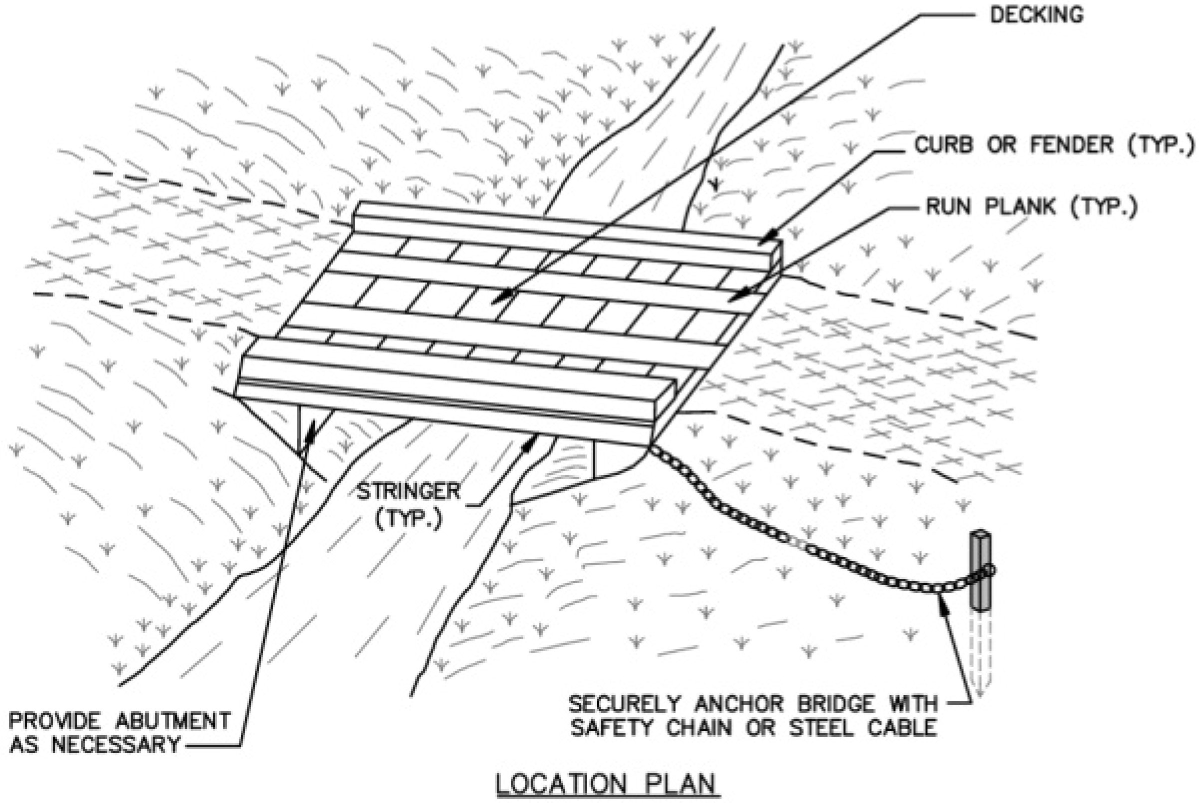
## 5.0 Design Criteria

**Table C-ENV-03-1 Temporary Bridge Crossing Design Criteria**

| Parameter | Notes on Proper Use |
|---|---|
| Construction | Structures may be designed in various configurations. However, use materials to construct the bridge that can withstand the anticipated loading of the construction traffic. Figure C-ENV-03-1 shows one example of such a crossing. |
| Crossing Alignment | Design the temporary waterway crossing to be at right angles to the stream.<br>Where approach conditions dictate, the crossing may vary 15 degrees from a line drawn perpendicular to the center line of the stream at the intended crossing location. |

| Table C-ENV-03-1 Temporary Bridge Crossing Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Roadway Approach | Design the centerlines of both roadway approaches to coincide with the crossing alignment centerline for a minimum distance of 50 feet from each bank of the waterway being crossed.<br><br>The 50-foot approach distance should be measured from the top of the waterway bank.<br>If physical or right-of-way restraints preclude the 50 feet minimum, a shorter distance may be explored. Consult with the VESMP Authority for assistance.<br>Limit all fill materials associated with the roadway approach to a maximum height of 2 feet above the existing floodplain elevation.<br><br>For approaches that slope to the waterway, construct a water diverting structure, such as a dike, waterbar, or swale (across the roadway on both roadway approaches), 50 feet (maximum) on either side of the waterway crossing.<br><br>Design the diverting structure in accordance with the criteria outlined in Temporary Right-of-Way Diversion/Waterbar (BMP C-ECM-07) or Temporary Diversion Dike (BMP C-ECM-04). |
| Perimeter Controls | Employ appropriate perimeter controls, such as Silt Fence (BMP C-PCM-04) or Turbidity Curtain (BMP C-SCM-09), when necessary, along banks of streams parallel to the streams. |
| Width | Design all crossings to have one traffic lane with a minimum width of 12 feet and a maximum width of 20 feet. |
| Additional Criteria | Further design/construction recommendations for temporary bridge construction are provided in Construction Specifications. |

**Figure C-ENV-03-1 Temporary Bridge Crossing**



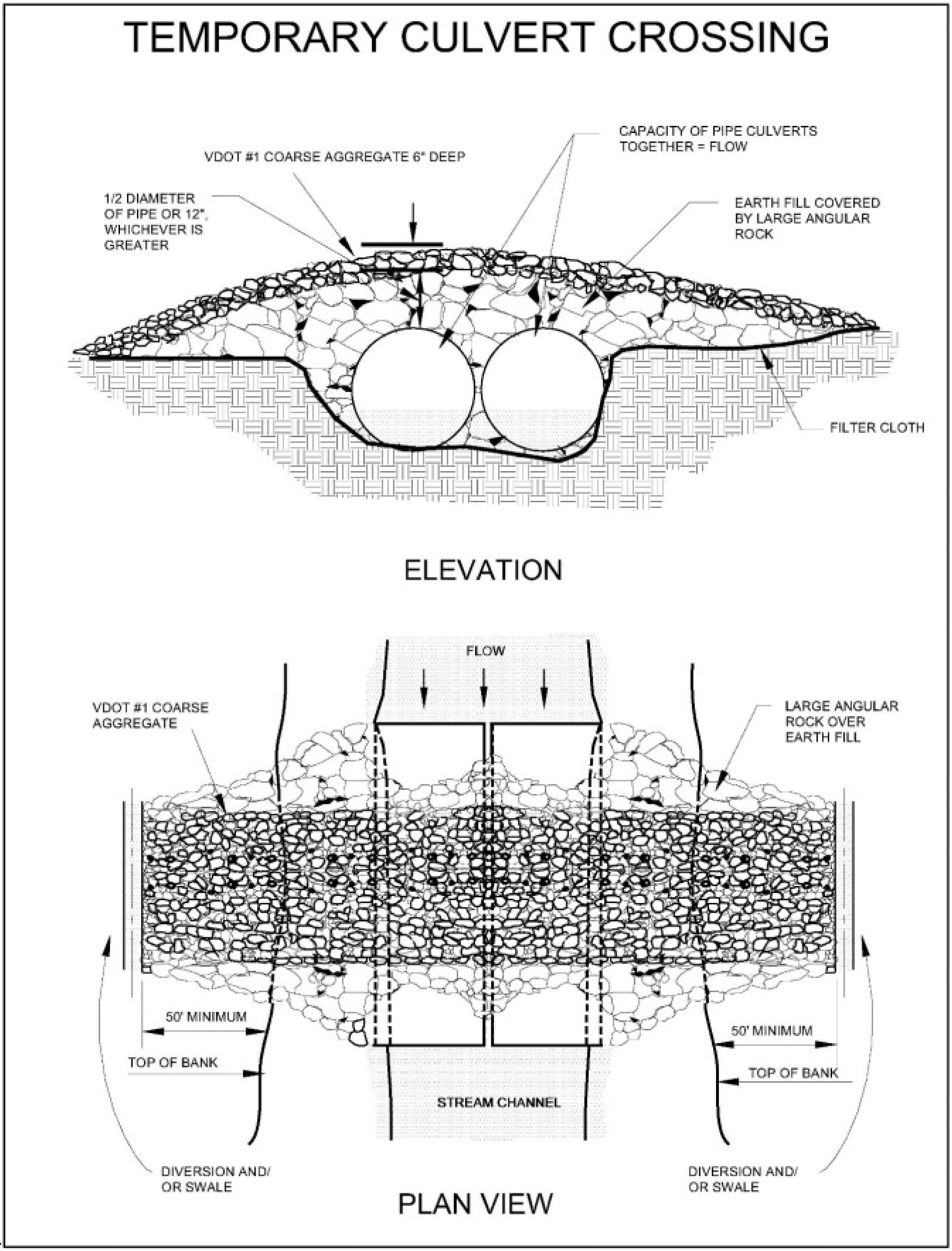

NOTE:
TIME OF YEAR RESTRICTIONS DO NOT APPLY TO THE CONSTRUCTION OR REMOVAL OF A TEMPORARY ACESS BRIDGE UNLESS THERE IS DISTURBANCE TO THE STREAM CHANNEL.

*Source: Maryland Department of the Environment 2011*

| Table C-ENV-03-2 Temporary Culvert Crossing Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Construction | Where culverts are installed, use Virginia Department of Transportation (VDOT) #1 Coarse Aggregate or larger to form the crossing. Ensure the depth of stone cover over the culvert is equal to one half the diameter of the culvert or 12 inches, whichever is greater. To protect the sides of the stone from erosion, design and use the riprap in accordance with Riprap (BMP C-ECM-13) (see Figure C-ENV-03-2). |
| Capacity | If the structure remains in place for up to 14 days, design the culvert to be large enough to convey the flow from a 2-year frequency storm without notably altering the stream flow characteristics. See Table C-ENV-03-3 for aid in selecting an appropriate culvert size (note all assumptions).<br>If the structure remains in place 14 days to 1 year, design the culvert to be large enough to convey the flow from a 10-year frequency storm. In this case, complete the hydrologic calculation and subsequent culvert size for the specific watershed characteristics.<br>If the structure must remain in place longer than 1 year, design the culvert crossing as a permanent measure by a qualified professional. |
| Size | Multiple culverts may be used in place of one large culvert if they have the equivalent capacity of the larger one.<br>Do not use culverts less than 18 inches in diameter. |
| Load | Design all culverts with sufficient cover and loading capacity to support their cross- sectioned area under maximum expected loads. |
| Length | Ensure the length of the culvert is adequate to extend the full width of the crossing including sideslopes. |
| Slope | Design the slope of the culvert to be at least 0.25 inch per foot (4 percent). |
| Crossing Alignment | Where conditions allow, install the temporary waterway crossing at right angles to the stream. Where approach conditions dictate, the crossing may vary 15 degrees from a line drawn perpendicular to the centerline of the stream at the intended crossing location. |

| Table C-ENV-03-2 Temporary Culvert Crossing Design Criteria | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Roadway Approach | Design the centerlines of both roadway approaches to coincide with the crossing alignment centerline for a minimum distance of 50 feet from each bank of the waterway being crossed. If physical or right-of-way restraints preclude the 50-foot minimum, a shorter distance may be provided. Limit all fill materials associated with the roadway approach to a maximum height of 2 feet above the existing floodplain elevation. Design the approaches to the structure to consist of stone pads meeting the following specifications:<br>1. Stone: VDOT #1<br>2. Minimum thickness: 6 inches<br>3. Minimum width: equal to the width of the structure<br>Construct a water diverting structure, such as a swale (across the roadway on both roadway approaches), 50 feet (maximum) on either side of the waterway crossing. The water diverting structure will prevent roadway surface runoff from directly entering the waterway. The 50-foot distance is measured from the top of the waterway bank.<br>Design the diverting structure in accordance with the criteria outlined in Temporary Right-Of-Way Diversion (BMP C-ECM-07) or Temporary Diversion Dike (BMP C-ECM-04). If the roadway approach is constructed with a reverse grade away from the waterway, a separate diverting structure is not necessary. |

**Figure C-ENV-03-2 Temporary Culvert Crossing**




SOURCE: VA. DSWC

*Figure C-ENV-03-2 Temporary Culvert Crossing*

*Source: Va. DSWC*

| Table C-ENV-03-3 Pipe Diameter for Stream Crossings | | | | |
|---|---|---|---|---|
| **Drainage Area (Acres)** | **Average Slope of Watershed (1%)** | **Average Slope of Watershed (4%)** | **Average Slope of Watershed (8%)** | **Average Slope of Watershed (16%)** |
| 1 – 25 | 24 | 24 | 30 | 30 |
| 26 – 50 | 24 | 30 | 36 | 36 |
| 51 – 100 | 30 | 36 | 42 | 48 |
| 101 – 150 | 30 | 42 | 48 | 48 |
| 151 – 200 | 36 | 42 | 48 | 54 |
| 301 – 350 | 42 | 48 | 60 | 60 |
| 351 – 400 | 42 | 54 | 60 | 60 |
| 451 – 500 | 42 | 54 | 60 | 72 |
| 501 – 550 | 48 | 60 | 60 | 72 |
| 551 – 600 | 48 | 60 | 60 | 72 |
| 601 – 640 | 48 | 60 | 72 | 72 |

1. Note: Table is based on USDA-SCS Graphical Peak Discharge Method for 2-year frequency storm event, CN = 65; Rainfall depth = 3.5 inches (average for Virginia).
2. Source: Va. DSWC.

## 6.0 Construction Specifications

**Temporary Bridge Crossing** (see Figure C-ENV-03-1)

1. Keep clearing and excavation of the stream bed and banks to a minimum.
2. Construct the temporary bridge structure at or above bank elevation to prevent the entrapment of floating materials and debris.
3. Place abutments parallel to and on stable banks.
4. Construct bridges to span the entire channel. If the channel width exceeds 8 feet (as measured from top-of-bank to top-of-bank), then a footing, pier, or bridge support may be constructed within the waterway. One additional footing, pier, or bridge support will be permitted for each additional 8-foot width of the channel. Do not construct a footing, pier, or bridge support within the channel for waterways less than 8 feet wide.

5. Construct stringers using logs, sawn timber, pre-stressed concrete beams, metal beams, or other approved materials.
6. Ensure decking materials are of sufficient strength to support the anticipated load. Place all decking members perpendicular to the stringers, butted tightly, and securely fastened to the stringers. Construct decking materials to be butted tightly to prevent any soil material tracked onto the bridge from falling into the waterway below.
7. Securely fasten run planking (optional) to the length of the span. Provide one run plank for each track of the equipment wheels. Although run planks are optional, they may be necessary to properly distribute loads.
8. Install curbs or fenders along the outer sides of the deck. Curbs or fenders are an option that will provide additional safety.
9. Securely anchor bridges at only one end using steel cable or chain. Anchoring at only one end will prevent channel obstruction if floodwaters float the bridge. Acceptable anchors are large trees, large boulders, or driven steel anchors. Ensure anchoring is sufficient to prevent the bridge from floating downstream and possibly causing an obstruction to the flow.
10. Stabilize all areas disturbed during installation within 7 calendar days of that disturbance in accordance with Minimum Standard #1.
11. When the temporary bridge is no longer needed, immediately remove all structures including abutments and other bridging materials. Consider the need for inspections and repairs prior to permit termination before the crossing is removed.
12. To achieve final cleanup, remove the temporary bridge from the waterway, protect the banks from erosion, and remove all construction materials. Store all removed materials outside the floodplain of the stream. Remove the bridge and clean up the area without construction equipment working in the waterway channel.

**Temporary Culvert Crossing** (see Figure C-ENV-03-2)

1. Keep clearing and excavation of the stream bed and banks to a minimum.
2. Install the invert elevation of the culvert on the natural streambed grade to minimize interference with fish migration.
3. Place filter fabric on the streambed and streambanks before placement of the pipe culvert(s) and aggregate. Ensure the filter fabric covers the streambed and extend a minimum of 6 inches and a maximum of 1 foot beyond the end of the culvert and bedding material. Filter fabric reduces settlement and improves crossing stability. See Riprap (BMP C-ECM-13) for required physical qualities of the filter fabric.
4. Extend the culvert(s) a minimum of 1 foot beyond the upstream and downstream toes of the aggregate placed around the culvert. Ensure the culvert length does not exceed 40 feet.
5. Cover the culvert(s) with a minimum of 1 foot of aggregate. If multiple culverts are used, separate the culverts by at least 12 inches of compacted aggregate fill. At a minimum, ensure the bedding and fill material used in the construction of the temporary access culvert crossings conforms with the aggregate requirements cited in Section 5.0 Design Criteria.

6. When the crossing has served its purpose, remove all structures including culverts, bedding, and filter fabric materials. Remove the structure and clean up the area without construction equipment working in the waterway channel. Consider the need for inspections and repairs prior to permit termination before the crossing is removed
7. Upon removal of the structure, immediately shape the stream to its original cross-section and properly stabilize.

## 7.0 Operations and Maintenance Considerations

Inspect temporary vehicular stream crossings after every rainfall and at least once a week, whether it has rained or not, and repair all damages immediately.

Inspect stream for bank erosion and in-stream degradation. If bank erosion is occurring, stabilize banks using erosion control practices such as erosion control blankets. If in-stream degradation is occurring, armor the culvert outlet(s) with riprap to dissipate energy. If sediment is accumulating upstream of the crossing, remove excess sediment as needed to maintain the functionality of the crossing.

Remove the temporary crossing when it is no longer needed for construction. Take care to minimize the amount of sediment lost into the stream upon removal. Once the crossing has been removed, stabilize the stream banks with seed and erosion control blankets.

## 8.0 References


Maryland Department of the Environment. 2011. 2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control. December.

USEPA. 2021. Temporary Stream Crossings. Stormwater Best Management Practice. EPA-832-F-21-028Y. December.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.


# C-ENV-04 Utility Stream Crossing

## 1.0 Definition

Utility stream crossing is a strategy for crossing small waterways when in-stream utility construction is involved.

## 2.0 Purpose and Applicability of Best Management Practice

Utility stream crossing helps to protect sediment from entering a stream from construction within approach areas and minimizes the amount of disturbance within the stream itself.

Utility stream crossing is generally applicable to flowing streams with drainage areas less than 1 square mile. For crossing streams with larger drainage areas, use structures or methodology that more accurately define the actual hydrologic and hydraulic parameters, which will affect the functioning of the structure.

## 3.0 Planning and Considerations

Utility construction, by virtue of its sprawling, linear nature, frequently crosses and impacts live streams. There is a potential for excessive sediment loss into a stream by both the disturbance of the approach areas and by the work within the stream bed and banks.

It is often difficult to decide what type of control to use as a utility stream crossing. Trenchless technologies involve pipe installation with minimal surface and environmental disruptions and include jack and bore, micro tunneling, and horizontal directional drilling (HDD).

Trenchless utility installation prevents disturbance within the watercourse and is a preferred method if it is practical. However, where in-stream work is unavoidable, consider providing adequate mitigation of sediment loss while minimizing the amount of encroachment (Minimum Standard #12) and time spent working in the channel. There is some "give and take" as far as the installation of controls – sometimes there is less damage to the environment created by providing substantial controls for the approach areas and refraining from installing extensive measures in the stream itself. However, when the installation of the utility line within streambed and banks will take an extended period of construction time, consider the use of substantial in-stream controls or stream diversion to prevent excessive sedimentation damage.

Because choosing the right method for a utility stream crossing is difficult, ensure designers and plan reviewers visit the sites of proposed crossings to ensure that the most appropriate method is chosen. Ensure the designer and plan reviewer are aware that modifications are subject to other state and federal construction permits.

The following are several methods for dealing with utility stream crossings (with varying construction time and stream size scenarios) that allow for "work in the dry" to prevent excessive sedimentation damage. By no means are these methods all-inclusive. As with other control measures, site-specific design and innovative variations are encouraged.

## 4.0 Stormwater Performance Summary

**MS-12: WATERCOURSE CONSTRUCTION** – When work in a live watercourse is performed, precautions will be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material will be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

**MS-14: OTHER WATERCOURSE REGULATIONS** – All applicable federal, state, and local requirements pertaining to working in or crossing live watercourses will be met.

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: MODERATE**

## 5.0 Design Criteria

**Table C-ENV-04-1 Design Criteria for Utility Stream Crossings**

| Design Component | Notes on Proper Use |
|---|---|
| Drainage Area | Ensure the drainage area is no larger than 1 square mile (640 acres). |
| Damming Methods | Refer to Cofferdam Crossing (C-ENV-05) for cofferdam and alternative damming methods to complete the crossings. |
| Filter Fabric | Use a filter fabric in the construction of the utility crossing that conforms to physical requirements noted in Riprap (BMP C-ECM-13). |

| Table C-ENV-04-1 Design Criteria for Utility Stream Crossings | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Water Diverting Structures | Use water diverting structures at all trenching and/or construction road approaches (50 feet on either side of the crossing). Refer to Temporary Vehicular Stream Crossing (BMP C-ENV-03). |
| Additional Criteria | Design criteria more specific to each crossing are provided on Figure C-ENV-04-1 through Figure C-ENV-04-5. |
| Dewatering | Before complete dewatering of the work area, remove trapped fish and other aquatic wildlife and relocate to the water body downstream of the lower barrier. |

## 6.0 Construction Specifications

| Table C-ENV-04-2 Construction Specifications for Utility Stream Crossings | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Diversion Channel Crossing | Diversion channel crossing is the preferred method if construction will remain in the area of stream for an extended period (longer than 72 hours) and site conditions (such as width of stream) make diversion practical.<br>1. Ensure the diversion channel crossing is operational before working in the stream (construction will be performed "in the dry" when no stream flow is present).<br>2. Construct the temporary diversion channel to have a minimum bottom width of 6 feet or equal to bottom width of existing streambed, whichever is less. Refer to Figure C-ENV-04-1 and Figure C-ENV-04-2.<br>3. Construct the temporary diversion channel with a maximum sideslope steepness of 2H:1V. Construct the depth and grade of the temporary diversion channel to be sufficient to ensure continuous flow of water in the diversion. However, the depth and grade may vary dependent on site conditions.<br>4. There are three types of diversion channel linings that can be used based on expected velocity of bank full flow. Refer to Figure C-ENV-04-2 and Table C-ENV-04-1.<br>5. TYPE A stream diversions may be seeded with a standard seed mix for the type of soils encountered and the time of year in which seed is sown. Achieve an average growth of 2 inches throughout the diversion with an 85% cover before water is turned through it.<br>6. Secure stream diversion liners at the upstream and downstream sides with non- erodible weights such as riprap. Ensure these weights allow normal flow of the stream. Do not mix soil in with stream diversion weights. Weights may also be needed along the stream diversion's length to secure the liner.<br>7. Overlap stream diversion liners when a single or continuous liner is not available or is impractical. Install overlaps so that continuous flow of the steam is maintained and an upstream section overlaps a downstream section by a minimum of 18 inches. Make overlaps along the cross-section so that a liner is placed in the steam diversion bottom first and additional pieces of liner on the slopes overlap the bottom piece by a minimum of 18 inches.<br>8. Entrench stream diversion liners at the tops of the diversion slopes (slope breaks) along with a line of silt fence. Silt fence may be excluded if the diversion liner is extended to such a point that siltation of the stream will not occur. If silt fence is excluded, secure the diversion liner. Extend liners from slope break to slope break as shown on Figure C-ENV-04-2.<br>9. Use staples employed in securing Soil Stabilization Blankets and Matting (BMP C-SSM-05) or non-erodible weights (riprap) as necessary to anchor stream diversion liners to the sideslopes of the diversion. Do not use wooden stakes on the diversion's bottom or side slopes.<br>10. Use non-erodible materials, such as riprap, jersey barriers, sandbags, plywood, or sheet piling, as flow barriers to divert the stream away from its original channel and prevent or reduce water backup into a construction area.<br>11. Remove the downstream flow barrier before the upstream barrier |

| Table C-ENV-04-2 Construction Specifications for Utility Stream Crossings | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Flume Pipe Crossing | Flume pipe crossing is to be used when in-stream construction will last less than 72 hours and the stream is narrow (less than 10 feet wide), making cofferdam construction impractical.<br>1. Make the flume pipe crossing operational before the start of construction in the stream.<br>2. Ensure the materials used (culvert[s], stone, and filter fabric) meet the physical constraints of those used in Temporary Vehicular Stream Crossing (BMP C-ENV-03).<br>3. Install a large flume pipe (or culvert) of an adequate size to support normal water channel flow (see Figure C-ENV-04-3) in the stream bed across the proposed pipeline trench centerline. Place Virginia Department of Transportation (VDOT) #1 Coarse Aggregate (minimum size) or riprap close to each end of the flume pipe to dam off the creek, forcing the water to flow through the flume pipe (see Figure C-ENV-04-3).<br>4. Pump the entrapped water from the creek within the dammed-off area and in the proposed trench centerline into an approved Dewatering Structure (BMP C-SCM-10).<br>5. Dig the trench under the flume pipe. Install the pipe sections within the trench to the proper depth under the flume pipe. After pipe sections are installed, backfill and restabilize the stream channel.<br>6. Ensure re-stabilization consists of the installation of non-grouted riprap on all disturbed streambank areas (or on the area 6 feet on both sides of the centerline of the utility trench, whichever is greater) with slopes of 3H:1V or greater. Refer to Riprap (BMP C-ECM-13) for installation requirements. For slopes of 3H:1V or less, vegetative stabilization may be used pending approval by the certified plan reviewer. Immediately stabilize the streambed, banks, and the approach areas following the attainment of final grade.<br>7. After completion of backfilling, restoration of stream banks, and leveling of stream bed, remove the flume pipe. Remove or spread the gravel in the stream bed depending on permit requirements. Do not remove sediment controls in approach areas until all construction is completed in the stream crossing area. Return all ground contours to their original condition.<br><br>Active Flume Pipe Utility Stream Crossing |

**Table C-ENV-04-2 Construction Specifications for Utility Stream Crossings**

| Design Component | Notes on Proper Use |
|---|---|
| Cofferdam Utility Crossing | Cofferdam utility crossing is to be used when stream diversion is not practical and the stream is wide enough (10 feet or wider) to accommodate cofferdam installation.<br><br>Active Cofferdam Utility Stream Crossing<br>1. Perform construction in low-flow periods.<br>2. Construct the crossing in a manner that will not prohibit the flow of the stream (see Figure C-ENV-04-4).<br>3. As with all utility line crossings, control approach areas with perimeter measures such as silt fence, compost filter sock, or straw bales.<br>4. Remove large rocks, woody vegetation, or other material from the streambed and banks that may impede placement of the riprap, sandbags, sheet metal, or wood planks or installing the utility pipe or line.<br>5. Form a cofferdam in a semicircle along the side of the stream in which the utility installation will begin. Surround and underlay the cofferdam with filter fabric as shown on Figure C-ENV-04-4. The height of and area within the dam will depend on the size of the work area and the amount of stream flow. Stack materials as high as will be necessary to keep water from overtopping the dam and flooding the work area. Refer to Cofferdam Crossing (BMP C-ENV-05) for additional details on cofferdams.<br>6. When the stream flow is successfully diverted by the cofferdam, dewater the work area and stabilize it with aggregate (VDOT #57 or #68 Coarse Aggregate) or sand. Make sure to discharge the water into a sediment trapping device; see Dewatering Structure (BMP C-SCM-10).<br>7. Install the utility pipe or line in half the streambed as noted on Figure C-ENV-04-4. Remove the riprap or other materials and begin placing them on the other side of the stream.<br>8. Ensure re-stabilization consists of the installation of non-grouted riprap on all disturbed streambank areas (or on the area 6 feet on both sides of the centerline of its utility trench, whichever is greater) with slopes of 3H:1V or greater. Refer to Riprap (BMP C-ECM-13) for installation requirements. For slopes of 3H:1V or less, vegetative stabilization may be used pending approval by certified plan reviewer. Immediately stabilize the streambed, banks, and the approach areas following the attainment of final grade. |

**Table C-ENV-04-2 Construction Specifications for Utility Stream Crossings**

| Design Component | Notes on Proper Use |
|---|---|
| Dam and Pump Bypass Crossing | Dam and pump bypass crossing is used when in-stream construction will last less than 72 hours and the stream is narrow (less than 10 feet wide), making cofferdam construction impractical.<br>1. Perform construction in low-flow periods.<br>2. As with all utility line crossings, control approach areas with perimeter measures such as silt fence, compost filter sock, or straw bales.<br>3. Remove large rocks, woody vegetation, or other material from the streambed and banks that may impede placement of the cofferdam or installing the utility pipe or line.<br>4. Form an upstream and downstream cofferdam at both ends of the in-stream work area by placing the cofferdam across the entire upstream and downstream width of the stream in which the utility will be installed. Surround and underlay the cofferdams with filter fabric as shown on Figure C-ENV-04-5. The height of and area within the dams will depend on the size of the work area and the amount of stream flow. Stack materials as high as necessary to keep water from overtopping the dams and flooding the work area. Refer to Cofferdam Crossing (BMP C-ENV-05) for additional details on cofferdams.<br>5. When the stream flow is successfully diverted by the cofferdam, dewater the work area and stabilize it with aggregate (Virginia Department of Transportation [VDOT] #57 or #68 Coarse Aggregate) or sand. Make sure to discharge the water into a sediment trapping device; see Dewatering Structure (BMP C-SCM-10). Pump water from the work area to a Dewatering Structure (BMP C-SCM-10) located such that the water drains back into the channel below the downstream cofferdams.<br>6. Pump stream flow around the work area upstream to downstream. Select a pump(s) sized to adequately pump the stream base flow at a head greater than the in-stream barrier height.<br>7. Discharge the pump onto a stable velocity dissipater made of riprap or sandbags at the downstream end. Maintain the bypass pump intake at the upstream end a sufficient distance from the bottom to prevent pumping of channel bottom materials.<br>8. Install the utility pipe or line across the streambed as noted on Figure C-ENV-04-5. Remove the riprap or other materials from the stream.<br>9. Ensure re-stabilization consists of the installation of non-grouted riprap on all disturbed streambank areas (or on the area 6 feet on both sides of the centerline of its utility trench, whichever is greater) with slopes of 3H:1V or greater. Refer to Riprap (BMP C-ECM-13) for installation requirements. For slopes of 3H:1V ... vegetation<br><br>Active Dam and Pump Bypass Stream Crossing |

| Table C-ENV-04-3 Diversion Channel Linings | | |
|---|---|---|
| **Lining Material** | **Classification** | **Acceptable Velocity Range (fps)** |
| Filter Fabric*, Polyethylene, or Grass | TYPE A | 0 – 2.5 |
| Filter Fabric * | TYPE B | 2.5 – 9.0 |
| Class I Riprap and Filter Fabric * | TYPE C | 9.0 – 13.0 |

* Filter fabric must meet the minimum physical requirements noted in Riprap (BMP C-ECM-13).

fps = feet per second

Source: Virginia Department of Transportation (VDOT) Standard Sheets.

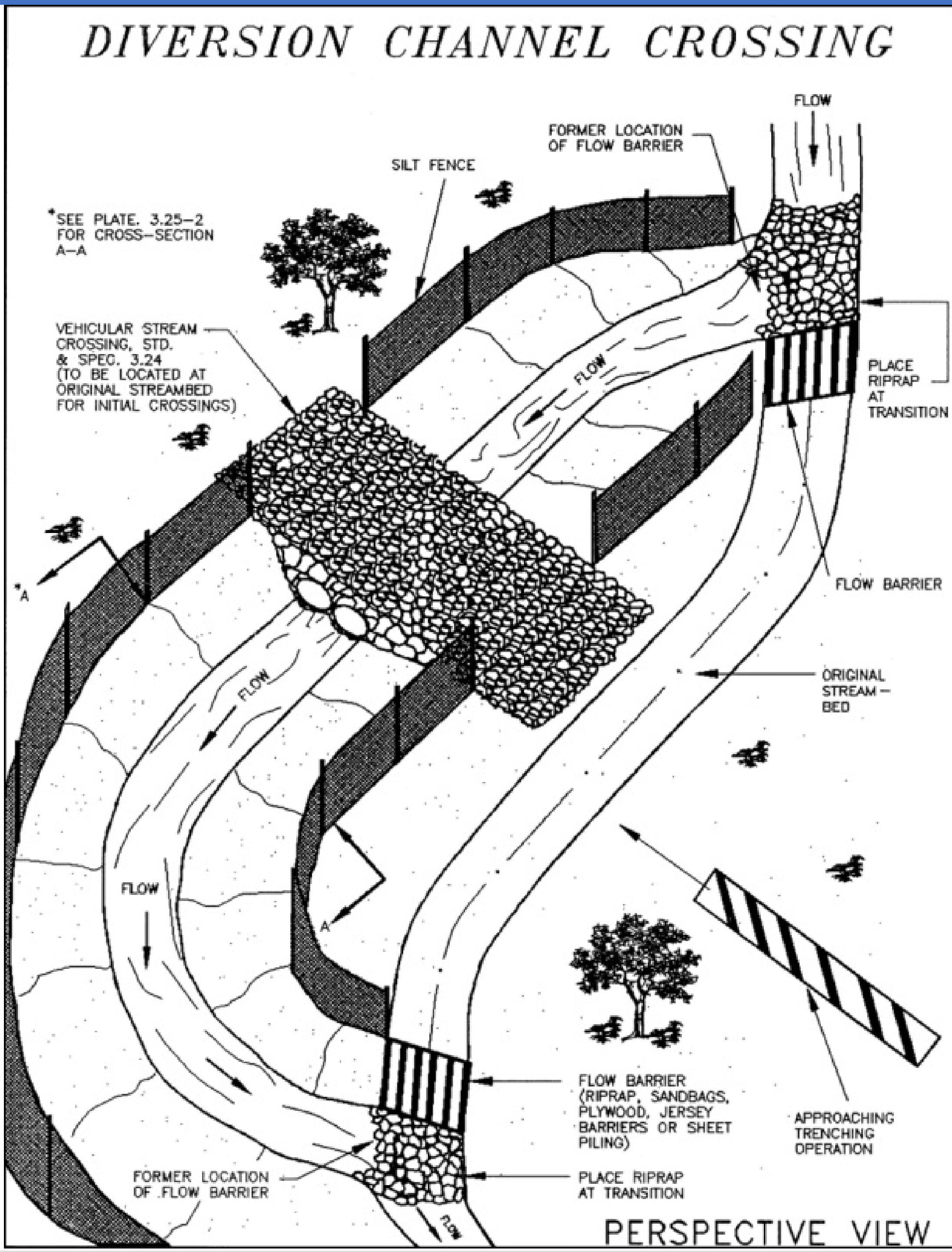
| Table C-ENV-04-4 Trenchless Technology | |
|---|---|
| **Technique** | **Notes on Proper Use** |
| Jack and Bore | Jack and bore, or auger boring, is one of the most popular methods of trenchless technologies. A sending pit and a receiving pit are excavated on either side of the crossing location. A jack and bore machine is placed in the sending pit. A hole is cut underground horizontally from the sending pit to the receiving pit using a rotating cutter head attached to an auger string. As the machine drills the hole, the new pipe or line is pushed into the drilled hole using a jacking frame. The rotating auger brings the spoil material back to the machine. The jack and bore machine is removed, and the pits are backfilled and surfaces restored. |
| Micro tunneling | Micro tunneling is defined as a remotely controlled and guided pipe jacking technique that provides continuous support to the excavation face and does not require personnel entry into the tunnel. Like jack and bore, a sending and receiving pit are excavated at either side of the crossing location, and the micro tunneling boring machine is placed in the sending pit. The rotating cutting head excavates the soil while pipe sections are pushed through the drilled hole using a jacking frame. There is a closed-loop slurry system in which excavated soil is mixed with clean water and bentonite that is transported to discharge cables into a separation system for recirculation or routing to storage tanks. |
| HDD | HDD, also known as directional boring, is a method of installing pipes underground using a steerable arc-drilling rig. HDD is surface launched, resulting in no need for sending and receiving pits to be excavated. First, a drill bit tool creates a pilot hole from the entry to the receiving locations at an angle of 5 to 30 degrees from the ground surface. The second phase is reaming, which enlarges the hole by approximately 50% and prepares it for pipe placement. A reamer tool replaces the drill bit and is pulled back or pushed forward by the HDD machinery to expand the pilot hole. The third phase is pipe pullback, in which the new pipe is attached to the reamer and pulled through the HDD borehole into place. Drilling fluid is used to suspend and remove soil cuttings, stabilize the hole, reduce friction, cool and lubricate the drill bit, and control soil pressures below the surface. Typically, drilling fluid consists of a mixture of water, bentonite, soda ash, and chemicals that prevent swelling. |

## 7.0 Operations and Maintenance Considerations

Take care to inspect any stream crossing area at the end of each day to make sure that the construction materials are positioned securely. This will ensure that the work area stays dry and that no construction materials float downstream.

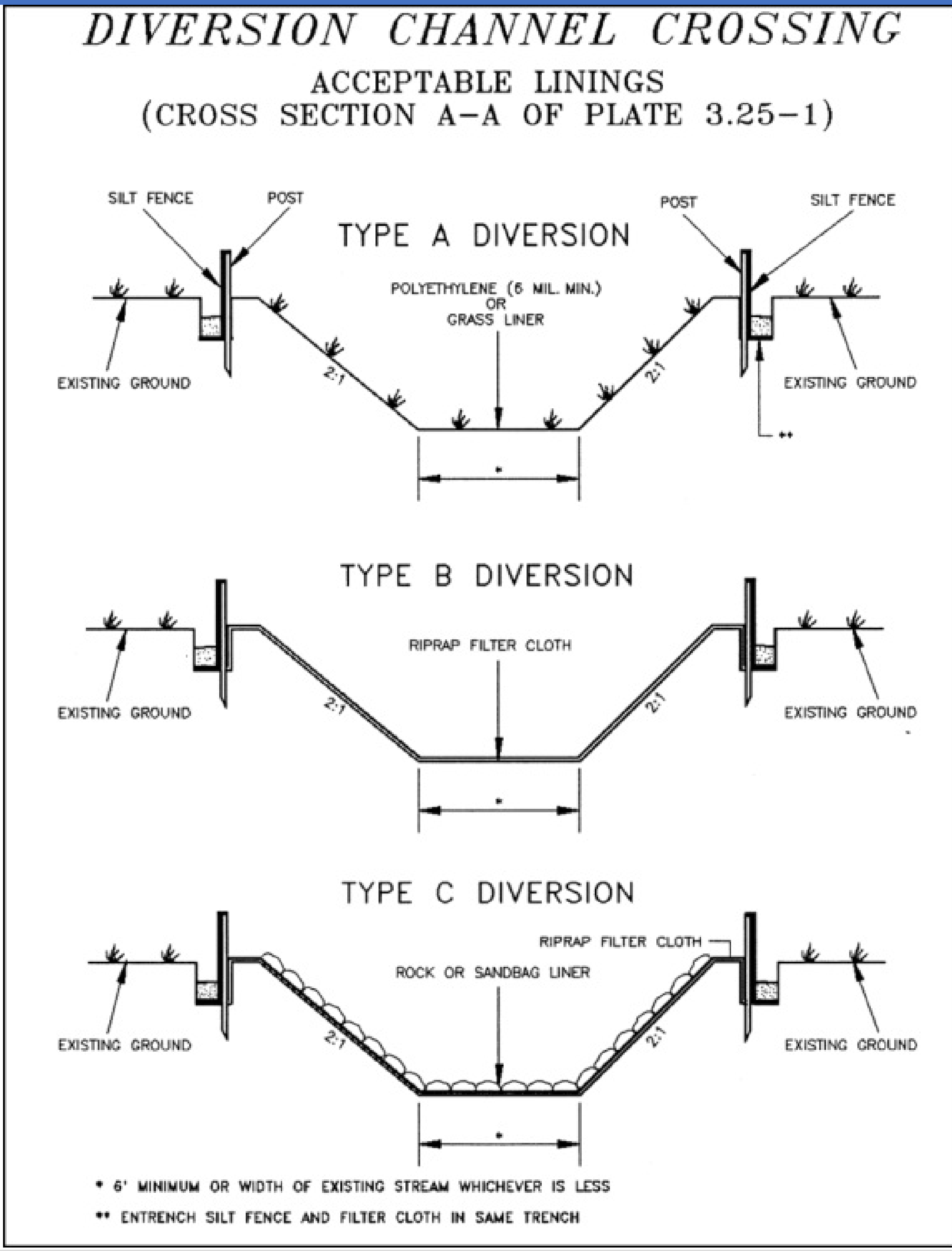
Continuously monitor the performance and configuration of the crossing for any changes in stream flow or diversion pipe or pump performance. Monitor the upstream or backwatered areas for headwater depths in relation to the heights of the dams to ensure water is not rising to the tops of the dams or flowing in undesirable locations. Keep the inlet of the diversion pipe and pump intake free from debris and ensure the intake protection is functioning. Maintain the pumps in operating condition and provide a backup pump in case of failure. Inspect the stable discharge point for indicators of erosion and repair any erosion observed.

**Figure C-ENV-04-1 Diversion Channel Crossing**



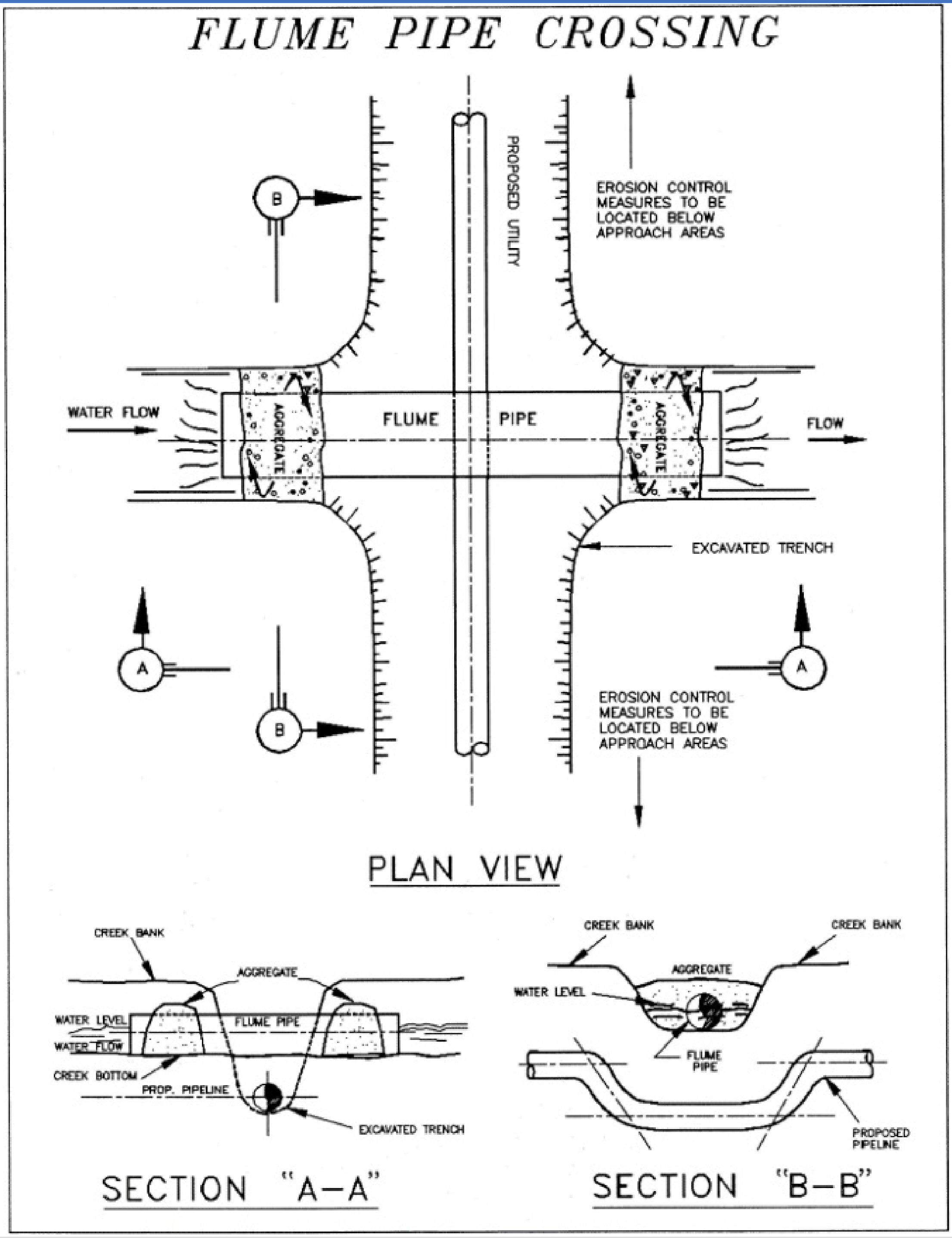

*Source: Va. DSWC*

**Figure C-ENV-04-2 Diversion Channel Crossing Acceptable Linings**



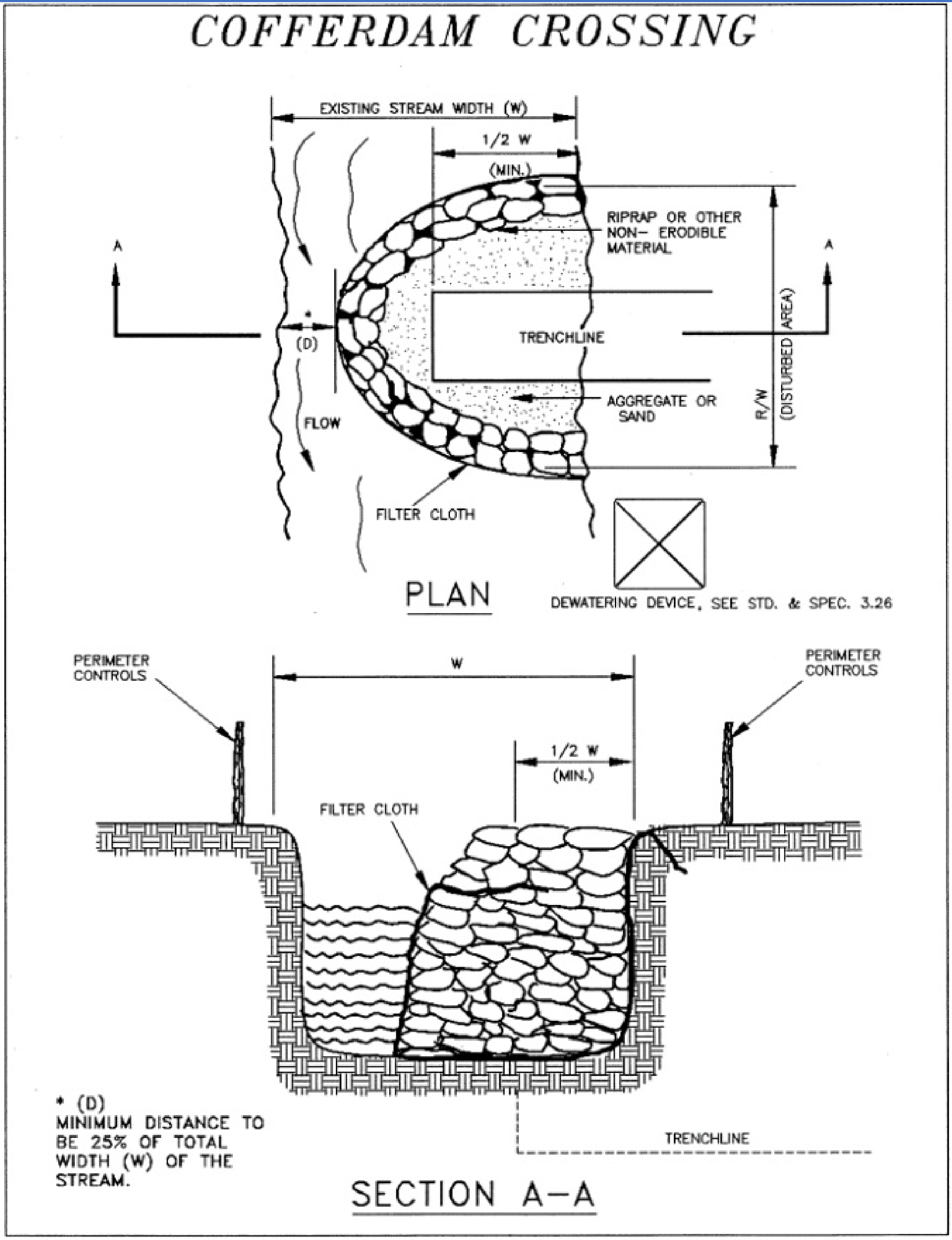

*Source: Adapted from VDOT Standard Sheets*

## Figure C-ENV-04-3 Flume Pipe Crossing



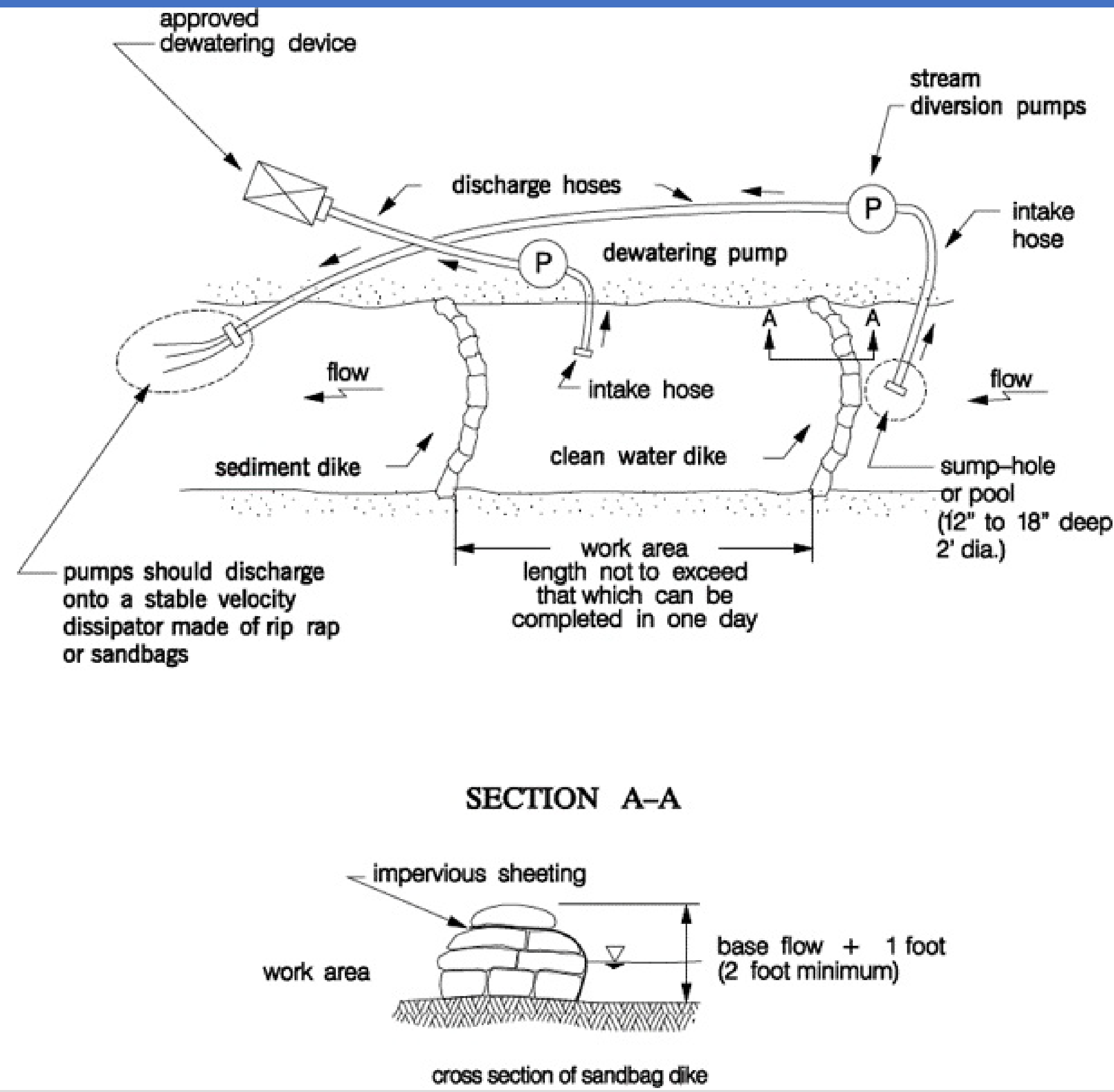

Source: Va. DSWC

**Figure C-ENV-04-4 Cofferdam Crossing**




*Source: Va. DSWC*

Figure C-ENV-04-5 Sandbag Dike




*Source: Maryland Department of the Environment 2011*

## 8.0 Reference

Maryland Department of the Environment. 2011. 2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control. December.

# C-ENV-05 Cofferdam Crossing

## 1.0 Definition

A cofferdam is a temporary structure within a waterway or body of water designed to provide a dry work area for temporary construction and to contain disturbed soil and/or suspended sediments.

## 2.0 Purpose and Applicability of Best Management Practice

Cofferdams allow work to be performed in a waterway or body of water while minimizing turbidity and sedimentation in adjacent and/or downstream areas.

Cofferdams are used as a temporary measure when work will be conducted in a waterway (stream, river, or other linear feature that conveys water) or body of water (lake, pond, or other impoundment). Water is either intercepted upstream and discharged downstream or diverted around the work site.

Typical activities requiring the use of cofferdams include shoreline stabilization of a waterbody; installation or replacement of a culvert, bridge, pier, or abutment; open-cutting for the installation of utilities; and stream restoration projects. Cofferdams may also be used to allow work in otherwise unsuitable conditions.

Where a cofferdam is needed, refer to Utility Stream Crossing (BMP C-ENV-04) and Pump Around Diversion (BMP C-ENV-08).

This practice standard should not take the place of engineered sheetpile, cellular, slurry wall, tie-back wall, brace excavation, or embankment cofferdams. Cofferdams designed using this standard may necessitate review by a licensed engineer depending on the size and scale of the cofferdam.

## 3.0 Planning and Considerations

Five typical cofferdam types are described herein, but others are possible. Design alternative cofferdams based on the general criteria of this standard and adapt the design to meet the requirements of similar cofferdam types. As an example, rather than stone for the stone and impermeable barrier cofferdam, sandbags or gravel bags may be used. In addition, the upstream and downstream cofferdam types can be different.

Do not leave cofferdams in for long periods, as cofferdams are temporary structures. Incorporate additional considerations for long-term cofferdam usage such as issues with ice flow or aquatic life movement. Long-term cofferdams may have to be built to withstand a less frequent (higher magnitude) storm event. ***Remove cofferdams immediately after the work in the waterbody is complete.***

Any work within a stream may be subject to the rules and regulations of the U.S. Army Corps of Engineers. A permit may also be required from the Virginia Department of Environmental Quality and Virginia Department of Conservation and Recreation.

Additional requirements may apply where state or federally threatened or endangered species or other species of local interest are present.

Before the installation or removal of a cofferdam, a Turbidity Curtain (BMP C-SCM-09) or a Modified Turbidity Curtain for Streams (BMP C-ENV-14) may be installed to contain turbid water and allow suspended solids resulting from the installation of the cofferdam to settle out. Do not place turbidity curtains across stream flow, as they may reduce flow and catch debris. Place the curtains parallel to flow or the shoreline to contain sedimentation that may occur during the installation of the cofferdam.

When installing a cofferdam in a linear water feature, make every effort to block only a portion of the waterway by using a partial cofferdam. The reason for using a partial cofferdam is to maintain stream flow and allow the movement of aquatic life during construction. Block the entire flow only when necessary.

## 4.0 Stormwater Performance Summary

**MS-12: WATERCOURSE CONSTRUCTION** – When work in a live watercourse is performed, precautions will be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material will be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

**MS-14: OTHER WATERCOURSE REGULATIONS** – All applicable federal, state, and local requirements pertaining to working in or crossing live watercourses will be met.

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

| Table C-ENV-05-1 Design Criteria for Cofferdam Crossings | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Diversion/ Bypass Flow | Size the diversion or bypass flow to safely convey the 2-year, 24-hour peak flow at a minimum. Design the cofferdam to overtop for any events greater than the 2-year, 24- hour peak elevation, unless higher peak flows are being bypassed. It is the responsibility of property owners and those performing work to safely convey flows to prevent damage to off-site properties.<br>If waterway information is not available, the ordinary high-water (OHW) mark (OHWM) can be used as an indicator. The term "low-flow conditions" refers to flow at or below the OHWM. The OHWM refers to a clear line developed by typical fluctuations in water levels.<br><br>Ensure the construction of any cofferdam, within a linear water feature and regardless of duration, does not cause a significant water level difference upstream or downstream of the project site. Maintain the stream velocity below the cofferdam at a rate equal to existing pre-installation flow conditions above the cofferdam. |
| Materials | Construct cofferdams of non-erodible materials such as stone, metal, geosynthetics, or other products as approved by the certified plan reviewer. Ensure the cofferdam materials are free of potential pollutants such as soil, silt, sand, clay, grease, or oil. Use non-toxic and non-hazardous substances to assemble or maintain cofferdams. Ensure any material used to minimize seepage underneath diversion structures, such as grout, is non-toxic, non-hazardous, and as close to neutral pH (7) as possible.<br><br>Acceptable cofferdam materials include sandbags, sand totes, Jersey wall sections, collapsible fabric membrane dams, A-frame, water filled bags/tubes, sheet piling, plastic wrapped hay bales/soil/aggregate/riprap, plastic sealed plywood, plastic sealed trench box lids, or other suitable materials.<br><br>Refer to the Utility Stream Crossing (BMP C-ENV-04) for alternative stream crossing methods. |
| Filter Fabric | Use filter fabric in the construction of the cofferdam that conforms to physical requirements noted in Riprap (BMP C-ECM-13) to line the water side of the cofferdam to prevent water passage into the work area. |
| Scheduling | To avoid or minimize impacts, schedule construction in a linear water feature during seasonal or temporary periods of low- or no-flow conditions. During scheduling, also consider seasonal releases of water from dams, water demands due to crop irrigation, and timed to minimize impacts on fish and other aquatic life. Do not use cofferdams across a stream bed when fish passage/spawning is of concern unless properly mitigated. |

| Table C-ENV-05-1 Design Criteria for Cofferdam Crossings | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Velocity Dissipator | Riprap- or sandbag-lined “plunge pool” sized to be non-erosive at the discharge pipe velocity. |

| Table C-ENV-05-2 Types of Cofferdams | |
|---|---|
| **Type** | **Notes on Proper Use** |
| Sandbag or Sand Tote | Suggested for temporary barriers in shallow water up to 3 feet. Sandbags or sand totes may be filled on site or pre-filled and made of burlap or polypropylene materials that are resistant to ultraviolet (UV) radiation, tearing, and puncture. Ensure sandbag or tote material is woven tightly enough to prevent leakage of the fill material (i.e., sand, or fine gravel). Refer to Plate 1. |
| Bladder | Only use inflatable bladders where there is a relatively flat base material. Wide variations in the base elevation will result in an improper seal, which will allow water seepage. Bladder cofferdams are appropriate for both full and partial cofferdam situations.<br><br>Construct inflatable bladder cofferdams in accordance with manufacturer specifications. Follow the specific sizing, installation requirements, maintenance, allowable flow velocities, and other pertinent information per the manufacturer specifications. Ensure all cofferdams are duel-chambered to avoid rolling. Refer to Plate 2. |
| A-Frame | Only use A-frame cofferdams where there is a relatively flat base material. Wide variations in the base elevation will result in an improper seal, which will allow water seepage. A-frame cofferdams are appropriate for both full and partial cofferdam situations.<br><br>Construct A-frame cofferdams in accordance with manufacturer specifications. Follow the specific sizing, installation requirements, maintenance, allowable flow velocities, and other pertinent information per the manufacturer specifications. Refer to Plate 3. |

| Table C-ENV-05-2 Types of Cofferdams | |
|---|---|
| **Type** | **Notes on Proper Use** |
| Stone & Impermeable Barrier | Only use stone and impermeable barrier cofferdams in intermittent streams of lower flow velocity. These cofferdams may be used in partial cofferdam situations in higher velocity linear water features and waterbodies.<br>This cofferdam method could be an option where underground electrical and gas lines may be present. It may also be a good option for areas with an uneven, stone, or bedrock base material.<br><br>To install a stone impermeable barrier cofferdam, first place the impermeable barrier on the bottom of the water feature. Extend the barrier out past the edge of the future cofferdam at a sufficient length so that it can be pulled back over the riprap after it has been installed. This will create a seamless barrier on the water side with the opening seam on the work area side. After the barrier is pulled over the riprap, it will likely be necessary to hold the impermeable barrier in place with riprap or sandbags.<br><br>Appropriately size riprap to ensure that the cofferdam can withstand design flows. Refer to Plate 4. |
| Steel Sheet | Steel sheet cofferdams are different from sheet pile cofferdams. Sheet pile cofferdams are engineered structures, where steel sheet cofferdams may not be. Steel sheet cofferdams are not recommended for partial cofferdams used in larger waterways or bodies of water.<br><br>Steel sheet cofferdams are appropriate for both full and partial cofferdam situations.<br><br>Do not use steel sheet cofferdams where underground electrical and gas lines may be present. Overhead wires located above the potential cofferdam location may also limit the use of this method. In areas with stone or bedrock base materials, the use of steel sheet for cofferdams may be difficult or impractical.<br><br>Drive the steel sheet into the base material a sufficient distance to avoid undercutting. Ensure steel sheets can create a fully enclosed work area. Refer to Plate 5. |
| Impermeable Barrier Material | The impermeable barrier used in this standard should consist of one of the following materials:<br>1. Rubber liner with a thickness of at least 45 mil. This material elongates up to 100% and has good UV resistance. A solvent weld is necessary to affix material into larger sections.<br>2. Polypropylene liner with a thickness of at least 40 mil. This material elongates up to 80%. A heat gun is necessary to weld pieces together. Fabric puncturing may be a concern for this material.<br>3. Polyvinyl chloride (PVC) liner with a thickness of at least 40 mil. High elongation properties but not UV stable. A solvent weld is necessary to affix material into larger sections. |

## 6.0 Construction Specifications

1. Before commencement of instream activities, properly install all appropriate soil erosion and sediment control measures.
2. During disturbance or removal of vegetation, do not exceed the minimum necessary to complete operations.
3. Do not allow construction equipment to enter standing or flowing water. If equipment access to the work area through water is necessary, construct a non-erodible causeway.
4. For cofferdams used in linear water features, provide for emergency overflow at the center of the cofferdam to prevent erosion along the banks. Ensure the overflow system includes an energy dissipating surface and does not contribute to or cause erosion of the stream.
5. Following cofferdam installation, completely dewater the work area to work under dry conditions. Before complete dewatering of the work area, remove trapped fish and other aquatic wildlife, and relocate to the water body downstream of the lower cofferdam. Pumping of water may be required throughout construction to maintain dry conditions. Use the criteria in Dewatering Structure (BMP C-SCM-10) to achieve dry conditions.

*Inflatable Bladder Cofferdam Crossing*
*Source: Detroit Tarp*

6. Maintain the exteriors of vehicles and equipment that will be within the coffered area free of grease, oil, fuel, and residues. Position stationary equipment, such as motors and pumps located within the work area or adjacent to a water body, over drip pans or other confinement area. Store all equipment outside of the floodplain when not in use to avoid inundation during a high-water event.
7. Filter water pumped from the work area to ensure that the discharge results in no visible increase in suspended solids or turbidity in the water surrounding the work area. Ensure the quality of discharge meets all applicable local, state, or federal regulations, whichever is most restrictive. Ensure that the filtered water is discharged in a manner that does not cause erosion.

   Provide stabilization measures to the flow path from the point of discharge to the receiving water body as required. Methods for cleaning water discharged from the work area include Dewatering Structure (BMP C-SCM-10) and Temporary Sediment Trap (BMP C-SCM-11).

*Inflatable Bladder Cofferdam Crossing*

*Source: Detroit Tarp*

8. Discharge all water pumped from or diverted around the work area on an energy dissipating surface so as not contribute to or cause erosion of the stream.
9. Remove all temporary materials after the completion of construction. Before cofferdam removal, stabilize the work area with appropriate vegetative and/or structural practices, in accordance with plan details and specifications, that are stable enough to accept flows as determined by the certified plan reviewer.
10. Remove the downstream cofferdam first, followed immediately by the removal of the upstream cofferdam.
11. Stabilize disturbed areas with the appropriate vegetation or other stabilization measures upon the completion of work or during periods of inactivity. Remove excavated material or spoils resulting from the activity from the coffered area as soon as possible and do not allow the excavated material or spoils to remain overnight. Restore waterways only with original channel bottom substrate materials following the completion of work.

## 7.0 Operations and Maintenance Considerations

Because the potential for washout is high, monitor the cofferdam daily and do not leave the cofferdam unattended for longer than 24 hours.

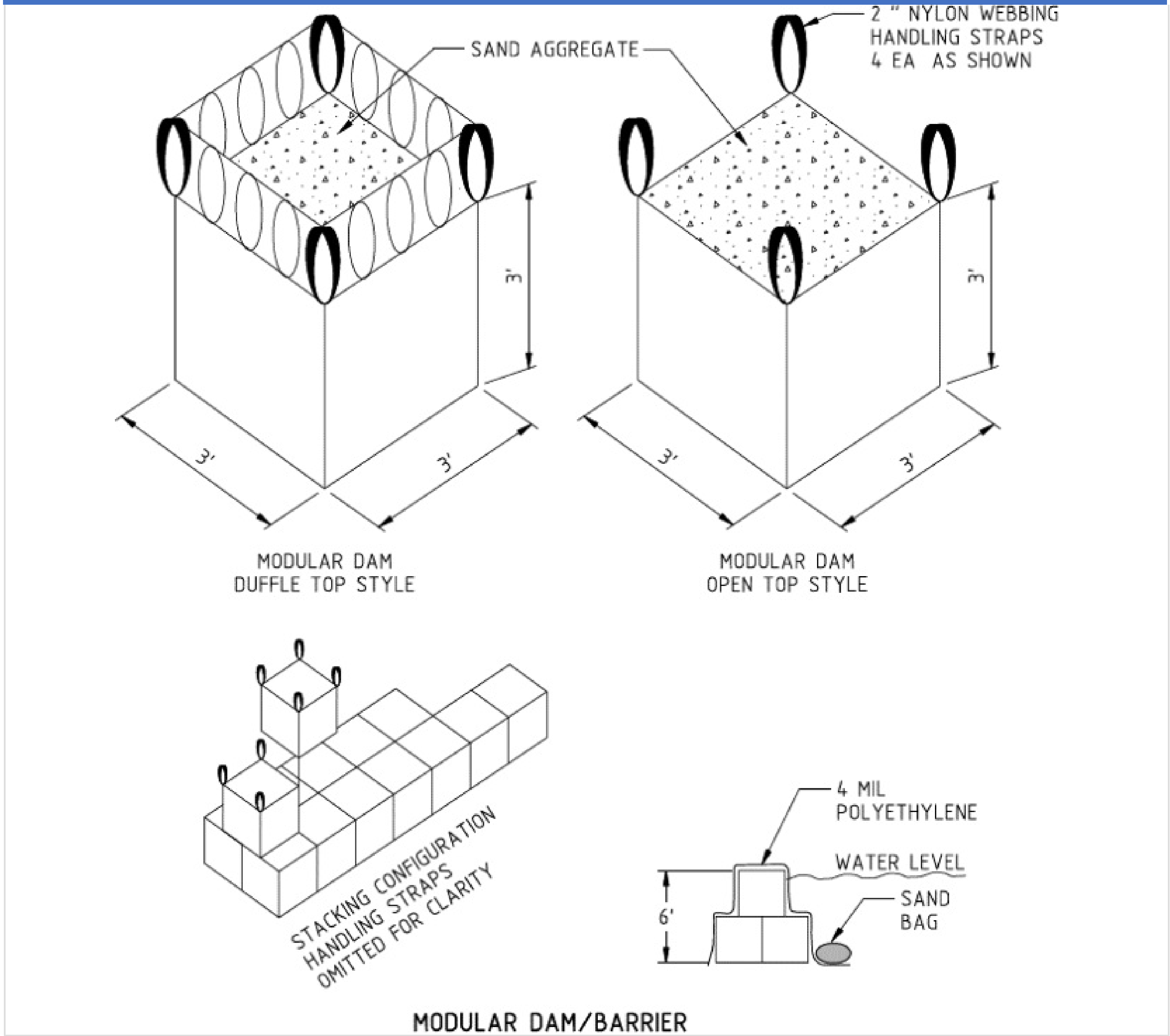
Observe weather reports daily. If a storm event is expected, stabilize the site as appropriate. Make all repairs immediately to prevent further damage to the installation.

Regularly inspect cofferdams for leaks or other deficiencies. Remove sandbags used within the cofferdam, if applicable, by hand to prevent breakage.

Return all disturbed soil within the coffered area to original condition with all possible efforts made to retain the existing soil profile before removal of the dams.

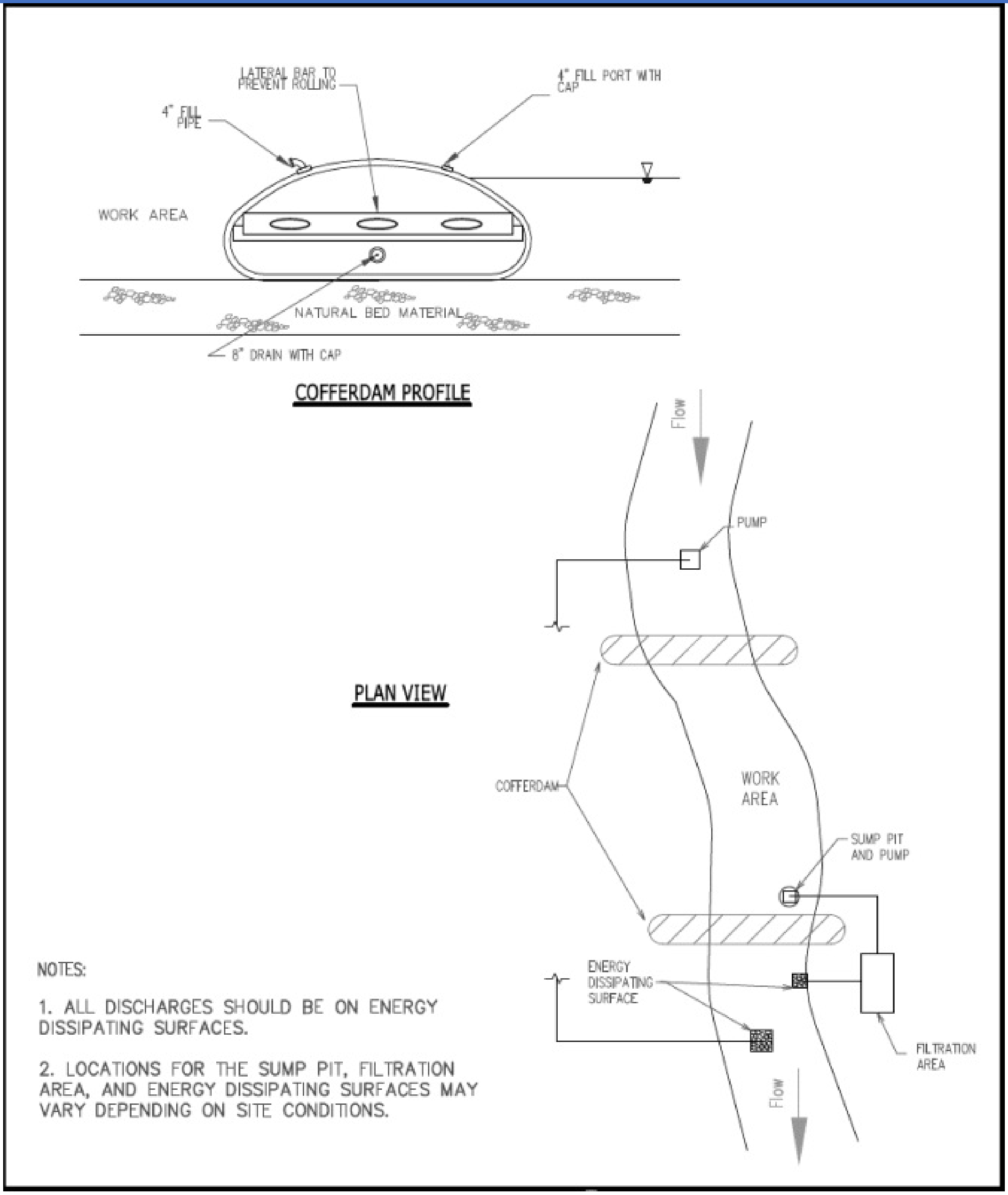
Reseed the sideslopes, stabilize with an appropriate erosion control blanket, and restore the substrate to pre-construction conditions. Initiate stabilization of all remaining disturbed areas immediately following the removal of the cofferdams. Do not leave areas adjacent to water features disturbed overnight.

**Figure C-ENV-05-1 Sandbag Tote Dam**



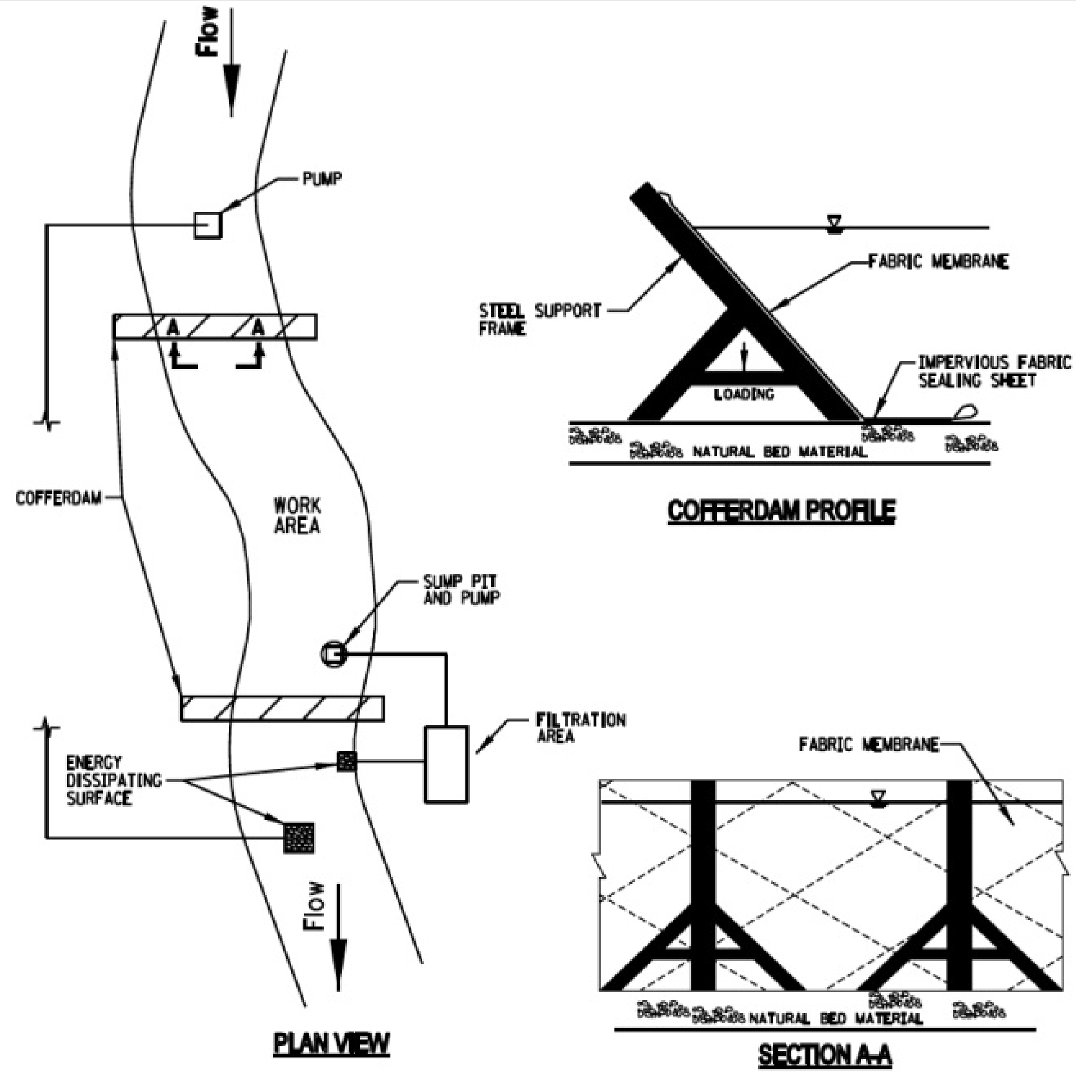

*Source: Virginia Department of Conservation and Recreation 2004*

## *Figure C-ENV-05-2 Inflatable Bladder Cofferdam Crossing Plan & Profile*




*Source: Illinois Environmental Protection Agency 2020*

## *Figure C-ENV-05-3 A-Frame Cofferdam Crossing Plan & Profile*




NOTES:

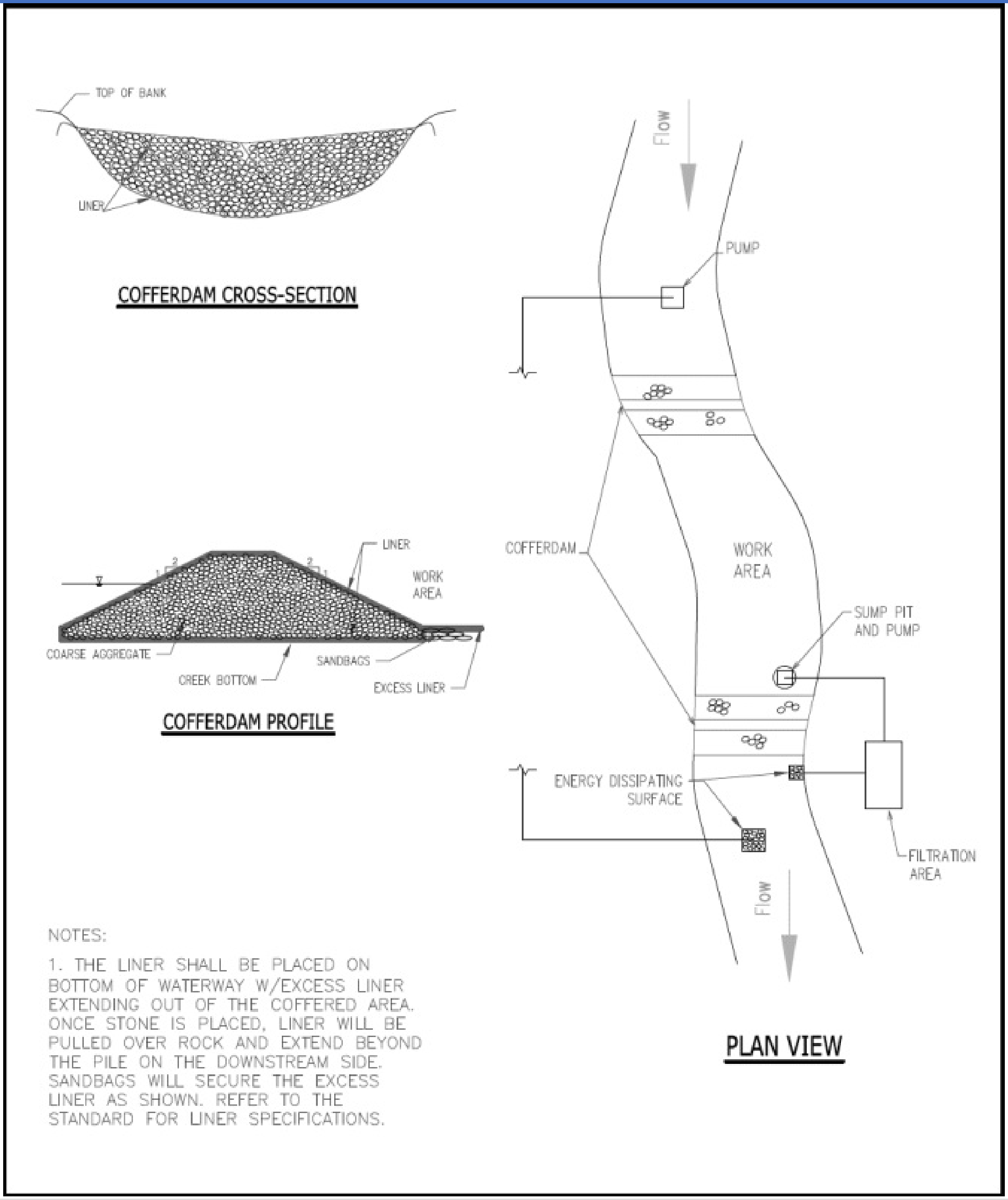
1. ALL DISCHARGES SHOULD BE ON ENERGY DISSIPATING SURFACES.

2. LOCATIONS FOR SUMP PIT, FILTRATION AREA, AND ENERGY DISSIPATING SURFACES MAY VARY DEPENDING ON SITE CONDITIONS.

3. A-FRAME SHOULD BE INSTALLED TO MANUFACTURER'S SPECIFICATIONS.

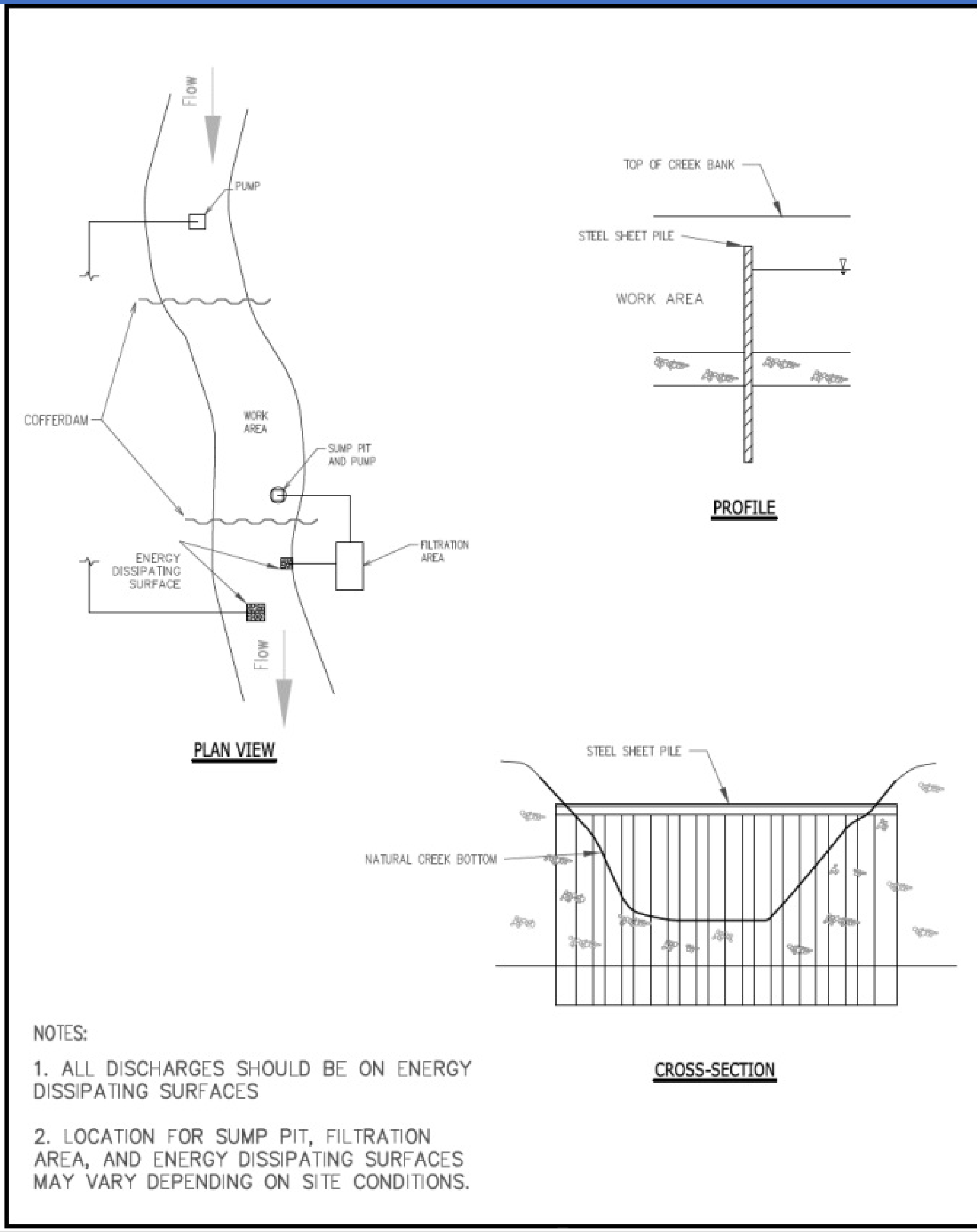
*Source: Illinois Environmental Protection Agency 2020*

## Figure C-ENV-05-4 Stone & Impermeable Barrier Cofferdam Crossing Plan & Profile




Source: Illinois Environmental Protection Agency 2020

**Figure C-ENV-05-5 Steel Sheet Cofferdam Crossing Plan & Profile**




*Source: Illinois Environmental Protection Agency 2020*

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Illinois Environmental Protection Agency. 2020. Illinois Urban Manual. February. Located at: www.illinoisurbanmanual.org.

Virginia Department of Conservation and Recreation. 2004. The Virginia Stream Restoration & Stabilization Best Management Practices Guide.

# C-ENV-06 Stable Wetland Crossing

## 1.0 Definition

A stable wetland crossing is a method or temporary structure used to cross a wetland with vehicles and/or equipment and/or strategy for crossing wetlands when in-wetland utility construction is involved.

## 2.0 Purpose and Applicability of Best Management Practice

Stable wetland crossings are used during wetland construction or when access through a wetland is unavoidable to minimize soil disturbances and reduce the potential for erosion to occur.

Stable wetland crossings are used where a crossing is needed to gain access, where there are no feasible or prudent alternatives (including upland alternatives) for in-wetland utility construction to be conducted, and where the crossing and/or in-wetland utility construction will not adversely impact the wetland resource (i.e., filling or changing the hydrology of the wetland).

## 3.0 Planning and Considerations

Where soils that have major hydric components or have hydric inclusions are present on or adjacent to construction, determine whether wetlands exist on or near the project site that could be affected by the proposed earthwork. Where such wetlands exist, identify where the wetlands are to be delineated and shown on the plan map(s). Wetland crossings require permit authorization from federal, state, and/or county authorities.

*Active Installation of Wooden Wetland Crossing*
*Source: Quality Mat Company 2023*

Conduct a site evaluation to determine the best site for constructing the crossing.

1. Ensure the area has a minimal potential for erosion of the disturbed land cover.
2. Design the area such that various types of crossings can be consolidated into a lesser number of crossings.
3. Avoid areas that have highly saturated wetland soils or habitat deemed important or critical to wildlife.

Undertake and complete crossings of the wetland during drier periods. For large wetland complexes, consider crossing from opposite sides where possible to avoid crossing the entire wetland. Do not permanently dredge or fill wetlands where it would cause a loss of any wetland area without first obtaining the proper permit approval.

## 4.0 Stormwater Performance Summary

**MS-12: WATERCOURSE CONSTRUCTION** – When work in a live watercourse is performed, precautions will be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material will be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

**MS-14: OTHER WATERCOURSE REGULATIONS** – All applicable federal, state, and local requirements pertaining to working in or crossing live watercourses will be met.

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

| Table C-ENV-06-1 Design Criteria for Stable Wetland Crossings | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Equipment and/or Vehicle Crossing | Avoid crossing wetlands with construction equipment and/or vehicles where possible. Where that is not possible, select the location and orientation of the crossing to have the least possible impact upon the wetland. Construct temporary equipment and/or vehicle crossings with materials that can be placed with a minimum disturbance to the soil surface and completely removed when no longer needed. Material used for temporary equipment and/or vehicle crossings must be free from pollutants in toxic amounts.<br><br>Use temporary pads or mats to minimize rutting and soil compaction. More than one layer of pads or mats may be necessary in areas that are inundated or have deep organic wetland soils.<br><br>Install a geotextile underlayment under a temporary wood mat. Construct wood mats using a minimum of 4-inch by 4-inch hardwood cabled together with 0.1875-inch galvanized steel cable. Install wood curbing or compost filter sock on either side of the wood mats to prevent sediment from entering the wetland from the wood mat. |
| In-Wetland Equipment Operation | Operate equipment in wetlands on temporary pads or mats. Do not use tree stumps, rock, brush, or soil imported from outside the wetland to stabilize the construction work area or as equipment pads or mats in wetlands.<br><br>Limit construction equipment operating in wetland areas to that needed to clear, perform in-wetland utility construction, and restore the disturbed area. Ensure all other construction equipment uses access roads located in upland areas to the maximum extent practicable. Where access roads in upland areas do not provide reasonable access, limit all other construction equipment to one pass through the wetland using temporary pads or mats. |
| Clearing | Limit tree clearing within wetlands to those necessary to complete construction. Cut vegetation off at ground level, leaving existing root systems in place, and remove vegetation from the wetland for disposal. Protect trees where possible in accordance with Tree Preservation and Protection (BMP C-SSM-01). |
| Work Adjacent to Wetlands | Where wetlands are adjacent to the proposed disturbed area, install perimeter control measures along the edges of the proposed disturbed area (silt fence, compost filter sock, hay bale barriers) as necessary to prevent sediment flow into the wetland.<br><br>Install the perimeter control measures along the edges of the proposed disturbed area before initiating earth disturbance and maintain the measures until revegetation of the disturbed area is complete.<br><br>Remove perimeter control measures after successful restoration of the disturbed area has been achieved. |

| Table C-ENV-06-1 Design Criteria for Stable Wetland Crossings | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Crossing Removal | Remove temporary pads or mats by backing out of the site, removing the pads or mats one at a time. Immediately regrade any rutting or significant indentations identified during pad/mat removal, taking care not to compact soils.<br>Clean pads or mats before transport to another wetland location and before installation in the wetland to remove soil and any invasive plant species seed stock or plant material. Cleaning methods may include but are not limited to shaking or dropping mats in a controlled manner with a piece of machinery to knock off attached soil and debris, spraying with water or air, and sweeping.<br>Inspect crossings following pad or mat removal to determine the level of restoration required. |
| Wetland Restoration | Revegetate disturbed wetland areas in accordance with Seeding, Mulching, and Soil Stabilization (Wetlands/Streams) (BMP C-ENV-15).<br>Remove perimeter control measures located within and at the boundary between wetland and adjacent upland areas after revegetation and stabilization of the wetland and adjacent upland areas. |

The crossing type will be specified on the plan based on the size of the wetland to be crossed, the expected equipment to be used, and the project details (including soil type); substitutions may be made after consultation with the design engineer.

## 6.0 Construction Specifications

*Rubber Equipment Pads for Wetland Crossing*
*Source: Presto Geosystems 2016*

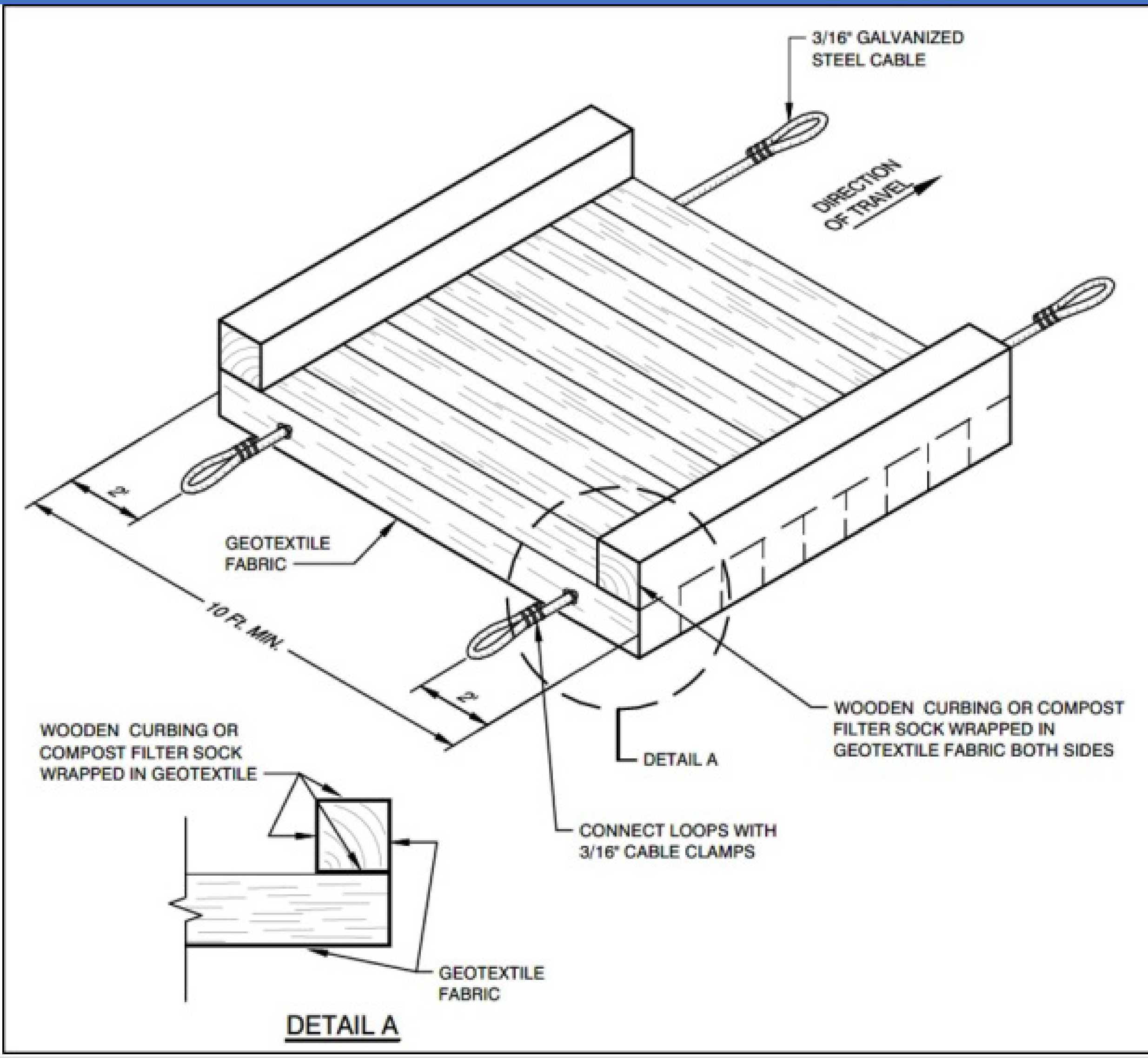
1. Install timber mats or equipment pads through entire wetland area. Equipment necessary for right-of-way clearing may make one pass through the wetland before pads or mats are installed. Install filter fabric under timber mats in accordance with Riprap (BMP C-ECM-13).
2. Cut vegetation to immediately above ground level, leaving the existing root systems in place, and remove the cleared vegetation from the wetland.
3. If flowing or excess surface water is present in the wetland, refer to Utility Stream Crossing (BMP C-ENV-04) for temporary diversion techniques.
4. Remove timber mats or equipment pads from wetlands upon completion and when access is no longer required.
5. Restore the surface to pre-construction contours such that drainage patterns are not altered.
6. Revegetate disturbed wetland areas.
7. Once revegetation is completed, remove temporary perimeter control measures and revegetate areas disturbed during removal of the temporary measures.

## 7.0 Operations and Maintenance Considerations

Inspect the crossing daily to ensure that the crossing and all perimeter control measures are functioning properly. Periodically clean wetland crossing pads or mats to ensure sediment is not being transported into adjacent protected areas. Immediately replace any destroyed pads or mats.

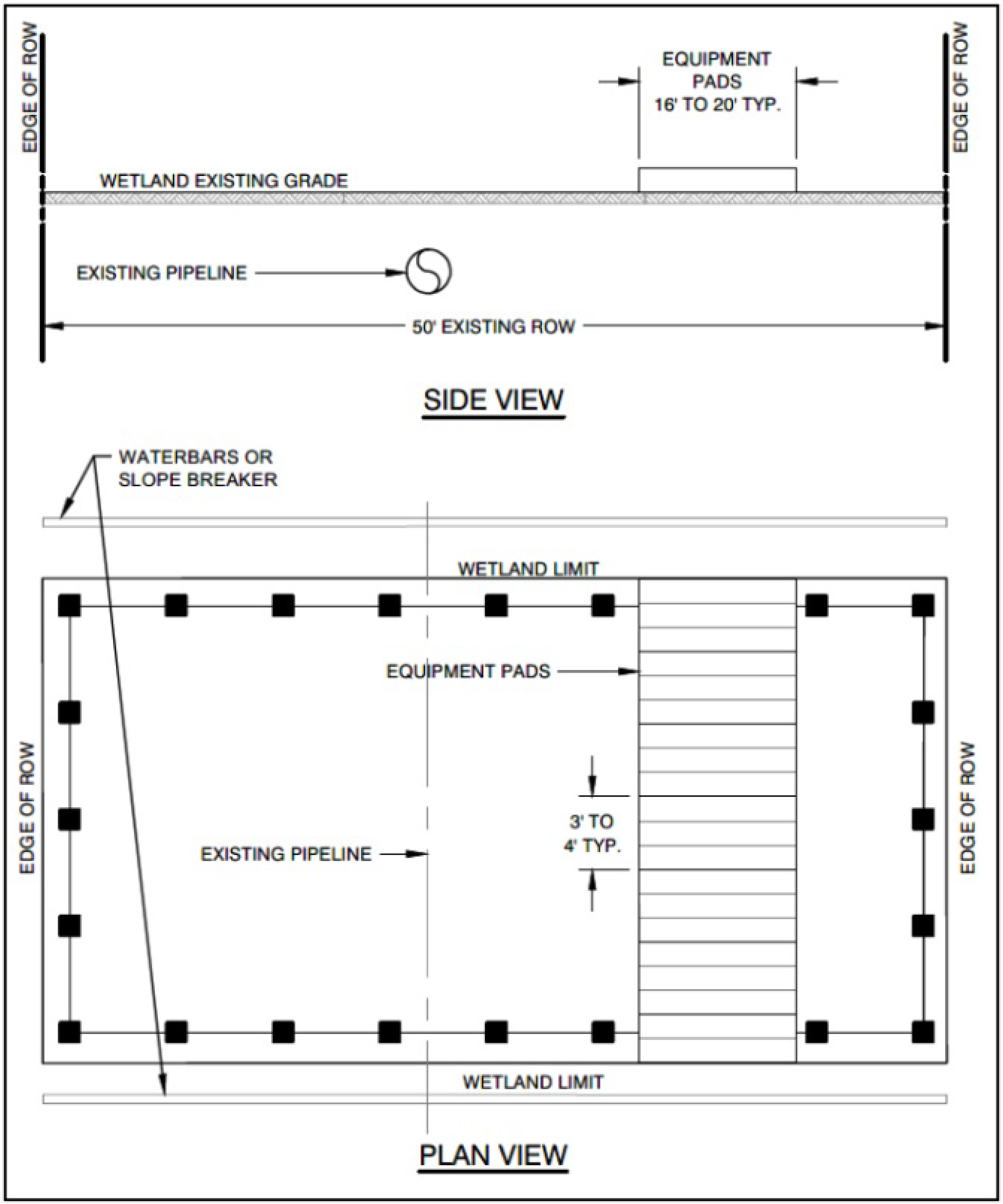
During maintenance, protect wetland crossings using lightweight, rubber-tracked equipment that exerts low ground pressure.

***Figure C-ENV-06-1 Wooden Wetland Crossing Detail***




*Source: VDEQ 1992*

### Figure C-ENV-06-2 Stable Wetland Crossing Layout Detail




*Source: VDEQ 1992*

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Presto Geosystems. 2016. Geoterra GTO Construction Mats – Portable Site Access Solution. Located at: https://www.prestogeo.com/products/construction-mats/geoterra-gto-construction-mats/?gclid=Cj0KCQjwuZGnBhD1ARIsACxbAVhiFG1yjf9AO_Ykdcf1FECxKVSfnHfTKuKHICGoA5LIm566rtc8BSUaAuISEALw_wcB.

Quality Mat Company. 2023. Quality Mat Company. Located at: www.qmat.com.

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VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

Wetland Studies and Solutions, Inc. 2020. General Erosion and Sediment Control Standards and Specifications for Wetland and Stream Mitigation Banks.

# C-ENV-07 Gabions

## 1.0 Definition

Gabions are rectangular baskets fabricated from a hexagonal mesh of heavily galvanized steel wire filled with rock material.

## 2.0 Purpose and Applicability of Best Management Practice

Gabions slow the velocity of concentrated runoff and stabilize slopes with seepage problems and/or non-cohesive soils.

Gabions can be used at soil-water interfaces where the soil conditions, water turbulence, water velocity, and expected vegetative cover are such that the soil may erode under the design flow conditions.

The baskets are also used to maintain stability and to protect streambanks and beds as identified in Structural Streambank Stabilization (BMP C-ENV-02) and as channel lining material for stormwater conveyance channels.

> Gabions can be used on steeper slopes than riprap and are sometimes the only feasible option for stabilizing an area where there is not enough room to accommodate a "softer," vegetated solution.

## 3.0 Planning and Considerations

The difference between a gabion basket and a gabion mattress is the thickness and the aerial extent of the basket. The benefit of gabions is that a basket or mattress can be filled with rocks that would individually be too small to withstand the erosive forces of the stream.

The gabion mattress is shallower (0.5 foot to 1.5 feet) than the basket and is designed to protect the bed or banks of a stream against erosion.

Gabion baskets are normally much thicker (approximately 1.5 feet to 3 feet) and cover a much smaller area. Gabion baskets are used to protect banks where mattresses are not adequate or to stabilize slopes, construct drop structures, pipe outlet structures, or nearly any other application where soil must be protected from the erosive forces of water.

Gabion mattresses are used for riverbank and scour protection, bridge and weir protection, channel linings, and embankment stability where the retaining properties of gabion baskets are not required.

Gabion baskets/mattresses can be made from either welded or woven wire mesh. The wire is normally galvanized to reduce corrosion but may be coated with plastic or other material to prevent corrosion and/or damage to the wire mesh containing the rock fill. New materials, such as a heavy-duty polymer plastic material, have been used in some applications in place of the wire mesh. If the wire baskets break, either through corrosion, vandalism, or damage from debris or bed load, the rock fill in the basket can be lost and the protective value of the method endangered.

Gabion baskets/mattresses are often used where available rock size is too small to withstand the erosive and tractive forces present at a project site. The available stone size may be too small due to the cost of transporting larger stone from remote sites or the desire to have a project with a smoother appearance than that obtained using riprap or other methods. Gabion baskets/mattresses also require about one third the thickness of material when compared to riprap designs. Riprap is often preferred, however, due to the low labor requirements for its placement.

The rocks contained within the gabion basket/mattress provide a substrate for a wide variety of aquatic organisms. Vegetation may be difficult to establish unless the voids in the rocks contained within the baskets/mattresses are filled with soil.

If large woody vegetation is allowed to grow in the gabion baskets/mattresses, there is a risk that the baskets/mattresses will break when the large woody vegetation is uprooted or as the root and trunk systems grow. Thus, it is normally not acceptable to allow large woody vegetation to grow in the baskets/mattresses. The possibility of damage must be weighed against the desirability of vegetation on the area protected by gabion baskets/mattresses and the stability of the large woody vegetation. If large woody vegetation is kept out of the baskets/mattresses, grasses and other desirable vegetation types may be established and provide a more aesthetic and ecologically desirable project than gabion baskets/mattresses alone.

The most important consideration for the installation of gabion baskets/mattresses is the stability of the stream. If the stream is undergoing rapid changes in base elevation (downcutting or deposition) or extreme lateral movement, make plans to correct the larger problems that are contributing to the local problem. If the larger problems are not addressed, local protection measures may be overwhelmed or flanked.

## 4.0 Stormwater Performance Summary

**MS-15: BED AND BANK STABILIZATION** – The bed and banks of a watercourse shall be stabilized immediately after work in the watercourse has been completed.

**MS-11: OUTLET PROTECTION** – Before any newly constructed stormwater conveyance channel can be made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and receiving channel.

9VAC25-875-560

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

Primary design considerations for gabion baskets and mattresses are: 1) foundation stability; 2) sustained velocity and shear-stress thresholds that the gabions must withstand; and 3) toe and flank protection.

| Table C-ENV-07-1 Design Criteria for Gabions | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Toe and Flank Protection | Place the base layers of gabions below the expected maximum scour depth. Alternatively, the toe can be protected with mattresses that will fall into any scoured areas without compromising the stability of the bank or bed protection portion of the project.<br>If bank protection does not extend above the expected water surface elevation for the design flood, install measures such as tiebacks to protect against flanking. |
| Filter Fabric | The use of a filter fabric behind or under the gabion baskets to prevent the movement of soil material through the gabion baskets is an extremely important part of the design process. Use filter fabric that conforms to physical requirements noted in Riprap (Table C-ECM-13-6).<br>Migration of soil through the baskets can cause undermining of the supporting soil structure and failure of the gabion baskets and mattresses. |
| Stability of Underlying Bed and Bank Materials | Another critical consideration is the stability of the gabion foundation. This includes both geotechnical stability and the resistance of the soil under the gabions to the erosive forces of the water moving through the gabions.<br>If there is any question regarding the stability of the foundation (e.g., possibility of rotational failures, slip failures) consult a qualified geotechnical engineer before and during the design of the bank/channel protection. Several manufacturers provide guidance on how to check for geotechnical failure.<br>Tilt stacked gabion baskets used for bank stability towards the soils they are protecting by a minimum of about 6 degrees from vertical. Gabions can be stacked with steps facing either out towards the front or back into the slope.<br>While the gabions can be stacked with no tilt, some tilt into the soil being protected is recommended. |

| Table C-ENV-07-1 Design Criteria for Gabions | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Median Stone Size for Gabion Baskets & Mattress | For gabion baskets, use a either gabion stone or Virginia Department of Transportation (VDOT) #3 Coarse Aggregate.<br><br>Because gabion mattresses are much shallower and more subject to movement than gabion baskets, care should be taken to design the mattresses such that they can withstand the forces applied to them by the water. However, mattresses have been used where very high velocities are present and have performed well. Carefully design projects using gabion mattresses.<br><br>Determine the median stone size for a gabion mattress from the following equation:<br><br>$d_m = S_f C_s C_v d \left[ \left( \frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{gdK_1}} \right]^{2.5}$<br><br>where:<br><br>$C_s$ = stability coefficient (use 0.1)<br>$C_v$ = velocity distribution coefficient = $1.283^{-0.2}$ log (R/W) (minimum of 1.0) and equals 1.25 at end of dikes and concrete channels<br>$d_m$ = average rock diameter in gabions d = local flow depth at V<br>g = acceleration due to gravity<br>$K_1$ = sideslope correction factor (Table 1)<br>R = centerline bend radius of main channel flow<br><br>$S_f$ = safety factor (1.1 minimum)<br>V = depth-averaged velocity<br>W = water surface width of main channel<br>$\gamma_s$ = unit weight of stone<br>$\gamma_w$ = unit weight of water<br><br>This equation was developed to design stone size that prevents movement of filler stone in the mattress, eliminating deformation that can occur when stone sizes are not large enough to withstand the forces of the water. The result of mattress deformation is stress on the basket wire, increases in resistance to flow, and the likelihood of basket failure.<br>Select the stone size in the gabion mattress such that the largest stone diameter is not more than about two times the diameter of the smallest stone diameter, and select the mattress size to be at least twice the depth of the largest stone size.<br><br>Ensure the size range varies by about a factor of two to ensure proper packing of the stone material into the gabions. Because the mattresses normally come in discrete sizes (i.e., 0.5, 1.0, and 1.5 feet in depth) normal practice is to size the stone and then select the basket depth that is deep enough to be at least two times the largest stone diameter. Size the smallest stone such that it cannot pass through the wire mesh. |

| Table C-ENV-07-1 Design Criteria for Gabions | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Shear-Stress Threshold | Maccaferri® Gabions offers a table (Table 2) in their materials giving guidance on sizing stone and allowable velocities for gabion baskets and mattresses. Use the equation above to take the depth of flow into account. Table 2 does, however, give some general guidelines for fill sizes and is a quick reference for maximum allowable velocities.<br><br>Maccaferri also gives guidance on the stability of gabions in terms of shear stress limits. The following equation gives the shear for the bed of the channel:<br><br>$\tau_b = \gamma_w S d$<br><br>where:<br><br>$\tau_m$ = bank shear = 75% of the bed shear = $\tau_m$ = 0.75$\tau_b$ S = bed or water surface slope through the reach<br><br>These values are then compared to the critical stress for the bed calculated by the following equation:<br>$\tau_c = 0.10(\gamma_s - \gamma_w)d_m$<br>with critical shear stress for the banks given as:<br><br>$\tau_s = \tau_c\sqrt{1 - \frac{\sin^2\theta}{0.4304}}$<br>where:<br><br>θ = the angle of the bank rotated up from horizontal<br><br>A design is acceptable if $\tau_b < \tau_c$ and $\tau_m < \tau_s$. If either $\tau_b > \tau_c$ or $\tau_m > \tau_s$, then a check must be made to see if they are less than 120% of $\tau_b$ and $\tau_s$. If the values are less than 120% of $\tau_b$ and $\tau_s$, the gabions will not be subject to more than what Maccaferri defines as "acceptable" deformation. However, it is recommended that stone size be increased to limit deformation if possible. |

| Table C-ENV-07-1 Design Criteria for Gabions | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| Sustained Velocity | One of the critical factors in determining stability is the velocity of the water that passes through the gabions and reaches the soil behind the gabion. The water velocity under the filter fabric (i.e., water that moves through the gabions and filter fabric) is estimated to be one quarter to one half of the velocity at the mattress/filter interface. The velocity at the mattress/filter interface ($V_b$) is estimated to be:<br>$V_b = \frac{1.486}{n_f}\left(\frac{d_m}{2}\right)^{2/3} S^{1/2}$<br>where:<br>$n_f$ = 0.02 for filter fabric, 0.022 for gravel filter material<br>S = the water surface slope (or bed slope) through the reach<br>If the underlying soil material is not stable, additional filter material must be installed under the gabions to ensure soil stability. Maccaferri also provides guidance on the stability of soil under the gabions in terms of velocity criteria.<br>The limit for velocity on the soil is different for each type of soil. The limit for cohesive soils is obtained from a chart, while maximum allowable velocities for other soil types are obtained by calculating $V_e$, the maximum velocity allowable at the soil interface, and comparing it to $V_f$, the residual velocity on the bed (i.e., under the gabion mattress and under the filter fabric).<br>Ve for loose soils = 16.1 x $d^{1/2}$<br>while $V_f$ is calculated by:<br>$V_f = \frac{1.486}{n_f}\left(\frac{d_m}{2}\right)^{2/3} SV_a^{1/2}$ where:<br>$V_a$ = the average channel velocity<br>$d_m$ = the average rock diameter<br>If $V_f$ is larger than two to four times $V_e$, install a gravel filter to further reduce the water velocity at the soil interface under the gabions until $V_f$ is in an acceptable range. To check for the acceptability of the filter use the average gravel size for dm in the $V_f$ equation. If the velocity $V_f$ is still too high, reduce the gravel size to obtain an acceptable value for $V_f$. |
| Other Design Considerations | It may be possible to combine gabions with less harsh methods of bank protection on the upper bank and still achieve the desired result of a stable channel.<br>Provisions for large woody vegetation and a more aesthetically pleasing project may also be used on the upper banks or within the gabions.<br>However, the stability of vegetation or other upper bank protection should be carefully analyzed to ensure stability of the upper bank area. A failure in the upper bank region can adversely affect gabion stability and lead to project failure. |

| Table C-ENV-07-2 K1 Versus Sideslope Angle | |
|---|---|
| **Sideslope** | **Sideslope Correction Factor (K1)** |
| 1H:1V | 0.46 |
| 1.5H:1V | 0.71 |
| 2H:1V | 0.88 |
| 3H:1V | 0.98 |
| <4H:1V | 1.0 |

Source: Freeman and Fischenich 2000.

| Table C-ENV-07-3 Stone Sizes and Allowable Velocities for Gabions | | | | | |
|---|---|---|---|---|---|
| **Type** | **Thickness (ft)** | **Filling Stone Range (in.)** | **D50 (in.)** | **Critical Velocity*** | **Limit Velocity**** |
| Mattress | 0.50 | 3 – 4 | 3.4 | 11.5 | 13.8 |
| | 0.50 | 3 – 6 | 4.3 | 13.8 | 14.8 |
| | 0.75 | 3 – 4 | 3.4 | 14.8 | 16.0 |
| | 0.75 | 3 – 6 | 4.7 | 14.8 | 20.0 |
| | 1.00 | 3 – 5 | 4.0 | 13.6 | 18.0 |
| | 1.00 | 4 – 6 | 5.0 | 16.4 | 21.0 |
| Basket | 1.50 | 4 – 8 | 6.0 | 19.0 | 24.9 |
| | 1.50 | 5 – 10 | 7.5 | 21.0 | 26.2 |

Source: Freeman and Fischenich 2000.

## 6.0 Construction Specifications

1. A gabion project is installed by first smoothing the area to be protected to the desired final slope. The filter fabric and any required gravel filter are then installed according to the design plans.
2. The gabions are next assembled and tied together, folded flat, stacked, and bundled by the supplier. The gabions are bent into the design form, and all ends and diaphragms are laced into place.
3. The assembled gabions are then placed in their proper location and laced (tied) to all surrounding gabions. It is important that all adjacent gabions be laced together, as the lacing prevents movement and the failure of a project due to the loss of one basket out of a protected area. Perform lacing in accordance with the manufacturer's recommendations.
4. After enough gabions are assembled, filling can start. Place the fill carefully in the gabions to prevent damage to the diaphragms and edges. Conduct filling in lifts of no more than 12 inches.

*Trapezoidal Gabion Basket Installation Under Dry Conditions*

Some hand adjustment may be required to obtain a smooth, attractive face. For gabion baskets taller than 12 inches, installation of tie wires or stiffeners are recommended after each lift to prevent exposed faces from bulging.

5. After filling, the covers are placed on the gabions and secured with tie wires (laced). The gabions can be seeded with grass or other cover vegetation if the soil is intermixed with the lifts of stone and if the hydrology is not limiting. Again, avoid planting large woody vegetation in the area protected by gabions.
6. Take care to determine soil properties if the gabions are to be covered. If the soil is saline or acidic, deterioration of the gabion wire can occur rapidly, leading to project failure. If the soil has a lower permeability than the underlying bank material, water may not be able to move readily through the gabions, resulting in hydrostatic pressure behind the gabions. This can cause a sliding or rotational failure of the gabions. If the soil placed on the gabions is porous enough to allow easy passage of water through the gabion, it may not retain enough water to support the desired vegetation.
7. If a grass cover can be established over gabions, it is possible that the grass will remain stable during high flows because the root system will be firmly attached to the gabion mesh and underlying rock fill. Carefully investigate the problems of adequate moisture and sufficient permeability of the soil. While gabions may be able to support some types of vegetation, use care when recommending covering and filling the gabions with intermixed soil and rock to support vegetation.

## 7.0 Operations and Maintenance Considerations

Check gabions for broken wires and repair if necessary to protect the stone contained in the gabions from being removed by the force of water passing the cage.

Remove any large woody vegetation that has started to grow in the gabions. Repair any damage to the gabions including replacing lost stone and repairing any damaged wire with wire like that used in the construction of the cages.

Monitor the project area for signs of erosion. If erosion is occurring at the toes of the gabion structures, take measures to protect the gabions from undercutting and subsequent failure. If water is eroding soil from behind a gabion wall, either divert the water or take measures to eliminate the erosion of soil from behind the gabions. This often occurs where surface runoff enters the stream at a location protected by gabions.

Monitor the project for any signs of geotechnical failure. If any of the gabions have shifted or appear to be bulging away from the bank, evaluate the seriousness of the problem. If proper geotechnical evaluations and measures are taken during the design and construction stages, there should be little chance of a major problem due to geotechnical failures.

## 8.0 References

Freeman, G.E. and J.C. Fischenich. 2000. Gabions for streambank erosion control. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-22). U.S. Army Engineer Research and Development Center. Vicksburg, MS.

Massachusetts Department of Environmental Protection. 2003. Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas. May.

# C-ENV-08 Pump Around Diversion

## 1.0 Definition

The pump-around diversion is a dewatering practice used for temporarily pumping flow around segments of a stream channel during construction; the practice involves installing a temporary pump-around system and instream barriers to divert flow around sections or reaches of the stream.

*East Palestine, OH*
*Source: Michael D. DeVuono, PE*

## 2.0 Purpose and Applicability of Best Management Practice

The pump-around diversion allows for clear water diversion around the designated work area during stream restoration projects. This form of diversion is necessary when restoration practices span the entire width of the stream channel and/or where a linear reach of stream segment is to be simultaneously dewatered and maintained in a dry condition. This practice is also used for utility stream crossings when a piped utility crosses a waterway using an open-trench installation method.

This practice also limits potential for downstream sedimentation because in-stream work will be completed in the dry and all denuded areas will be stabilized before re-introduction of water back into the stream channel.

## 3.0 Planning and Considerations

Design the total work area of the pump-around diversion not to exceed the length of area that can be completed and stabilized in 1 working day.

Complete the associated work and remove the pump-around diversion at the end of each working day and stabilize the work area. If the length of time to complete and stabilize the work area will exceed 1 working day, use alternative practices.

Limit the use of this practice to base- or low-flow conditions where applicable to ensure adequacy of pump equipment. This practice is most applicable in small to medium watersheds with relatively small base-flow discharges, which allows for multiple pumping options and equipment to sufficiently handle necessary pump capacity.

Limit the use of this practice to watersheds less than 1 square mile in size; however, the size of the watershed may be increased by demonstrating adequate pump capacity and height of in-stream barriers.

Size the pump selected to adequately pump base flow at a head greater than the in-stream barrier height.

The capacity of flow diversion is limited to the capacity of the pump and height of the in-stream barriers.

A downstream riprap or sandbag-lined “plunge pool” may be used at the pump discharge location to allow for dispersion of pump discharge to a non-erosive velocity within the existing stream channel.

## 4.0 Stormwater Performance Summary

**MS-12: Watercourse Construction** – When work in a live watercourse is performed, precautions shall be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material shall be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

Jurisdiction of wetlands and shorelines in coastal areas and areas under the Chesapeake Bay Act may have complicated jurisdictional divisions.

**MS-14: Other Watercourse Regulations** – All applicable federal, state, and local requirements pertaining to working in or crossing live watercourses shall be met.

9VAC25-875-560

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: N/A**

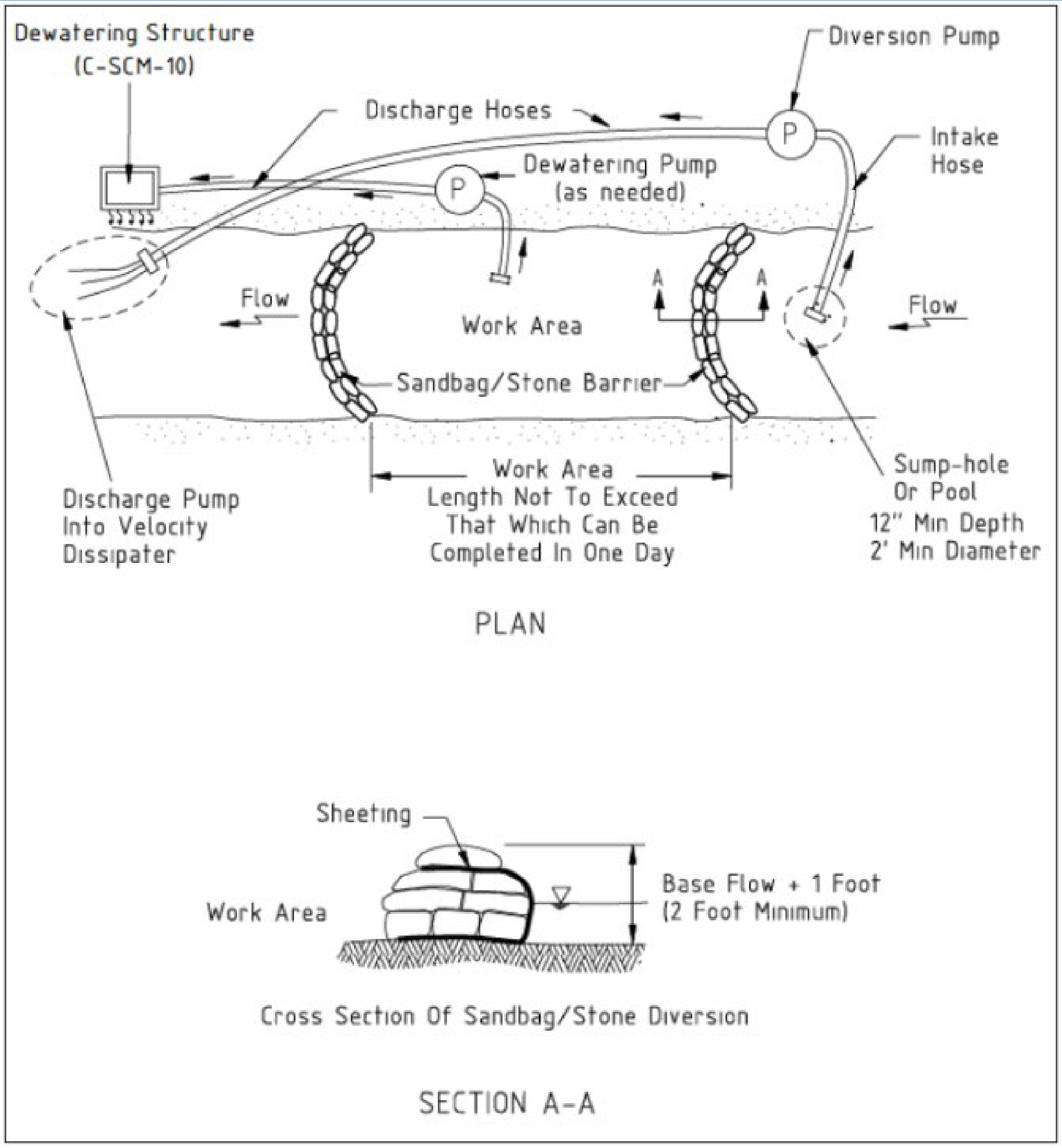
## 5.0 Design Criteria

| Table C-ENV-08-1 Design Criteria for Pump Around Diversions | |
|---|---|
| **Parameters** | **Notes on Proper Use** |
| Pump Selection | Pump selection requires the computation of total dynamic head (TDH; Godwin 2003):<br>***TDH = Static Suction Lift + Static Discharge Head + Friction Loss + Velocity Head***<br>Always use a pump with a capacity greater than that required to pump the desired flow. |
| Height of Instream Barriers | **For In-stream Barriers Installed and Removed in the Same Workday:** Design the heights of in-stream barriers for the normal base flow depth plus 1 foot of freeboard for pump-around diversions.<br>**For In-stream Barriers for Continuous Pump-Around:** Design the heights of in- stream barriers for the 2-year storm elevation plus 1 foot of freeboard.<br>The minimum in-stream barrier height is 2 feet. |

## 6.0 Construction Specifications

| Table C-ENV-08-2 Material Specifications for Pump-Around Diversions | |
|---|---|
| **Design Component** | **Notes on Proper Use** |
| In-stream Barrier | Refer to the in-stream barriers identified in Cofferdam Crossing (BMP C-ENV-05) for additional information on alternative in-stream barriers. |
| Sheeting | Seamless polyethylene plastic sheeting with a minimum 6-mil thickness impervious and resistant to puncture, tearing, and ultraviolet degradation or equivalent. |
| Pumping Equipment | Electric, diesel, or gasoline venturi, vacuum, or centrifugal primed pump. Appropriately sized rigid intake and discharge pipe/hose with positive restrained joints. Necessary connectors and properly stored fuel. |
| Dewatering Structure | Select and install a dewatering structure in accordance with Dewatering Structure (BMP C-SCM-10). |
| Velocity Dissipater | Riprap or sandbag-lined "plunge pool" sized to be non-erosive at the discharge pipe velocity in accordance with Outlet Protection (BMP C-ECM-15). |

**Figure C-ENV-08-1 Pump-Around Diversion Practice**




*Source: Virginia Department of Conservation and Recreation 2004*

## 7.0 Operations and Maintenance Considerations

- Sandy material may be used to fill sandbags. If permitted, material from the channel may be used to fill the bags.
- Determine the length of stream to be dewatered by the amount of work that can be completed in 1 work day.
- Continuous pumping adds increased costs and risks of failure and delays.
- Where possible, use existing pools within the stream in place of an excavated sump hole.
- Strategic placement of the in-stream barrier can eliminate multiple installations during construction.
- Remove all large debris located within the foundation of the barrier to ensure proper sealing and reduce leakage through the barrier.

- Sandbag/stone barrier should be monitored daily for leakage and repaired as necessary.

During active pump-arounds, the performance of the configuration and surrounding area is to be monitored continuously for any changes in the stream flow or pump performance. The backwatered area is to be monitored for headwater depths to not rise to the top of the water barricade or start flowing in undesirable directions out of the stream channel. The intake is to be kept free of debris. Confirm that the intake protection is functioning. Maintain the pump in operating condition, and ensure that adequate fuel is immediately available for the expected work duration until completion. Monitor the stable discharge point for indicators of erosion and revise as necessary to maintain a stable discharge point.

Before complete dewatering of the work area, remove trapped fish and other aquatic wildlife, and relocate to the waterbody downstream of the lower barrier.

Ensure that the filtered water is discharged in a manner that does not cause erosion. Provide stabilization measures to the flow path from the point of discharge to the receiving waterbody as required.

## 8.0 References

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

Virginia Department of Conservation and Recreation. The Virginia Stream Restoration & Stabilization Best Management Practices Guide. 2004.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-ENV-09 Overnight Channel Protection

## 1.0 Definition

Overnight channel protection is the temporary stabilization of a stream channel bed using secured filter fabric while in-stream work is not actively taking place. This practice is used during stream restoration projects when there is active disturbance to an existing natural stream channel bed.

## 2.0 Purpose and Applicability of Best Management Practice

***Overnight*** channel stabilization is used to temporarily stabilize the disturbed stream bed to prevent excessive sediment movement downstream and accommodate base flow and/or storm flows. It is ***intended for use for a less than 24-hour period*** (Wetland Studies and Solutions, Inc. 2020).

Overnight channel protection is used within an existing or proposed stream channel when active work needs to temporarily cease for a period of less than 24 hours due to inclement weather or other short duration stoppage of work. Overnight channel protection is also used when temporary vehicle access to the stream channel is needed for a period of less than 24 hours to deliver equipment and/or materials and where a crossing has not been installed.

## 3.0 Planning and Considerations

Only use overnight channel protection when active work operations in the stream channel will cease or vehicle access within the stream channel will be needed for a period of less than 24 hours. If longer periods of work stoppage or vehicular access to the stream channel are needed, install additional stabilization of the stream channel bed and banks including Soil Stabilization Blankets and Matting (BMP C-SSM-05); Temporary Seeding (BMP C-SSM-09) or Permanent Seeding (BMP C-SSM-10) and Mulching (C-SSM-11); or stream diversion measures including Utility Stream Crossing (C-ENV-04), Cofferdam Crossing (BMP C-ENV-05), or Pump-Around Diversion (BMP C-ENV-08).

## 4.0 Stormwater Performance Summary

**MS-12: WATERCOURSE CONSTRUCTION** – When work in a live watercourse is performed, precautions shall be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material shall be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

**MS-14: OTHER WATERCOURSE REGULATIONS** – All applicable federal, state, and local requirements pertaining to working in or crossing live watercourses shall be met.

9VAC25-875-560

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

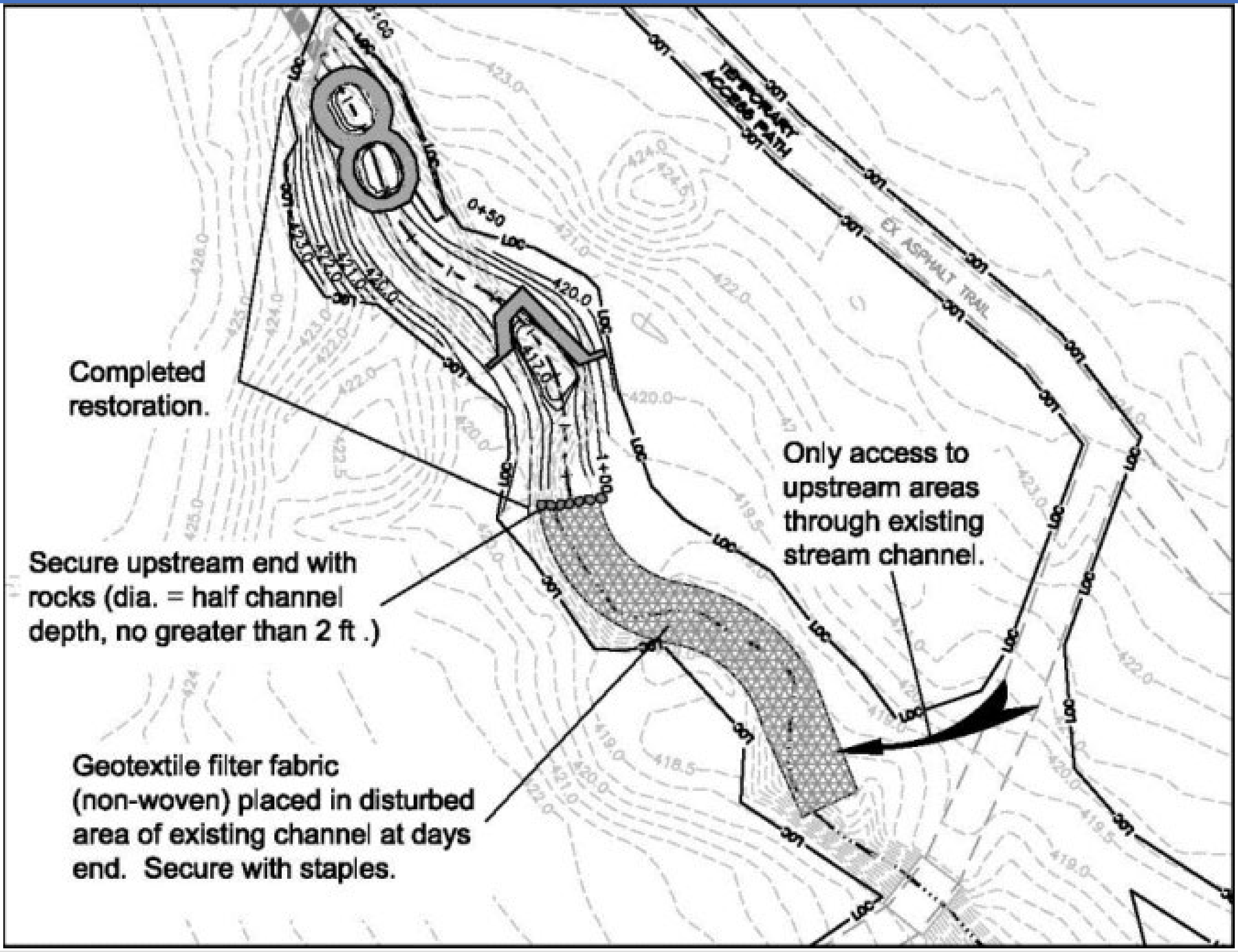
Use filter fabric that meets the minimum physical requirements noted in Riprap (BMP C-ECM-13).

Use staples for anchoring filter fabric that are No. 11 gauge wire or heavier with a minimum length of 6 inches. Use a larger staple with a length of up to 12 inches on loose, sandy, or unstable soils.

## 6.0 Construction Specifications

1. Place filter fabric in the channel and adequately secure.
2. Ensure the fabric covers the entire disturbed area within the channel and overlaps onto the undisturbed area by a minimum of 3 feet on all sides.
3. Before placement, rough grade the disturbed channel area to provide proper drainage.
4. Secure the upstream edge of the fabric with rocks of sufficient size to prevent movement – roughly half the size of the channel depth but no greater than 2 feet in diameter. If sufficient size rocks are not available on the site, staple the upper edge of the fabric at a maximum spacing of 1 foot.
5. Along the sides and downstream edge of the fabric, use staples at a maximum 2-foot spacing to ensure the fabric is adequately secured to the existing ground surface.
6. Once work in the channel is to resume, remove the staples first along the sides and downstream edge, then remove the rocks along the upstream edge.
7. Roll the fabric beginning at the upstream edge toward the downstream edge, remove from the channel, and continue with channel work.

**Figure C-ENV-09-1 Overnight Channel Protection Layout**




*Source: Wetland Studies and Solutions, Inc. 2020*

## 7.0 Operations and Maintenance Considerations

Inspect the channel to ensure that the protection is installed correctly and functioning properly. Immediately resecure any channel protection filter fabric or rocks that have become dislodged or displaced (Wetland Studies and Solutions, Inc. 2020).

## 8.0 References


Wetland Studies and Solutions, Inc. 2020. General Erosion and Sediment Control Standards and Specifications for Wetland and Stream Mitigation Banks.


# C-ENV-10 Trenchless Silt Fence

## 1.0 Definition

Trenchless silt and super silt fence is a temporary sediment barrier consisting of a synthetic filter fabric stretched across and attached to supporting posts with no trench.

## 2.0 Purpose and Applicability of Best Management Practice

Trenchless silt fence is used to intercept and detain small amounts of sediment from disturbed areas during construction to prevent sediment from leaving the site where typical silt fence (trenched) would adversely impact the surrounding woody vegetation to be preserved. Trenchless silt fence decreases the velocity of sheet flows.

*Trenchless Super Silt Fence Installation*
*Source: The Davey Resource Group*

## 3.0 Planning and Considerations

Use trenchless silt fence below disturbed areas where sheet and rill erosion would occur adjacent to undisturbed areas in which woody vegetation is to be maintained.

Only use trenchless silt fence where the size of the drainage area is no more than 0.25 acre per 100 feet of silt fence length.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

9VAC25-875-560

**Erosion Control Efficiency: LOW**

**Sediment Removal Efficiency: MEDIUM**

## 5.0 Design Criteria

Due to the detrimental effect on tree roots during placement, typical silt fence (trenched) is not installed at the outer limits of disturbance to maximize the preservation of woody vegetation in the areas surrounding the construction project.

Where silt fence is used on construction projects and existing woody vegetation is to be preserved, use the trenchless silt fence to minimize damage to the surrounding tree roots. The trenchless silt fence is designed to protect the tree's critical root zone (CRZ), which is the minimum area beneath a tree that needs to remain undisturbed to preserve enough of the root mass to provide a tree the greatest chance for survival.

Root aeration matting (RAM) is for permanent grade fills within the CRZ, and root protection matting (RPM) is for temporary construction within the CRZ. RAM and RPM are typically a combination of geotechnical products designed to spread loads, provide tree roots in the rhizosphere with air/gas exchange, and provide moisture access to the roots below. These products are to be installed by an ISA Certified Arborist trained in root protection, product specifications, and installations.

Design trenchless silt fence and its derivations following the maximum slope length provided in Silt Fence (BMP C-PCM-04).

Locate trenchless silt fence at least 5 to 7 feet beyond the base of disturbed slopes with grades greater than 7%.

Do not exceed the maximum slope length in existing, temporary, and final grade above any trenchless silt fence shown in Silt Fence (BMP C-PCM-04). The slope length shown is the distance from the fence to the drainage divide or the nearest upslope channel.

Use trenchless silt fence only where the size of the drainage area is no more than 0.25 acre per 100 feet of standard silt fence length.

In minor swales or ditch lines where the maximum contributing drainage area is no greater than 1 acre and flow is no greater than 1 cubic foot per second.

## 6.0 Construction Specifications

Use filter fabric, stakes, and reinforcing as specified in Silt Fence (BMP C-PCM-04).

**Installation for Standard and Reinforced Trenchless Silt Fence**

1. Install posts at a maximum of 6 feet apart when wire support is not used (standard silt fence or high-performance silt fence) and a maximum of 10 feet apart when wire support is used (reinforced silt fence). Drive posts a minimum of 18 inches below ground surface.
2. Install silt fence such that the height is a minimum of 18 inches above the original ground surface for standard silt fence, a minimum of 30 inches above the original ground surface for reinforced silt fence, and does not exceed 34 inches above ground elevation.
3. When wire support is used (reinforced silt fence), standard-strength filter fabric may be used. the wire mesh fence securely to the upslope side of the posts using heavy duty wire staples at least 1 inch long, tie wires, or hog rings. Extend the wire to the existing ground surface and do not extend more than 34 inches above the original ground surface. Staple or wire the standard-strength fabric to the wire fence and extend a minimum of 1 foot onto the existing ground surface. Do not staple the fabric to existing trees.
4. When wire support is not used (standard silt fence or high-performance silt fence), use extra-strength filter fabric. Fasten the filter fabric securely to the upslope side of the posts using 1-inch-long (minimum) heavy-duty wire staples or tie wires and extend a minimum of 1 foot onto the existing ground surface. Do not staple the fabric to existing trees.
5. When attaching two silt fences, first place the end post of one fence inside the end post of the other fence. Rotate both posts at least 180 degrees in a clockwise direction to create a tight seal with the fabric material. Drive both posts a minimum of 18 inches into the ground, and extend the flap a minimum of 1 foot onto the existing ground surface.
6. If a silt fence is to be constructed across a ditch line or swale, ensure the measure is of sufficient length to eliminate end-flow and the plan configuration resembles an arc or horseshoe with the ends oriented upslope. Use extra-strength filter fabric for this application with a maximum 3-foot spacing of posts.
7. Anchor silt fence to the existing ground surface at a spacing of 1 foot on center with landscape nails a minimum of 12 inches long.
8. Install RAM/RPM on top of silt fence overlapped onto existing ground surface.
9. Anchor the RAM/RPM with 12-inch-long landscape nails at a spacing of 3 feet on center.
10. Secure a second layer of silt fence to stakes and overlap the filter fabric a minimum of 1 foot onto the RAM/RPM.
11. Depending on application type, place a minimum of 6 inches of course crushed aggregate or compost filter sock on top of RAM/RPM.
12. Remove the silt fence when the fence has served its useful purpose, but not before the upslope area has been permanently stabilized.

**Installation for Trenchless Super Silt Fence**

1. Install chain link fence with the fence on the upslope side of the support poles.
2. Install 2.5-inch-diameter galvanized or aluminum poles set at 10-foot maximum spacing. Install poles a minimum of 24 inches below the ground surface and extend a minimum of 33 inches above ground. A posthole drill is necessary to do this for most sites. Poles do not need to be set in concrete.
3. Fasten chain link fence securely to fence posts with wire ties.
4. Ensure chain link is galvanized No. 11.5 Ga. steel wire with 2.25-inch opening, No. 11 Ga. aluminum-coated steel wire in accordance with ASTM-A-491, or galvanized No. 9 Ga. steel wire top and bottom with galvanized No. 11 Ga. steel intermediate wires. Install No. 7 gage tension wire horizontally through holes at top of chain link fence or attach with hog rings at 5-foot (maximum) centers.
5. Stretch filter fabric and securely fasten to the fence with wire fasteners, staples, or preformed clips. Extend the fabric a minimum of 33 inches above the existing ground surface and a minimum of 1 foot onto the existing ground surface. Ensure the filter fabric width is a minimum of 42 inches.
6. Fasten the filter fabric securely to the chain link fence with fasteners, staples, or preformed clips spaced horizontally 24 inches at the ground surface, top, and midsection.
7. When attaching two silt fences, first place the end pole of one fence inside the end pole of the other fence. Rotate both poles at least 180 degrees in a clockwise direction to create a tight seal with the fabric material. Drive both poles a minimum of 36 inches into the ground, and extend the flap a minimum of 1 foot onto the existing ground surface.
8. Place the fabric toe a minimum of 1 foot onto the existing ground surface.
9. Anchor silt fence to the existing ground surface at a spacing of 1 foot on center with landscape nails a minimum of 12 inches long.
10. Install RAM/RPM on top of silt fence overlapped onto existing ground surface.
11. Anchor the RAM/RPM with 12-inch-long landscape nails at a spacing of 3 feet on center.
12. Remove and properly dispose of super silt fence when the disturbed area tributary to the fence is permanently stabilized.

## 7.0 Operations and Maintenance Considerations

Inspect silt fences immediately after each rainfall and at least daily during prolonged rainfall. Make any repairs immediately.

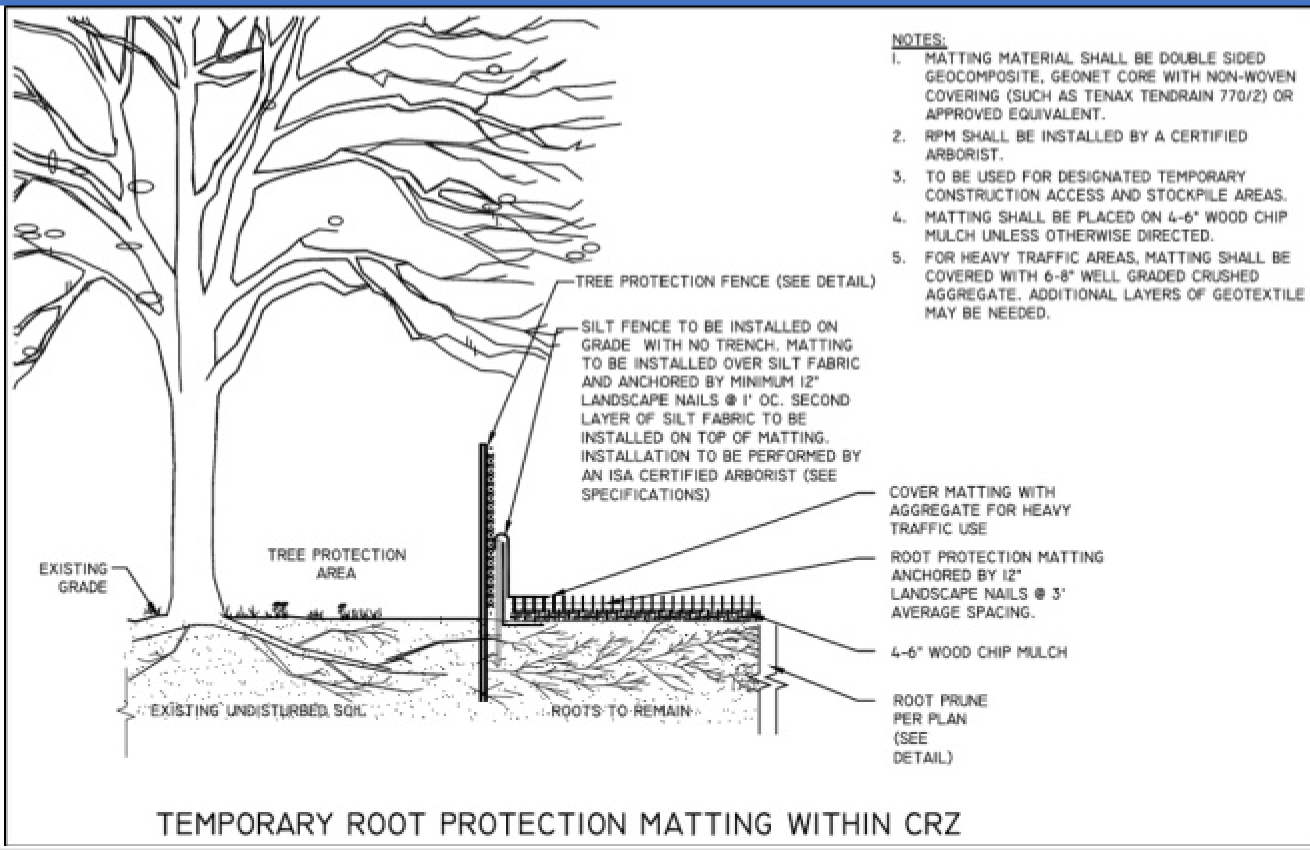
Pay close attention to the repair of damaged silt fence resulting from end runs and undercutting. This is commonly a sign that the fence has either been improperly installed or is placed in a less than optimal location. If the fence cannot be relocated, more frequent inspections may be warranted.

Replace the fabric promptly if the fabric on a silt fence decomposes or becomes ineffective before the end of the expected usable life and the barrier is still necessary.

Remove sediment deposits after each storm event and when deposits reach approximately one half the height of the barrier.

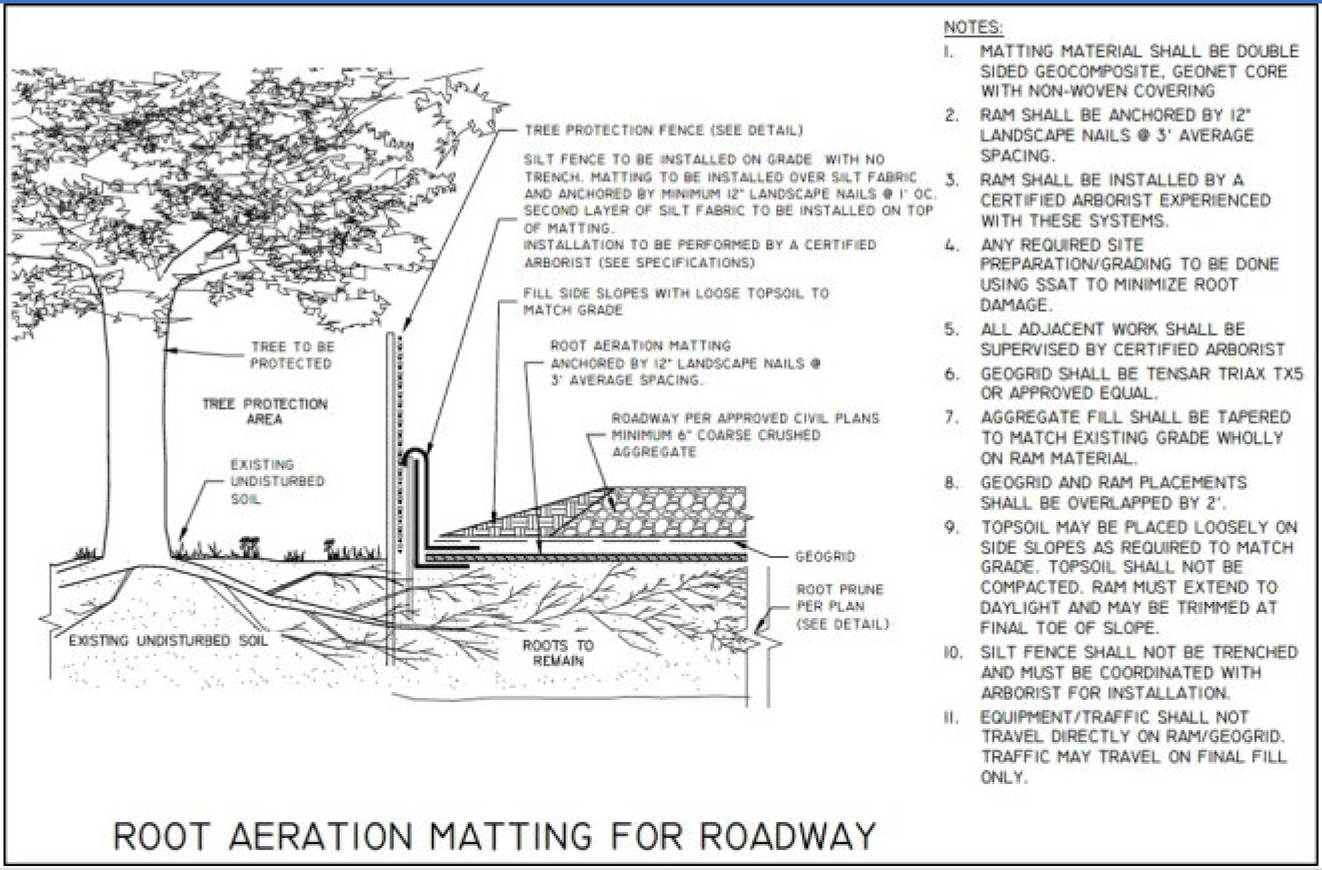
Dress to conform to existing grade, prepare, and seed any sediment deposits remaining in place after the silt fence is no longer required.

## *Figure C-ENV-10-1 Temporary Root Protection Matting within CRZ*



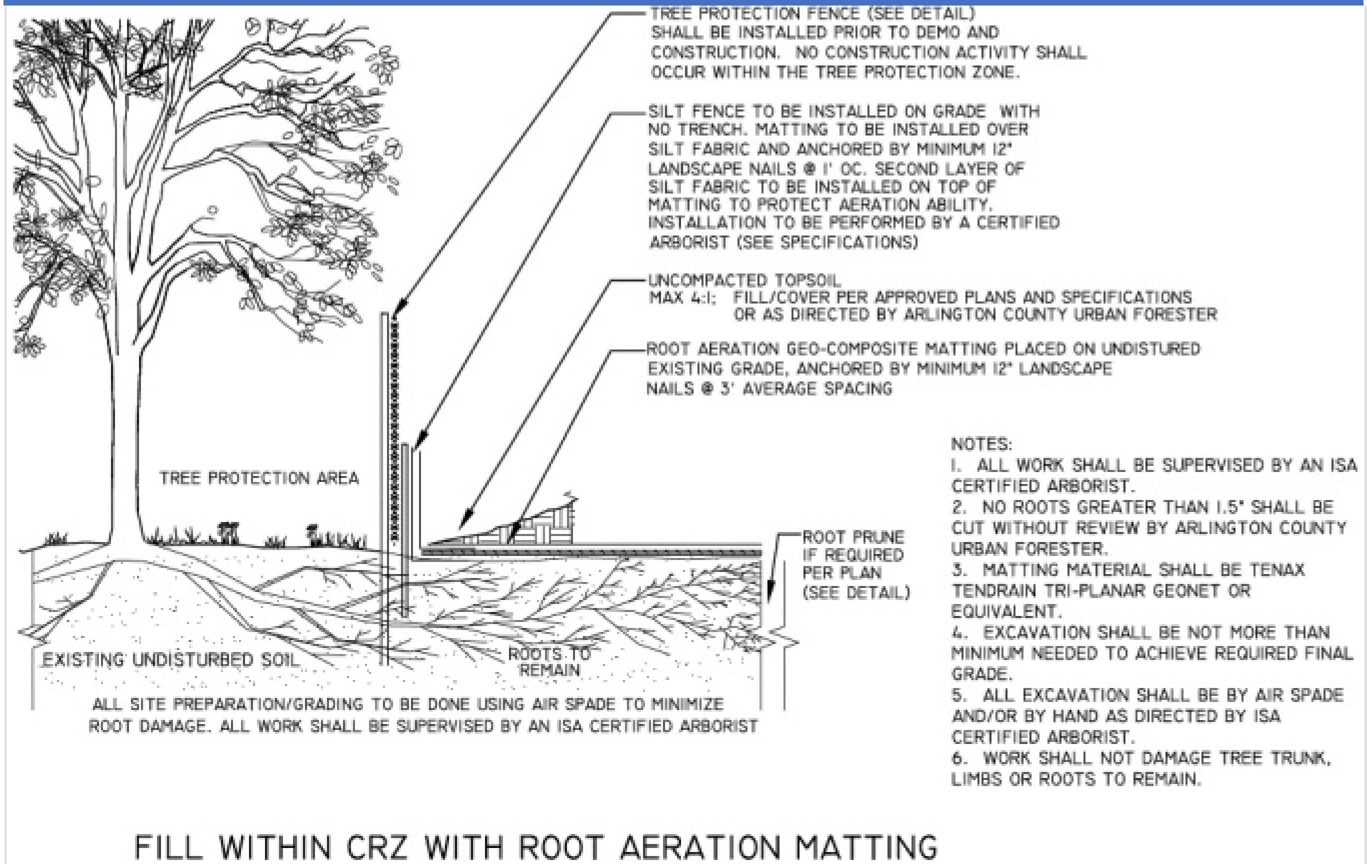

*Source: Arlington Virginia Department of Parks and Recreation*

## Figure C-ENV-10-2 Root Aeration Matting for Roadway



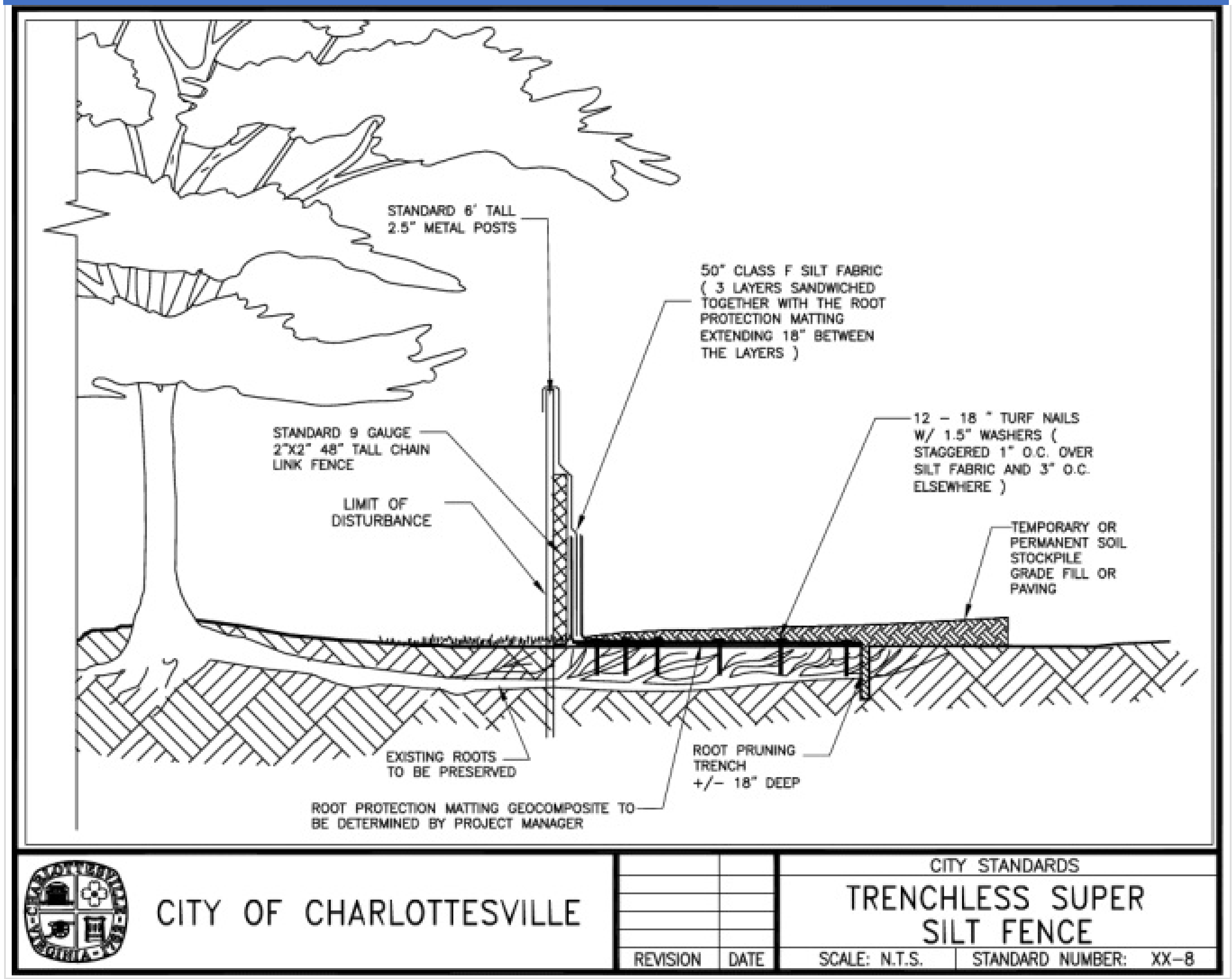

*Source: Arlington Virginia Department of Parks and Recreation*

***Figure C-ENV-10-3 Fill Within CRZ With Root Aeration Matting***




*Source: Arlington Virginia Department of Parks and Recreation*

**Figure C-ENV-10-4 Trenchless Super Silt Fence**




*Source: City of Charlottsville 2010*

## 8.0 References


City of Charlottesville. 2010. Best Management Practices for Tree Preservation, Transplanting, Removal and Replacement. Neighborhood Development Services. January.

Fairfax County Virginia. (n.d.). https://www.fairfaxcounty.gov/landdevelopment/chesapeake-bay-preservation-ordinance

Wetland Studies and Solutions, Inc. 2020. General Erosion and Sediment Control Standards and Specifications for Wetland and Stream Mitigation Banks.


# C-ENV-11 Wetland Berm

## 1.0 Definition

A wetland berm is an earthen berm structure used in the creation, restoration, and enhancement of wetlands through the collection and retention of water that flows by gravity or other means to the bermed area (Angler Environmental 2020).

## 2.0 Purpose and Applicability of Best Management Practice

A wetland berm is used to create wetland cells, which are flat areas, typically with less than 2% slopes, surrounded by permanent perimeter earth berms with hydraulic control structures (Wetland Weir Outlet [C-ENV-12]) connecting the cells. Wetlands can be constructed by excavating basins, by building up earth embankments, or through a combination of the two (USEPA 1995).

## 3.0 Planning and Considerations

Wetland berms are constructed along the perimeters of wetland cells to capture rainfall and runoff and minimize runoff to downstream receiving channels. During construction, wetland berms capture sediment-laden runoff from the area disturbed to create the wetland and serve as temporary sediment trapping devices in accordance with Wetland Cell Sediment Trap (C-ENV-13). The wetland berm should remain in place after vegetative stabilization of the site to contain rainfall and runoff to facilitate long-term wetland hydrology. Design the wetland berm to be accompanied with a stabilized outfall structure in accordance with the Wetland Weir Outlet (C-ENV-12).

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

9VAC25-875-560

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: LOW**

## 5.0 Design Criteria

| Table C-ENV-11 Design Criteria for Wetland Berms | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Height | Design berm heights to range between 1 and 2 feet at the upslope side of the berm. |
| Sideslope | Design berm sideslope to be a minimum of 2H:1V. |
| Width | Design berm to have a minimum bottom width of 5 feet. |
| Outlet | Provide a sediment trap rock outlet structure during construction to allow conveyance of storm events without overtopping. Once site is stabilized, construct a permanent concrete outlet weir. |
| Materials | Use clay with a hydraulic conductivity less than or equal to 1 x $10^{-6}$ centimeters per second (cm/s) or a geomembranee liner in accordance with P-SUP-01 to construct the clay core and key of the wetland berm. Use compacted fill material to construct the remainder of the wetland berm above the clay core and key. |

## 6.0 Construction Specifications

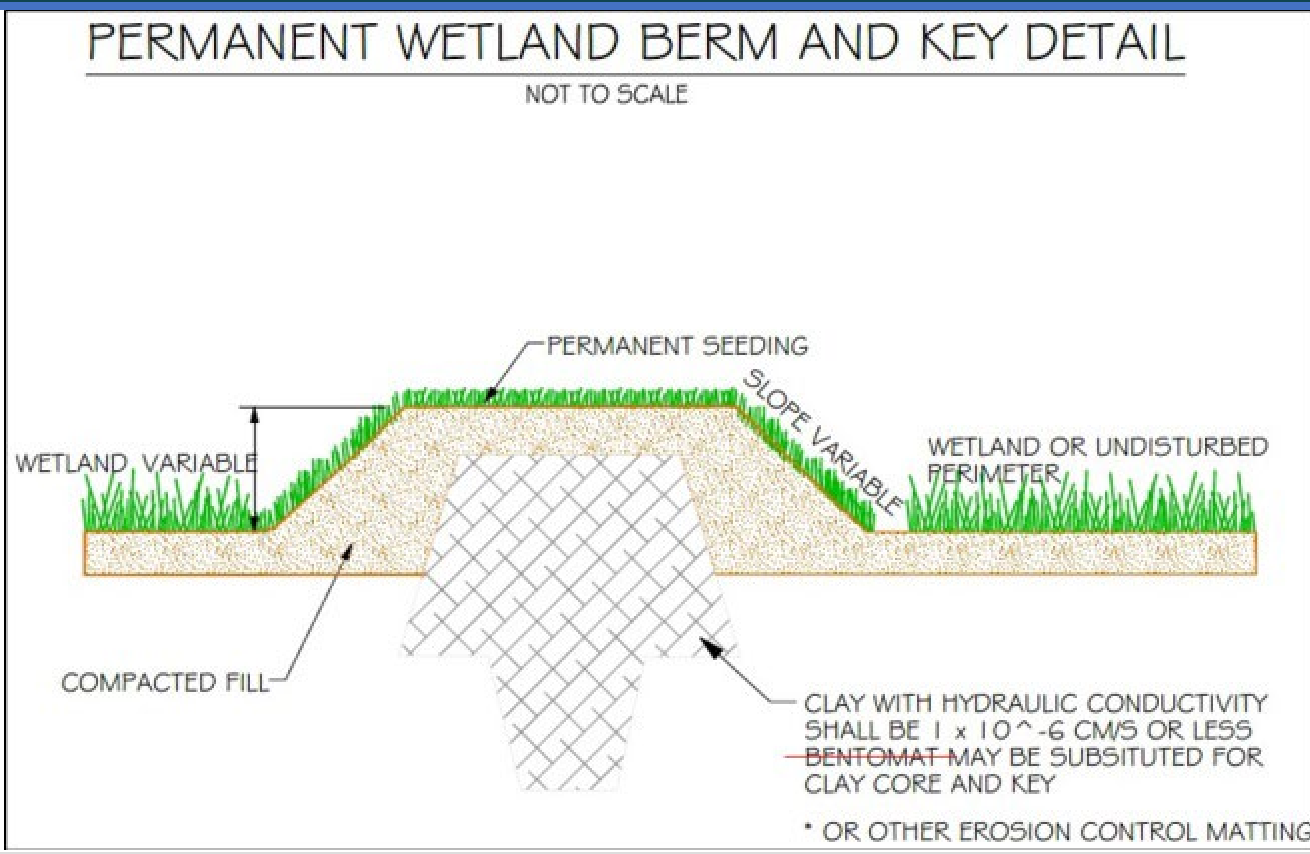
1. Base the sizes, locations, and frequency of structures on site conditions and design the structure(s) to maintain non-erosive discharge velocities.
2. Construct the clay core and key.
3. Install compacted topsoil over the clay core and key. Topsoil must be composed of soil that is free from excessive organic debris, rock, or other objectionable materials.
4. Place permanent seed on the area in accordance with the specifications for Seeding, Mulch, and Soil Stabilization (Wetlands/Streams) (BMP C-ENV-15) and Soil Erosion Control Blanket or Matting (BMP C-SSM-05).

## 7.0 Operations and Maintenance Considerations

Immediately following construction, inspect the berm for establishment of a stabilizing permanent vegetative cover. Reseed and mulch areas as needed where seeding fails to establish.

Inspect berms after every runoff-generating storm event during construction. If the integrity of the berm is jeopardized due to erosion, immediately repair the erosion by re-grading the area and stabilizing with native seed, mulch, and/or soil stabilization blanket and matting in accordance with Seeding, Mulch, and Soil Stabilization (Wetlands/Streams) (C-ENV-15) and Soil Erosion Control Blanket or Matting (C-SSM-05)

**Figure C-ENV-11-1 Wetland Berm**




*Source: Angler Environmental 2020*

## 8.0 References

Angler Environmental, a RES Company. 2020. Erosion and Sediment Control for Stream and Wetland Mitigations Banks and Nutrient-Reducing Stream Restoration Projects: 2020 Annual Standards and Specifications. October 14.

United States Environmental Protection Agency (USEPA). 1995. Handbook of Constructed Wetlands: A Guide to Creating Wetlands for Agricultural Wastewater Domestic Wastewater Coal Mine Drainage Stormwater in the Mid-Atlantic Region Volume 1: General Considerations.

# C-ENV-12 Wetland Weir Outlet

## 1.0 Definition

A wetland weir outlet is an overflow water control structure that regulates the volume of water impounded in the created, restored, or enhanced wetland (Angler Environmental 2020).

## 2.0 Purpose and Applicability of Best Management Practice

Typically, the creation, restoration, or enhancement of wetlands for wetland mitigation bank projects include multiple wetland cells that consist of both perimeter and intermediate earth berms with several wetland weir outlets.

## 3.0 Planning and Considerations

Because of the structural composition of a wetland cell, and because the associated berms and outlets are installed as a first step in the construction process, these structures provide effective erosion and sediment control. The locations, sizes, and frequency of the outlets are based on site conditions and designed to maintain non-erosive discharge velocities. In most cases, the only denuded area draining to the outlet is the wetland cell itself.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

9VAC25-875-560

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

Design wetland weir outlets to handle the maximum permitted discharge from the wetland.

## 6.0 Construction Specifications

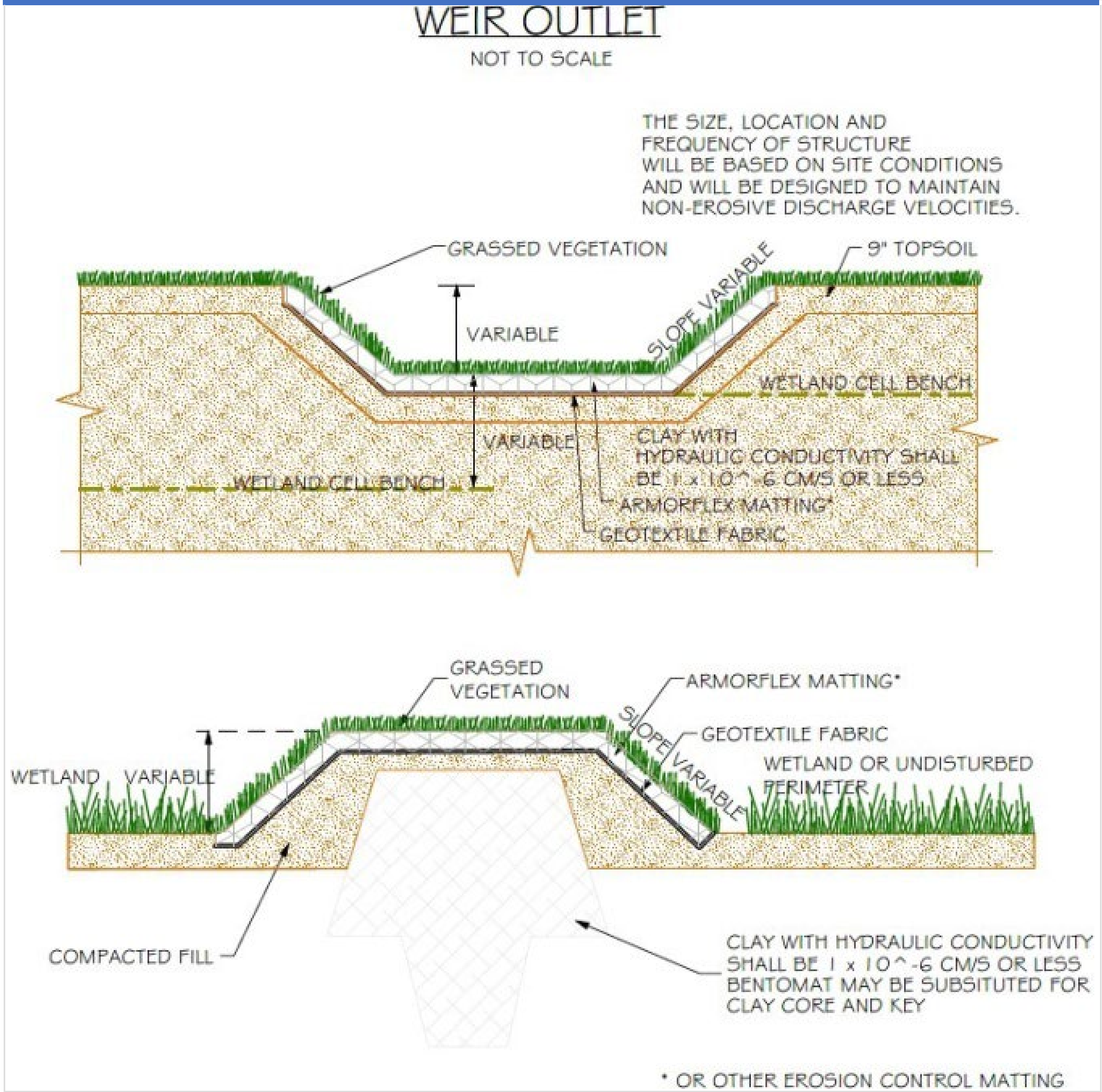
1. Base the sizes, locations, and frequency of structures on site conditions and design the structure(s) to maintain non-erosive discharge velocities.
2. Construct the clay core and key of the outlet using clay with a hydraulic conductivity less than or equal to 1 x 10-6 centimeters per second (cm/s) or a geosynthetic clay liner.
3. Install a 9-inch-thick topsoil layer over the clay core and key.
4. Place filter fabric as specified in Riprap (C-ECM-13) over the topsoil.

5. Place native permanent seed on the area in accordance with the Seeding, Mulch, and Soil Stabilization (Wetlands/Streams) (C-ENV-15) and Soil Erosion Control Blanket or Matting (C-SSM-05) over the filter fabric.

## 7.0 Operations and Maintenance Considerations

Maintain the weir outlet in a stabilized condition and maintain the design elevations relative to the surrounding storage volume and permanent berm.

**Figure C-ENV-12-1 Wetland Weir Outlet**




*Source: Angler Environmental 2020*

## 8.0 References

Angler Environmental, a RES Company. 2020. Erosion and Sediment Control for Stream and Wetland Mitigations Banks and Nutrient-Reducing Stream Restoration Projects: 2020 Annual Standards and Specifications. October 14.

# C-ENV-13 Wetland Cell Sediment Trap

## 1.0 Definition

Wetland mitigation bank projects create and restore wetlands through the construction of wetland cells that are large, flat areas used as "giant" sediment traps where applicable during construction.

## 2.0 Purpose and Applicability of Best Management Practice

Wetland cell sediment traps are used during wetland construction to detain sediment-laden runoff from the area being disturbed for creation of the mitigation bank wetland.

## 3.0 Planning and Considerations

Proper waivers from local jurisdictions may be required to use wetland cells as temporary sediment traps.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance.

**MS-6: TRAPS AND BASINS** – Sediment traps and basins shall be designed and constructed based on the total drainage area they serve.

9VAC25-875-560

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

Sizes of wetland cells can vary to several acres due to the shallow water depths and slower flows through the wetland. Because a wetland cell is designed to have very little slope or no slope at all, and is surrounded by wetland berm(s) with wetland weir outlet(s), the cell provides a storage volume that is much greater than typically required for sediment traps. During construction of a wetland mitigation bank project, the weir outlet will control sediment-laden discharge, as well as convert any concentrated discharge to sheet flow, releasing it uniformly into a lower wetland cell or the undisturbed perimeter.

Because all storage in the wetland cells is dry storage, design each wetland cell sediment trap to have a minimum storage volume of 202 cubic yards per acre.

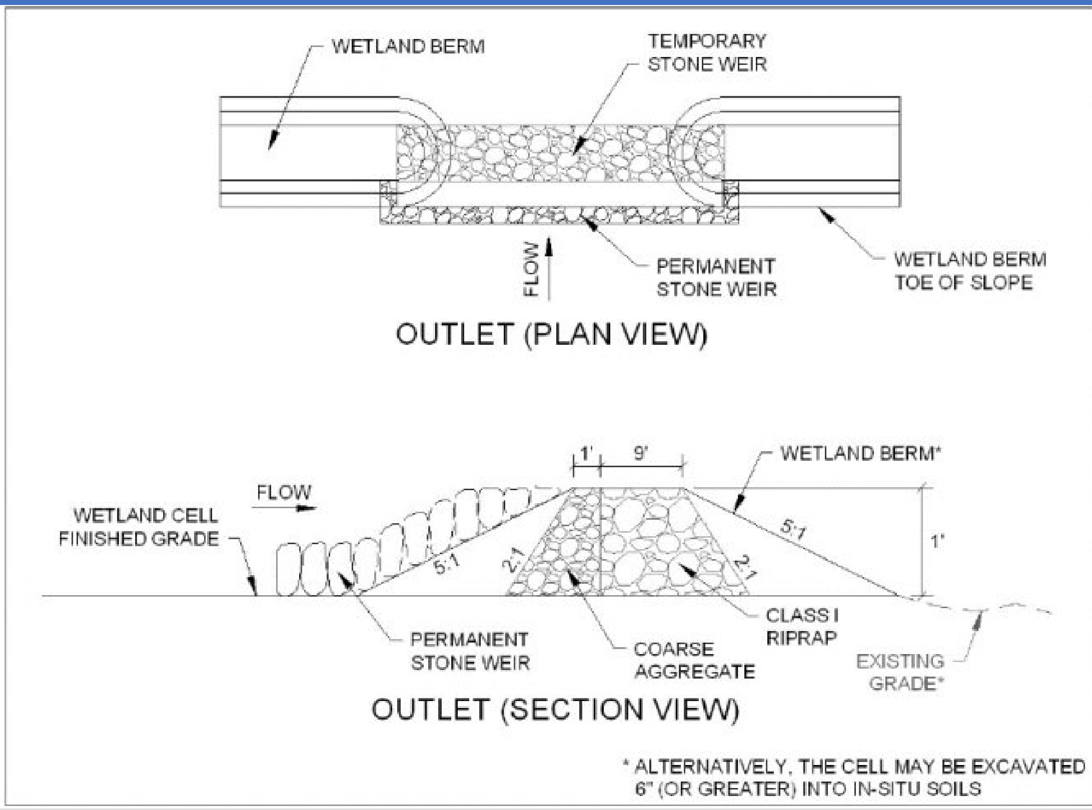
## 6.0 Construction Specifications

Construct wetland cells to be surrounded by a minimum 1-foot-tall earth berm or excavated at least 6 inches into the in-situ soils.

## 7.0 Operations and Maintenance Considerations

Inspect the wetland cell sediment trap weekly and immediately after each rainfall to ensure that the sediment trap is functioning properly. Remove sediment and restore the trap to its original dimensions when the sediment has accumulated to one half the design volume of the dry storage. Deposit sediment removed from the wetland cell in a suitable area and in such a manner that it will not erode and cause sedimentation problems.

***Figure C-ENV-13-1 Wetland Cell Sediment Trap Layout***




*Source: 2020 Wetland Studies and Solutions, Inc. 2020*

## 8.0 References

Wetland Studies and Solutions, Inc. 2020. General Erosion and Sediment Control Standards and Specifications for Wetland and Stream Mitigation Banks.

# C-ENV-14 Modified Turbidity Curtain for Streams

## 1.0 Definition

A modified turbidity curtain is a floating or staked barrier installed across stream flow that may also be referred to as a floating boom, silt barrier, or silt curtain.

– CAD C-ECM-14-1 Level Spreader

– CAD C-ECM-14-2 Level Spreader

## 2.0 Purpose and Applicability of Best Management Practice

Where all other erosion and sediment control measures have been implemented and there is still concern that a significant amount of sediment could be released downstream, a turbidity curtain can be applied. Use modified turbidity curtains for streams as a secondary control measure for the prevention of downstream sedimentation, as well as to further isolate the work from downstream reaches.

## 3.0 Planning and Considerations

Do not use modified turbidity curtains for streams as the primary control for stream projects; always use this practice in conjunction with other measures. The cross-stream application of a turbidity curtain in stream restoration projects may minimize the transport of sediment from in-stream work areas.

Carefully assess the depth, flow or current of water, and nature of construction to determine if a floating or staked turbidity curtain is required.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-12: WATERCOURSE CONSTRUCTION** – When work in a live watercourse is performed, precautions shall be taken to minimize encroachment (work in the dry whenever possible), control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material shall be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

**MS-14: OTHER WATERCOURSE REGULATIONS** – All applicable federal, state, and local regulations pertaining to working in or crossing live watercourses shall be met.

9VAC25-875-560

**Erosion Control Efficiency: LOW**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

- Only leave the curtain in place during working hours, and remove the curtain after each working day or when there is an immediate threat of significant rain.
- Locate the curtain downstream of the work area, and install the curtain to span the stream in an area with a minimum base flow depth of greater than or equal to 2 feet. Anchor the curtain solidly on the stream banks.
- Leave a minimum 6-inch gap between the bottom of the turbidity curtain and the stream bed at base flow conditions.
- Design the curtain to conform to the Type III turbidity curtain as specified in Turbidity Curtain (C-SCM-09).
- Remove sediment in the area located upstream of the curtain only after upstream work is completed and other temporary stream diversion techniques are employed adjacent to the area.

## 6.0 Construction Specifications

Construct the modified turbidity curtain for streams in accordance with the construction specification listed in Turbidity Curtain (C-SCM-09).

## 7.0 Operations and Maintenance Considerations

1. Maintain the filter curtain throughout the project to ensure the continuous protection of the watercourse.
2. Repair the geotextile fabric as necessary using repair kits available from the manufacturers. Follow manufacturer's instructions to ensure the adequacy of the repair.
3. When the curtain is no longer required, remove the curtain and related components to minimize turbidity. Ensure remaining sediment is sufficiently settled before removing the curtain. Sediment may be removed and the original watercourse depth (or plan elevation) restored. Transport any spoils to an upland area and stabilize the spoils.

## 8.0 References

Angler Environmental, a RES Company. 2020. Erosion and Sediment Control for Stream and Wetland Mitigations Banks and Nutrient-Reducing Stream Restoration Projects: 2020 Annual Standards and Specifications. October 14.

Georgia Soil and Water Conservation Commission. 2016. Manual for Erosion and Sediment Control in Georgia.

# C-ENV-15 Seeding, Mulching, and Soil Stabilization (Wetlands/Streams)

## 1.0 Definition

Seeding, mulching, and soil stabilization for wetlands and streams involves establishment of perennial vegetative cover on disturbed areas by planting seed; applying a protective blanket of mulch to the soil surface during the establishment of seeding; and planting of forb, shrubs, and/or trees in stream and/or wetland areas during restoration.

– CAD C-ECM-15-1 Pipe Outlet Conditions

– CAD C-ECM-15-2 Paved Channel Outlet

## 2.0 Purpose and Applicability of Best Management Practice

The purpose of seeding, mulching, and soil stabilization of streams and wetlands is to restore the impacted stream and/or wetlands to reduce erosion and decrease sediment yield, permanently stabilize disturbed areas, improve wildlife habitat, and enhance natural beauty.

This practice applies to any disturbed stream or wetland areas that require seeding, mulching, and soil stabilization to establish permanent, long-lived vegetative cover to stabilize the soil.

## 3.0 Planning and Considerations

A riparian buffer is an area adjacent to a stream, lake, or wetland that contains a combination of trees, shrubs, and/or other perennial plants and is managed differently from the surrounding landscape, primarily to provide conservation benefits. Buffers are used in agricultural, row crop, range, suburban, and urban settings. A wide variety of state and federal programs support the installation of riparian forest buffers on public and private lands.

Riparian buffers can deliver a number benefits including filtering nutrients, pesticides, and animal waste from agricultural land runoff; stabilizing eroding banks; filtering sediment from runoff; providing shade, shelter, and food for fish and other aquatic organisms; providing wildlife habitat and corridors for terrestrial organisms; protecting cropland and downstream communities from flood damage; producing income from farmland that is frequently flooded or has poor yields; providing space for recreation; and diversifying landowner income.

Several factors can impact the effectiveness of riparian buffers in meeting these objectives. These include site conditions such as adjacent agricultural practices and crop types, stream size, topography, and soils; landscape conditions such as position in the watershed, adjacent land use, and buffer continuity; and other conditions such as markets and public interest.

The riparian buffer areas identified herein include palustrine scrub-shrub (PSS), palustrine emergent (PEM), palustrine forested (PFO), upland, shady PFO, shady variable, sunny PFO, and sunny variable.

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization will be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization will be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization will be applied in areas to be left dormant for more than 1 year.

**MS-3: PERMANENT VEGETATION** – A permanent vegetative cover will be established on denuded areas not otherwise permanently stabilized. Permanent vegetation will not be considered established until achievement of a ground cover that is uniform, mature enough to survive, and will inhibit erosion.

**Sediment Removal Efficiency: N/A**

**Erosion Control Efficiency: HIGH**

## 5.0 Design Criteria

No formal design criteria.

## 6.0 Construction Specifications

Perform seeding within 7 days of construction completion. Apply seed uniformly with a broadcast seeder or hydroseeder on a firm, friable seedbed.

Species and quantities of seed will vary depending on the type of project, as shown in the schedules on the following pages. The plants specified have been studied over several years of wetland and stream mitigation projects and have been chosen based on climate, topography, soils, land use, planting season, and hydrologic regime. Use at least 75% of the species listed on the following pages depending on availability. Substitution for up to 25% of these species does not constitute a specification revision and does not require revision or approval.

Use straw mulch for wetland projects that is free of weed seeds. Use hay or straw mulch for stream projects that is free of weed seeds. Mulch may be spread by hand or by machine. Apply mulch at the rates specified in Mulching (BMP C-SSM-11) for hay and straw mulch.

| Table C-ENV-15-1 Permanent Seeding Vegetation (PEM Riparian Buffer Areas) | | | |
|---|---|---|---|
| **Species Group** | **Species Name** | **Common Name** | **Seed Rate (lbs./acre)** |
| **Grasses** | | | |
| 5 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Italian Bristle Grass | 45 |
| 6 | Elymus riparius | Riverbank Wild Rye | 10 |
| | Elymus virginicus | Virginia Wild-Rye | 10 |
| | Panicum dicotomiflorum | Smooth Panic Grass | 10 |
| | Tripsacum dactyloides | Gama Grass | 10 |
| 7 | Carex comosa | Bearded Sedge | 0.5 |
| | Carex lurida | Shallow Sedge | 0.5 |
| | Carex vulpinoidea | Fox Sedge | 0.5 |
| | Juncus effusus | Soft Rush | 0.5 |
| **Forbs** | | | |
| 8 | Asclepias incarnata | Swamp Milkweed | 0.1 |
| | Eutrochium fistulosum | Joe Pye Weed | 0.1 |
| | Symphyotrichum novae-angliae | New England Aster | 0.1 |
| | Symphyotrichum puniceum | Purple-Stemmed Aster | 0.1 |
| | Vernonia noveboracensis | Ny Ironweed | 0.1 |
| 9 | Eupatorium perfoliatum | Boneset | 0.2 |
| | Leersia oryzoides | Rice Cut Grass | 0.2 |
| | Ludwigia alternifolia | Bushy Seedbox | 0.2 |
| | Scirpus atrovirens | Green Bulrush | 0.2 |
| 10 | Bidens cernua | Nodding Beggar Ticks | 0.2 |
| | Bidens frondosa | Beggar Ticks | 0.2 |
| | Eutrochium maculatum | Spotted Joe Pye Weed | 0.2 |
| | Euthamia graminifolia | Grassleaf Goldenrod | 0.2 |
| | Iris versicolor | Blueflag | 0.2 |
| 11 | Persicaria sagittata | Arrow-Leaved Tearthumb | 0.2 |
| | Persicaria pensylvanica | Pa Smartweed | 0.2 |
| | Solidago rugosa | Wrinkled Goldenrod | 0.2 |

| Table C-ENV-15-1 Permanent Seeding Vegetation (PEM Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Verbena hastata | Blue Vervain | 0.2 |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 5.
- Three of the four species in Group 6.
- Three of the four species in Group 7.
- Four of the five species in Group 8.
- Three of the four species in Group 9.
- Four of the five species in Group 10.
- Three of the four species in Group 11.

| Table C-ENV-15-2 Permanent Seeding Vegetation (PSS Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| **Grasses** | | | |
| 4 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Italian Bristle Grass | 45 |
| 5 | Elymus riparius | Riverbank Wild Rye | 7.5 |
| | Elymus virginicus | Virginia Wild Rye | 7.5 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 7.5 |
| | Tripsacum dactyloides | Gama Grass | 7.5 |
| | Panicum dichotomiflorum | Smooth Panic Grass | 7.5 |
| 6 | Carex scoparia | Blunt Broom Sedge | 0.5 |
| | Carex squarrosa | Squarrose Sedge | 0.5 |
| | Carex vulpinoidea | Fox Sedge | 0.5 |
| | Juncus effusus | Soft Rush | 0.5 |
| **Forbs** | | | |
| 7 | Asclepias incarnata | Swamp Milkweed | 0.1 |
| | Symphyotrichum novae-angliae | New England Aster | 0.1 |
| | Symphyotrichum pilosum | White Oatfield American-Aster | 0.1 |
| | Eutrochium fistulosum | Joe Pye Weed | 0.1 |

| Table C-ENV-15-2 Permanent Seeding Vegetation (PSS Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Vernonia noveboracensis | New York Ironweed | 0.1 |
| 8 | Eupatorium perfoliatum | Boneset | 0.2 |
| | Leersia oryzoides | Rice Cut Grass | 0.2 |
| | Ludwigia alternifolia | Bushy Seedbox | 0.2 |
| | Scirpus cyperinus | Woolgrass | 0.2 |
| 9 | Helenium autumnale | Common Sneezeweed | 0.2 |
| | Helianthus angustifolius | Narrow-Leaf Sunflower | 0.2 |
| | Bidens cernua | Nodding Beggar Ticks | 0.2 |
| | Verbena hastata | Blue Vervain | 0.2 |
| | Verbesina alternifolia | Wingstem | 0.2 |
| 10 | Persicaria pensylvanica | Pa Smartweed | 0.2 |
| | Carex intumescens | Greater Bladder Sedge | 0.2 |
| 11 | Cornus amomum | Silky Dogwood | 0.2 |
| | Cephalanthus occidentalis | Buttonbush | 0.2 |
| | Hibiscus moscheutos | Crimson-Eyed Rose Mallow | 0.2 |
| | Ilex verticillata | Winterberry | 0.2 |
| | Rosa palustris | Swamp Rose | 0.2 |
| | Sambucus nigra spp. canadensis | Elderberry | 0.2 |
| | Viburnum dentatum | Southern Arrowwood | 0.2 |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 4.
- Four of the five species in Group 5.
- Three of the four species in Group 6.
- Four of the five species in Group 7.
- Three of the four species in Group 8.
- Four of the five species in Group 9.
- All the species in Group 10.
- Five of the seven species in Group 11.

| Table C-ENV-15-3 Permanent Seeding Vegetation (PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| **Species Group** | **Species Name** | **Common Name** | **Seed Rate (lbs./acre)** |
| | **Grasses** | | |
| 6 | Setaria italica | Italian Bristle Grass | 45 |
| | Elymus riparius | Riverbank Wild Rye | 10 |
| 7 | Elymus virginicus | Virginia Wild-Rye | 10 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 10 |
| | Tripsacum dactyloides | Gama Grass | 10 |
| | Carex lurida | Shallow Sedge | 0.5 |
| | Carex vulpinoidea | Fox Sedge | 0.5 |
| | **Forbs** | | |
| 8 | Persicaria pensylvanica | Pa Smartweed | 0.5 |
| | Scirpus atrovirens | Green Bulrush | 0.5 |
| | Bidens frondosa | Beggar Ticks | 0.2 |
| | Helenium autumnale | Common Sneezeweed | 0.2 |
| 9 | Onoclea sensibilis | Sensitive Fern | 0.2 |
| | Persicaria sagittata | Arrow-Leaved Tearthumb | 0.2 |
| | Eutrochium fistulosum | Joe Pye Weed | 0.1 |
| | Eupatorium perfoliatum | Boneset | 0.1 |
| | Ludwigia alternifolia | Bushy Seedbox | 0.1 |
| 10 | Scirpus cyperinus | Wool Grass | 0.1 |
| | Vernonia noveboracensis | Ny Ironweed | 0.1 |
| | Symphyotrichum novae-angliae | New England Aster | 0.1 |
| | Symphyotrichum puniceum | Purple-Stemmed Aster | 0.1 |
| 11 | Carex comosa | Bearded Sedge | 0.1 |
| | Carex squarosa | Squarrose Sedge | 0.2 |
| | Helianthus angustifolius | Narrow-Leaf Sunflower | 0.2 |
| | Juncus effusus | Soft Rush | 0.2 |
| | Verbena hastata | Blue Vervain | 0.2 |
| | **Shrubs** | | |
| 12 | Viburnum dentatum | Southern Arrowwood | 0.5 |

| Table C-ENV-15-3 Permanent Seeding Vegetation (PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| **Species Group** | **Species Name** | **Common Name** | **Seed Rate (lbs./acre)** |
| | Cephalanthus occidentalis | Buttonbush | 0.5 |
| | Cornus amomum | Silky Dogwood | 0.5 |
| | Ilex verticillata | Winterberry | 0.5 |
| | Sambucus nigra spp. canadensis | Elderberry | 0.5 |
| **Trees** | | | |
| 13 | Acer rubrum | Red Maple | 0.5 |
| | Acer negundo | Boxelder | 0.5 |
| | Betula nigra | River Birch | 0.5 |
| | Liquidambar styraciflua | Sweetgum | 0.5 |
| | Platanus occidentalis | American Sycamore | 0.5 |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 5.
- Three of the four species in Group 6.
- Three of the four species in Group 7.
- Three of the four species in Group 8.
- Four of the five species in Group 9.
- Two of the three species in Group 10.

Three of the four species in Group 11.

- Four of the five species in Group 12.
- Four of the five species in Group 13.

| Table C-ENV-15-4 Permanent Seeding Vegetation (Upland Riparian Buffer Areas) | | | |
|---|---|---|---|
| **Species Group** | **Species Name** | **Common Name** | **Seed Rate (lbs./acre)** |
| **Grasses** | | | |
| 5 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Italian Bristle Grass | 45 |
| 6 | Coreopsis lanceolata | Lance-Leaved Coreopsis | 8 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 8 |
| | Panicum virgatum | Switchgrass | 8 |
| | Sorghastrum nutans | Indiangrass | 8 |

| Table C-ENV-15-4 Permanent Seeding Vegetation (Upland Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Tridens flavus | Purpletop | 8 |
| **Forbs** | | | |
| 7 | Carex normalis | Greater Straw Sedge | 0.1 |
| | Hypericum punctatum | Spotted St. Johnswort | 0.1 |
| | Solidago juncea | Early Goldenrod | 0.1 |
| | Symphyotrichum pilosum | White Oldfield American-Aster | 0.1 |
| 8 | Asclepias tuberosa | Butterfly Milkweed | 0.1 |
| | Apocynum cannabinum | Indianhemp | 0.1 |
| | Eupatorium perfoliatum | Boneset | 0.1 |
| | Euthamia caroliniana | Slender Goldentop | 0.1 |
| | Andropogon virginicus | Broomsedge Bluestem | 0.1 |
| 9 | Asclepias syriaca | Common Milkweed | 0.2 |
| | Juncus tenuis | Path Rush | 0.2 |
| | Penstemon digitalis | Penstemon | 0.2 |
| | Verbesina alternifolia | Wingstem | 0.2 |
| 10 | Heliopsis helianthoides | Oxeye Sunflower | 0.2 |
| | Rudbeckia hirta | Black Eyed Susan | 0.2 |
| | Senna hebecarpa | Wild Senna | 0.2 |
| **Shrubs** | | | |
| 11 | Amelanchier canadensis | Canadian Serviceberry | 0.5 |
| | Hamamelis virginiana | Witch Hazel | 0.5 |
| | Viburnum dentatum | Southern Arrow Wood | 0.5 |
| | Viburnum prunifolium | Black-Haw | 0.5 |
| **Trees** | | | |
| 12 | Acer rubrum | Red Maple | 0.5 |
| | Carpinus caroliniana | Musclewood | 0.5 |
| | Cercis canadensis | Eastern Redbud | 0.5 |
| | Cornus florida | Flowering Dogwood | 0.5 |
| | Nyssa sylvatica | Black Gum | 0.5 |

| Table C-ENV-15-4 Permanent Seeding Vegetation (Upland Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Platanus occidentalis | American Sycamore | 0.5 |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 5.
- Four of the five species in Group 6.
- Three of the four species in Group 7.
- Four of the five species in Group 8.
- Three of the four species in Group 9.
- Two of the three species in Group 10.
- Three of the four species in Group 11.
- Five of the six species in Group 12.

| Table C-ENV-15-5 Permanent Seeding Vegetation (Shady PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| **Grasses** | | | |
| 10 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Italian Bristle Grass | 45 |
| 11 | Elymus riparius | Riverbank Wild Rye | 10 |
| | Elymus virginicus | Virginia Wild Rye | 10 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 10 |
| 12 | Panicum dichotomiflorum | Smooth Panic Grass | 10 |
| | Carex scoparia | Blunt Broom Sedge | 0.5 |
| | Carex squarrosa | Squarrose Sedge | 0.5 |
| | Carex vulpinoidea | Fox Sedge | 0.5 |
| **Forbs** | | | |
| 13 | Bidens frondosa | Beggar Ticks | 0.1 |
| | Bidens cernua | Nodding Beggar Ticks | 0.1 |
| | Eutrochium fistulosum | Joe Pye Weed | 0.1 |
| | Solidago rugosa | Wrinkled Goldenrod | 0.1 |
| | Symphyotrichum novae-angliae | New England Aster | 0.1 |

| Table C-ENV-15-5 Permanent Seeding Vegetation (Shady PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Symphyotrichum puniceum | Purple-Stemmed Aster | 0.1 |
| | Vernonia noveboracensis | New York Ironweed | 0.1 |
| 14 | Helianthus angustifolius | Narrow-Leaf Sunflower | 0.2 |
| | Iris versicolor | Blueflag | 0.2 |
| | Lobelia siphilitica | Great Blue Lobelia | 0.2 |
| | Senna hebecarpa | Wild Senna | 0.2 |
| | Onoclea sensibilis | Sensitive Fern | 0.2 |
| | Penstemon digitalis | Foxglove Penstemon | 0.2 |
| | Verbena hastata | Blue Vervain | 0.2 |
| **Shrubs** | | | |
| 15 | Cephalanthus occidentalis | Buttonbush | 0.2 |
| | Cornus amomum | Silky Dogwood | 0.2 |
| | Ilex verticillata | Winterberry | 0.2 |
| | Lindera benzoin | Northern Spicebush | 0.2 |
| | Eupatorium perfoliatum | Common Boneset | 0.2 |
| | Viburnum dentatum | Southern Arrow Wood | 0.2 |
| **Trees** | | | |
| 16 | Acer negundo | Box Elder | 0.4 |
| | Acer rubrum | Red Maple | 0.4 |
| | Betula nigra | River Birch | 0.4 |
| | Carpinus caroliniana | Musclewood | 0.4 |
| | Nyssa sylvatica | Black Gum | 0.4 |
| | Platanus occidentalis | American Sycamore | 0.4 |

| Table C-ENV-15-5 Permanent Seeding Vegetation (Shady PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

All the species in Group 10.

- Three of the four species in Group 11.
- Two of the three species in Group 12.
- Five of the seven species in Group 13.
- Five of the seven species in Group 14.
- Five of the six species in Group 15.
- Five of the six species in Group 16.

| Table C-ENV-15-6 Permanent Seeding Vegetation (Shady Variable Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| **Grasses** | | | |
| 9 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Foxtail Millet/Italian Bristle Grass | 45 |
| 10 | Elymus riparius | Riverbank Wild Rye | 10 |
| | Elymus virginicus | Virginia Wild Rye | 10 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 10 |
| | Senna hebecarpa | Wild Senna | 10 |
| 11 | Agrimonia parviflora | Harvestlice | 0.2 |
| | Carex squarrosa | Squarrose Sedge | 0.2 |
| | Parthenocissus quinquefolia | Virginia Creeper | 0.2 |
| | Juncus tenuis | Path Rush | 0.2 |
| **Forbs** | | | |
| 12 | Anemone virginiana | Thimbleweed | 0.1 |
| | Eupatorium perfoliatum | Common Boneset | 0.1 |
| | Symphyotrichum pilosum | White Oldfield American-Aster | 0.1 |
| | Rhus glabra | Smooth Sumac | 0.1 |
| | Solidago speciosa | Showy Goldenrod | 0.1 |
| | Vernonia noveboracensis | New York Ironweed | 0.1 |

| Table C-ENV-15-6 Permanent Seeding Vegetation (Shady Variable Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| 13 | Bidens frondosa | Beggar Ticks | 0.2 |
| | Geum canadense | White Avens | 0.2 |
| | Chamaecrista nicitans | Sensitive Partridge Pea | 0.2 |
| | Desmodium glabellum | Dillenius' Tick-Trefoil | 0.2 |

It is expected and preferred that all species in each of the Species Groups 116 are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 9.
- Three of the four species in Group 10.
- Three of the four species in Group 11.
- Five of the six species in Group 12.
- Five of the seven species in Group 13.
- Four of the five species in Group 14.
- Five of the six species in Group 15.

| Table C-ENV-15-7 Permanent Seeding Vegetation (Sunny PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| **Grasses** | | | |
| 10 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Italian Bristle Grass | 45 |
| 11 | Elymus riparius | Riverbank Wild Rye | 10 |
| | Elymus virginicus | Virginia Wild Rye | 10 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 10 |
| | Panicum dichotomiflorum | Fall Panic Grass | 10 |
| 12 | Anemone virginiana | Thimbleweed | 0.1 |
| | Symphyotrichum novae-angliae | New England Aster | 0.1 |
| | Symphyotrichum pilosum | White Oldfield American-Aster | 0.1 |
| | Symphyotrichum prenanthoides | Crooked-Stem Aster | 0.1 |
| | Solidago juncea | Early Goldenrod | 0.1 |
| 13 | Carex scoparia | Blunt Broom Sedge | 0.2 |
| | Carex squarrosa | Squarrose Sedge | 0.2 |

| Table C-ENV-15-7 Permanent Seeding Vegetation (Sunny PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Carex vulpinoidea | Fox Sedge | 0.2 |
| | Cyperus esculentus | Yellow Nut Sedge | 0.2 |
| | Juncus effusus | Soft Rush | 0.2 |
| | Juncus tenuis | Poverty Rush | 0.2 |
| | | **Forbs** | |
| 14 | Eutrochium fistulosum | Joe Pye Weed/Trumpetweed | 0.1 |
| | Eupatorium perfoliatum | Boneset | 0.1 |
| | Euthamia graminifolia | Grass Leaved Goldentop | 0.1 |
| | Solidago canadensis | Canada Goldenrod | 0.1 |
| | Solidago speciosa | Showy Goldenrod | 0.1 |
| | Vernonia noveboracensis | Ny Ironweed | 0.1 |
| | Lobelia cardinalis | Cardinal Flower | 0.1 |
| 15 | Asclepias syriaca | Common Milkweed | 0.2 |
| | Bidens frondosa | Beggar Ticks | 0.2 |
| | Helenium autumnale | Common Sneezeweed | 0.2 |
| | Helianthus angustifolius | Swamp Sunflower | 0.2 |
| | Onoclea sensibilis | Sensitive Fern | 0.2 |
| | Penstemon digitalis | Foxglove Beardtongue | 0.2 |
| | Verbena hastata | Blue Vervain | 0.2 |
| | Verbesina alternifolia | Wingstem | 0.2 |
| 16 | Coreopsis lanceolata | Lance Leaf Tickseed | 0.2 |
| | Heliopsis helianthoides | Smooth Oxeye | 0.2 |
| | Persicaria pensylvanica | Pa Smartweed | 0.2 |
| | Rudbeckia hirta | Black Eyed Susan | 0.2 |
| | Leersia oryzoides | Rice Cutgrass | 0.2 |
| | | **Shrubs** | |
| 17 | Hamamelis virginiana | Witch Hazel | 0.2 |
| | Ilex verticillata | Winterberry | 0.2 |
| | Lindera benzoin | Northern Spicebush | 0.2 |

| Table C-ENV-15-7 Permanent Seeding Vegetation (Sunny PFO Riparian Buffer Areas) | | | |
|---|---|---|---|
| **Species Group** | **Species Name** | **Common Name** | **Seed Rate (lbs./acre)** |
| | Aronia melanocarpa | Black Chokeberry | 0.2 |
| | Physocarpus opulifolius | Common Ninebark | 0.2 |
| | Viburnum dentatum | Southern Arrow Wood | 0.2 |
| | Viburnum prunifolium | Black-Haw | 0.2 |
| | **Trees** | | |
| 18 | Acer rubrum | Red Maple | 0.2 |
| | Carpinus caroliniana | American Hornbeam/Musclewood | 0.2 |
| | Cercis canadensis | Eastern Redbud | 0.2 |
| | Cornus florida | Flowering Dogwood | 0.2 |
| | Nyssa sylvatica | Black Gum | 0.2 |
| | Platanus occidentalis | American Sycamore | 0.2 |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 10.
- Three of the four species in Group 11.
- Four of the five species in Group 12.
- Five of the six species in Group 13.
- Five of the seven species in Group 14.
- Six of the eight species in Group 15.
- Four of the five species in Group 16.
- Five of the seven species in Group 17.

| Table C-ENV-15-8 Permanent Seeding Vegetation (Sunny Variable Riparian Buffer Areas) | | | |
|---|---|---|---|
| **Species Group** | **Species Name** | **Common Name** | **Seed Rate (lbs./acre)** |
| | **Grasses** | | |
| 9 | Lolium perenne spp. multiflorum | Annual Ryegrass | 45 |
| | Setaria italica | Italian Bristle Grass | 45 |
| 10 | Elymus riparius | Riverbank Wild Rye | 10 |
| | Elymus hystrix | Eastern Bottle-Brush Grass | 10 |
| | Dichanthelium clandestinum | Deer Tongue Grass | 10 |

| Table C-ENV-15-8 Permanent Seeding Vegetation (Sunny Variable Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| | Panicum virgatum | Switchgrass | 10 |
| 11 | Carex scoparia | Blunt Broom Sedge | 0.2 |
| | Agrimonia parviflora | Harvestlice | 0.2 |
| | Clematis virginiana | Virgin'S Bower | 0.2 |
| | Juncus effusus | Soft Rush | 0.2 |
| | Juncus tenuis | Path Rush | 0.2 |
| **Forbs** | | | |
| 12 | Anemone virginiana | Thimbleweed | 0.1 |
| | Symphyotrichum novae-angliae | New England Aster | 0.1 |
| | Symphyotrichum pilosum | White Oldfield American-Aster | 0.1 |
| | Solidago juncea | Early Goldenrod | 0.1 |
| 13 | Eutrochium fistulosum | Joe Pye Weed | 0.1 |
| | Euthamia graminifolia | Grass Leaved Goldenrod | 0.1 |
| | Solidago speciosa | Showy Goldenrod | 0.1 |
| | Senna hebecarpa | Wild Senna | 0.1 |
| | Carex granularis | Limestone Meadow-Sedge | 0.1 |
| 14 | Asclepias syriaca | Common Milkweed | 0.2 |
| | Helenium autumnale | Common Sneezeweed | 0.2 |
| | Geum canadense | White Avens | 0.2 |
| | Onoclea sensibilis | Sensitive Fern | 0.2 |
| | Penstemon digitalis | Penstemon | 0.2 |
| | Chamaecrista nicitans | Sensitive Partridge Pea | 0.2 |
| | Desmodium glabellum | Dillenius' Tick-Trefoil | 0.2 |
| | Verbesina alternifolia | Wingstem | 0.2 |
| 15 | Coreopsis lanceolata | Lance Leaved Coreopsis | 0.2 |
| | Heliopsis helianthoides | Oxeye Sunflower | 0.2 |
| | Persicaria pensylvanica | Pa Smartweed | 0.2 |
| | Rudbeckia hirta | Black Eyed Susan | 0.2 |
| | Rhus glabra | Smooth Sumac | 0.2 |

| Table C-ENV-15-8 Permanent Seeding Vegetation (Sunny Variable Riparian Buffer Areas) | | | |
|---|---|---|---|
| Species Group | Species Name | Common Name | Seed Rate (lbs./acre) |
| **Shrubs** | | | |
| 16 | Amelanchier canadensis | Canadian Serviceberry | 0.2 |
| | Hamamelis virginiana | Witch Hazel | 0.2 |
| | Prunus americana | American Plum | 0.2 |
| | Lindera benzoin | Northern Spicebush | 0.2 |
| | Physocarpus opulifolius | Common Ninebark | 0.2 |
| | Viburnum dentatum | Southern Arrow Wood | 0.2 |
| | Viburnum prunifolium | Black-Haw | 0.2 |
| **Trees** | | | |
| 17 | Acer rubrum | Red Maple | 0.2 |
| | Carpinus caroliniana | American Hornbeam | 0.2 |
| | Cercis canadensis | Eastern Redbud | 0.2 |
| | Cornus florida | Flowering Dogwood | 0.2 |
| | Nyssa sylvatica | Black Gum | 0.2 |
| | Platanus occidentalis | American Sycamore | 0.2 |

It is expected and preferred that all species in each of the Species Groups are planted. The tolerances listed in this note are intended to incorporate flexibility according to species availability. At a minimum, provide at least:

- All the species in Group 5.
- Three of the four species in Group 10.
- Four of the five species in Group 11.
- Three of the four species in Group 12.
- Four of the five species in Group 13.
- Six of the eight species in Group 14.
- Four of the five species in Group 15.
- Five of the seven species in Group 16.
- Five of the six species in Group 17.

## 7.0 Operations and Maintenance Considerations

Even with careful, well-planned seeding operations, failures can occur. When plants have not germinated on an area or have died, reseed these areas immediately to prevent erosion damage.

However, it is extremely important to determine why germination failed and take any corrective action necessary before reseeding the area. Healthy vegetation is the most effective erosion control available.

Inspect all mulches and soil coverings periodically and after rainstorm events to check for erosion. Where erosion is observed in mulched areas, apply additional mulch. Inspect mulches until grasses are firmly established.

*Source: Bluegrass Stream, LLC n.d.*

## 8.0 References


Bluegrass Stream LLC. n.d. Kanawha Sapsucker Run Stream Restoration Project. Located at: bluegrassstream.com/Kanawha-sapsucker-run.html.

Bluegrass Stream LLC. 2006. Mud Creek Stream Mitigation Project. Located at: bluegrassstream.com/mud-creek.html.

U.S. Forest Service (USFS). n.d. Riparian Forest Buffers. Located at: fs.usda.gov/nac/practices/riparian-forest-buffers.php.

Wetland Studies and Solutions, Inc. 2020. General Erosion and Sediment Control Standards and Specifications for Wetland and Stream Mitigation Banks.


# C-PCM-01 Safety Fence

## 1.0 Definition

Safety fence is a protective barrier installed to prevent access to a land-disturbing activity or erosion control measure.

– CAD C-PCM-01-1 Safety Fence

## 2.0 Purpose and Applicability of Best Management Practice

Safety fence will be used as a best management practice (BMP) to prohibit public access to a land-disturbing activity and/or erosion control measure. Safety fence will also be used to delineate the limits of environmentally sensitive areas to be protected and to prevent encroachment by construction activity.

Safety fence is applicable to any land-disturbing activity, control measure, or series of control measures that can be considered unsafe by virtue of potential for access by the public.

## 3.0 Planning and Considerations

The safety of the public should always be considered at both the planning and implementation phases of a land-disturbing activity. If there is any question concerning the risk of a particular erosion control measure to the public, the measure should be relocated to a safer area, or an appropriate safety fence should be installed to prevent undesired access. Properly designed and installed safety fences prevent the trespassing of people into potentially dangerous areas such as children using a sediment basin or a stormwater retention structure as play areas. The installation of these fences will protect people from hazards and the owner from possible litigation.

Two different types of fence are discussed in this specification. The designer, developer, and contractor should always be sure that the most appropriate type of fence is used for a particular need.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any land-disturbing activity and will be made functional before upslope land disturbance takes place.

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

1. Safety fences should be located to create a formidable barrier to undesired access while allowing for the continuation of necessary construction operations.
2. Safety fences are most applicable to the construction of berms, traps, and dams. In use with those structures, safety fences should be located far enough beyond the outer toe of the embankment to allow for the passage of maintenance vehicles. Fences should not be installed across the slope of a dam or dike.
3. The height of the fence should be a minimum of 5 feet for plastic fence and 6 feet for metal fence. A fence must never be so short as to become an attraction for children to climb on or over.
4. Signs noting potential hazards such as "DANGER-QUICKSAND" or "HAZARDOUS AREA-KEEP OUT" should be posted and easily seen by anyone approaching the protected area.
5. Plastic (polyethylene) fence may be used as safety fencing, primarily in situations where the need is for a temporary barrier (see Figure C-PCM-01-1) such as marking tree protection zones and non-compaction areas. The fence should meet the physical requirements noted in Table C-PCM-01-1.
6. Metal or chain link fence should be used when a potentially dangerous control measure will remain in place permanently such as a stormwater detention or retention basin (see Figure C-PCM-01-1). However, the metal fence may also be used for measures that serve a temporary function at the discretion of those responsible for project safety. The metal fence should meet the following physical requirements:
    a. Fabric should be a minimum 2-inch mesh, 9-gauge zinc-coated steel.
    b. Zinc coating should have a minimum weight of 1.8 ounces per square foot.
    c. Posts should be zinc-coated steel pipe.
    d. Top nails should be zinc-coated steel pipe.
    e. Braces should be made of zinc-coated steel.
    f. Gates should be single- or double-swing, zinc-coated steel. Gates should be a minimum of 12 feet wide.

## 6.0 Construction Specifications

| Table C-PCM-01-1 Physical Properties of Plastic Safety Fence | | |
|---|---|---|
| **Physical Property** | **Test** | **Requirements** |
| Recommended Color | Not applicable | "International Orange" |
| Tensile Yield | ASTM D636 | Average 2,000 pounds (lbs), per 4-foot width |
| Ultimate Tensile Strength | ASTM D636 | Average 2,900 lbs, per 4-foot width |
| Elongation at Break (%) | ASTM D636 | Greater than 1,000% |
| Chemical Resistance | Not applicable | Inert to most chemicals and acids |

*Source: Conwed Plastics.*

*Figure C-PCM-01-1 Safety Fence*


SOURCE: CONWED PLASTICS
VDOT ROAD AND BRIDGE STANDARDS
VA. DSWC

1. Safety fences should be installed before the erosion and sediment control measure becomes accessible.
2. The polyethylene web of the plastic safety fence should be secured to a conventional metal "T" or "U" post driven into the ground to a minimum depth of 18 inches; posts should be spaced at 6-foot centers. See perspective view on Figure C-PCM-01-1.

3. The metal safety fence should be installed as per the following procedure:
   a. Line posts should be placed at intervals of 10 feet measured from center to center of adjacent posts. In determining the post spacing, measurement will be made parallel with the ground surface. See perspective view on Figure C-PCM-01-1.
   b. Posts will be set in concrete and backfilled or anchored by other acceptable means.
   c. Posts set in the tops of concrete walls should be grouted into pre-formed holes to a minimum depth of 12 inches.
   d. All corner posts, end posts, gate posts, and pull posts should be embedded, braced, and trussed as shown in the "Standard Fence – Chain Link" detail found in the latest version of the Virginia Department of Transportation (VDOT) Road and Bridge Standards.
   e. Fencing fabric should not be stretched until at least 4 days after the posts are grouted into walls or 14 days after the posts are set into concrete.
   f. The fabric should be stretched taut and securely fastened by means of tie clips to the posts at intervals not exceeding 15 inches and to the top rails or tension wires at intervals not exceeding 2 feet. Care should be taken to equalize the tension on each side of each post.

4. Applicable warning signs noting hazardous conditions must be installed immediately upon installation of safety fence.

## 7.0 Operations and Maintenance Considerations

Safety fence should be checked regularly for weather-related or other damage. Any necessary repairs must be made immediately. Care should be taken to secure all access points (gates) at the end of each working day. All locking devices must be repaired or replaced as necessary.

## 8.0 References

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-PCM-02 Straw Bale Barrier

## 1.0 Definition

A straw bale barrier is a temporary barrier made of anchored straw used to intercept sediment-laden runoff from small drainage areas.

– CAD C-PCM-02-1 Straw Bale Barrier

## 2.0 Purpose and Applicability of Best Management Practice

Straw bale barriers are used to intercept and detain small amounts of sediment from small, disturbed areas to prevent sediment from leaving the construction site and to decrease the velocity of sheet flows.

Straw barriers can be used in the following conditions:

1. Below disturbed areas subject to sheet and rill erosion;
2. Where effectiveness is required for less than 3 months;

3. Where there is no concentration of water in a channel or other drainageway above the barrier; or
4. Where the size of the drainage area is no greater than 0.25 acre per 100 feet of barrier length.

Due to the varied effectiveness of straw bale barriers, limit the use of straw bale barriers as perimeter control measures to where no other practice is feasible.

Do not use straw bale barriers where water may concentrate in defined ditches and minor swales, in live streams or where there is a possibility of a washout, or where rock or another hard surface prevents the full and uniform anchoring of the barrier.

## 3.0 Planning and Considerations

Based on observations made in Virginia, Pennsylvania, Maryland, and other parts of the nation, straw bale barriers have not been as effective as intended when used to slow down and filter concentrated flows for the following reasons:

1. Improper use in streams and drainageways where high water depth and velocities have destroyed or damaged the control;
2. Improper placement and installation that leads to undercutting and end flow, such as staking the bales directly to the ground with no soil seal or entrenchment; and
3. Inadequate maintenance leading to reduced effectiveness of the barrier.

For these reasons, use straw bale barriers judiciously and with caution as erosion control measures.

## 4.0 Stormwater Performance Summary

### 4.1 MS-4: First-Step Measures

Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any land-disturbing activity and will be made functional before upslope land disturbance takes place.

**Sediment Removal Efficiency: Low**

**Erosion Control Efficiency: Low**

## 5.0 Design Criteria

Locate straw bale barriers at least 5 to 7 feet from the base of disturbed slopes.

Ensure the size of the drainage area to the straw bale barrier is no greater than 0.25 acre per 100 feet of barrier length. Install the straw bale barriers such that the length of the slope above the straw bale barrier does not exceed the limits shown in Table C-PCM-02-1.

**Table C-PCM-02-1 Design Criteria for Straw Bale Barriers**

| Constructed Slope | Percent Slope | Slope Length (feet) |
|---|---|---|
| 2:1 | 50 | 25 |
| 3:1 | 33 | 50 |
| 4:1 | 25 | 75 |

Note: Where slope gradient changes through the drainage area, steepness refers to the steepest slope section contributing to the straw bale barrier.

Table C-PCM-02-1 is generally adequate for a 1-inch rainfall event. Larger storms could cause failure of this practice. Specifically design the straw bale barriers to store the expected runoff if they are used in sensitive areas for longer than 1 month.

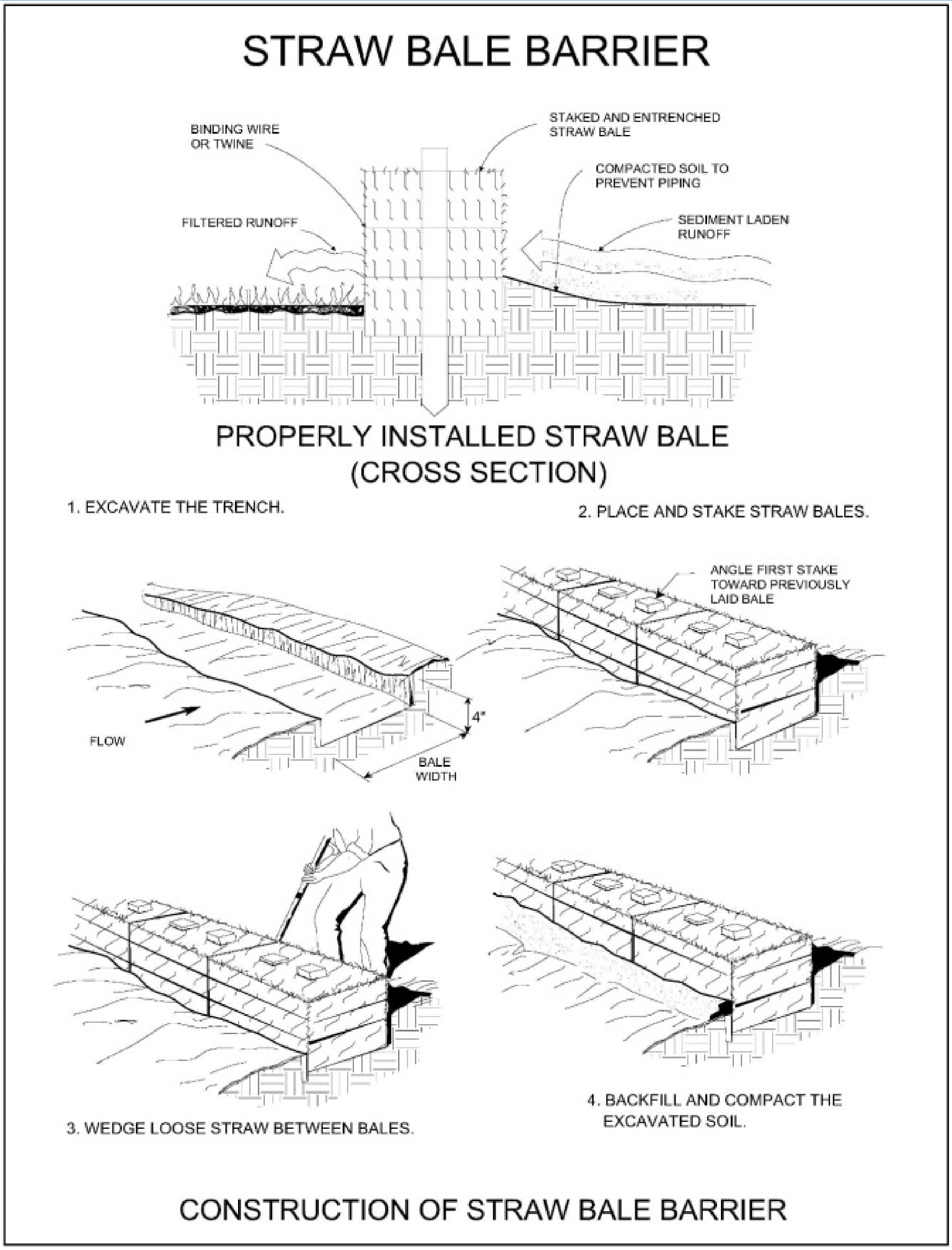
## 6.0 Construction Specifications

1. Place bales in a single row, lengthwise on the contour, with ends of adjacent bales tightly abutting one another.
2. Ensure all bales are either wire-bound or string-tied. Install straw bales such that bindings are oriented around the sides rather than along the tops and bottoms of the bales to prevent deterioration of the bindings (see Figure C-PCM-02-1).
3. Entrench and backfill the barrier. Excavate a trench the width of a bale and the length of the proposed barrier to a minimum depth of 4 inches. After the bales are staked and chinked (gaps filled by wedging), backfill the excavated soil against the barrier. Grade the backfill soil to conform to the ground level on the downhill side and build up the backfill to 4 inches against the uphill side of the barrier (see Figure C-PCM-02-1).
4. Securely anchor each bale using at least two stakes (minimum dimensions 2 inches x 2 inches x 36 inches) or standard “T” or “U” steel posts (minimum weight of 1.33 pounds per linear foot) driven through the bale. Drive the first stake or steel post in each bale toward the previously laid bale to force the bales together. Drive the stakes or steel posts a minimum of 18 inches deep into the ground to securely anchor the bales.
5. Chink (fill by wedging) the gaps between bales with straw to prevent water from escaping between the bales. Loose straw scattered over the area immediately uphill from a straw bale barrier tends to increase barrier efficiency.
6. Ensure both ends of the barrier extend at least 8 feet upslope at 45 degrees to the main barrier alignment.

## 7.0 Operations and Maintenance Considerations

1. Inspect straw bale barriers immediately after each rainfall and at least daily during prolonged rainfall.
2. Pay close attention to the repair of damaged bales, end runs, and undercutting beneath bales.
3. Repair or replace bales promptly.
4. Remove sediment deposits after each rainfall. Remove accumulated sediment when the level of deposition reaches approximately one half the height of the barrier.
5. Remove straw bale barriers after they have served their usefulness, but not before the upslope areas have been permanently stabilized; see Permanent Seeding (BMP C-SSM-10), Sodding (BMP C-SSM-06), and Topsoiling (BMP C-SSM-02).
6. After removing the straw bale barrier, dress any sediment deposits remaining in place to conform to the existing grade, prepare, and seed.

*Figure C-PCM-02-1 Construction of Straw Bale Barrier*




SOURCE: VA. DSWC

## 8.0 References

New York State Department of Environmental Conservation. 2016. New York State Standards and Specifications for Erosion and Sediment Control. November.

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-PCM-03 Brush Barrier

## 1.0 Definition

A brush barrier is a temporary sediment barrier constructed at the perimeter of a disturbed area from the residue materials available from clearing and grubbing the site.

– CAD C-PCM-03-1 Construction of a Brucsh Barrier Covered by Filter Fabric

## 2.0 Purpose and Applicability of Best Management Practice

Brush barriers are a best management practice (BMP) used to intercept and retain sediment from disturbed areas of limited extent, preventing sediment from leaving the site.

Brush barriers are installed below disturbed areas subject to sheet and rill erosion, where enough residue material is available for construction of such a barrier.

Brush barriers will reduce flow velocity and provide coarse sediment control.

## 3.0 Planning and Considerations

During clearing and grubbing, equipment can push or dump the mixture of limbs, small vegetation, and root mat (along with minor amounts of rock) into windrows along the toe of a slope where erosion and accelerated runoff are expected.

Brush barriers may be beneficial on wooded or rocky slopes where other perimeter controls may be less effective.

Brush barriers may be used around sinkholes and any naturally occurring closed depression, but not placed into the sinkholes/depressions.

Field experience has shown that brush barrier installations are not effective when there are large voids created from using material that is too large (such as tree stumps). Ensure brush barrier installations provide a compact, dense barrier. Consider alternative practices if sufficient material is not available onsite.

Do not use brush barriers to treat concentrated flows or for drainage areas more than 0.25 acre per 100 feet of barrier length. Do not use brush barriers within 50 feet of a receiving surface water.

Take care that removal of the BMP does not create an erosive condition needing perimeter controls. Use this practice where removal of the barrier upon completion of construction would not be required.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any land-disturbing activity and will be made functional before upslope land disturbance takes place.

**Sediment Removal Efficiency: LOW**

**Erosion Control Efficiency: N/A**

**Note:** Sediment control function can be enhanced by encasing the brush barrier with filtering fabric such as a geotextile. Remove filter fabric before construction ends unless it is made from natural plant fibers unaltered by synthetic materials.

## 5.0 Design Criteria

Install the brush barrier parallel to contours downslope of drainage areas no greater than 0.25 acre per 100 feet of barrier length; the maximum slope length behind the barrier is 100 feet; and the maximum slope gradient behind the barrier is 50 percent (2H:1V). Do not use material larger than 6 inches in diameter.

Brush barriers may be constructed of chipped site vegetation, live cuttings, fascines, or composted or wood-based mulch. When site vegetation is used, ensure invasive species are not incorporated.

Construct the brush barrier of sufficient height and width to provide treatment for flow and prevent flow from going around or under the brush barrier.

## 6.0 Construction Specifications

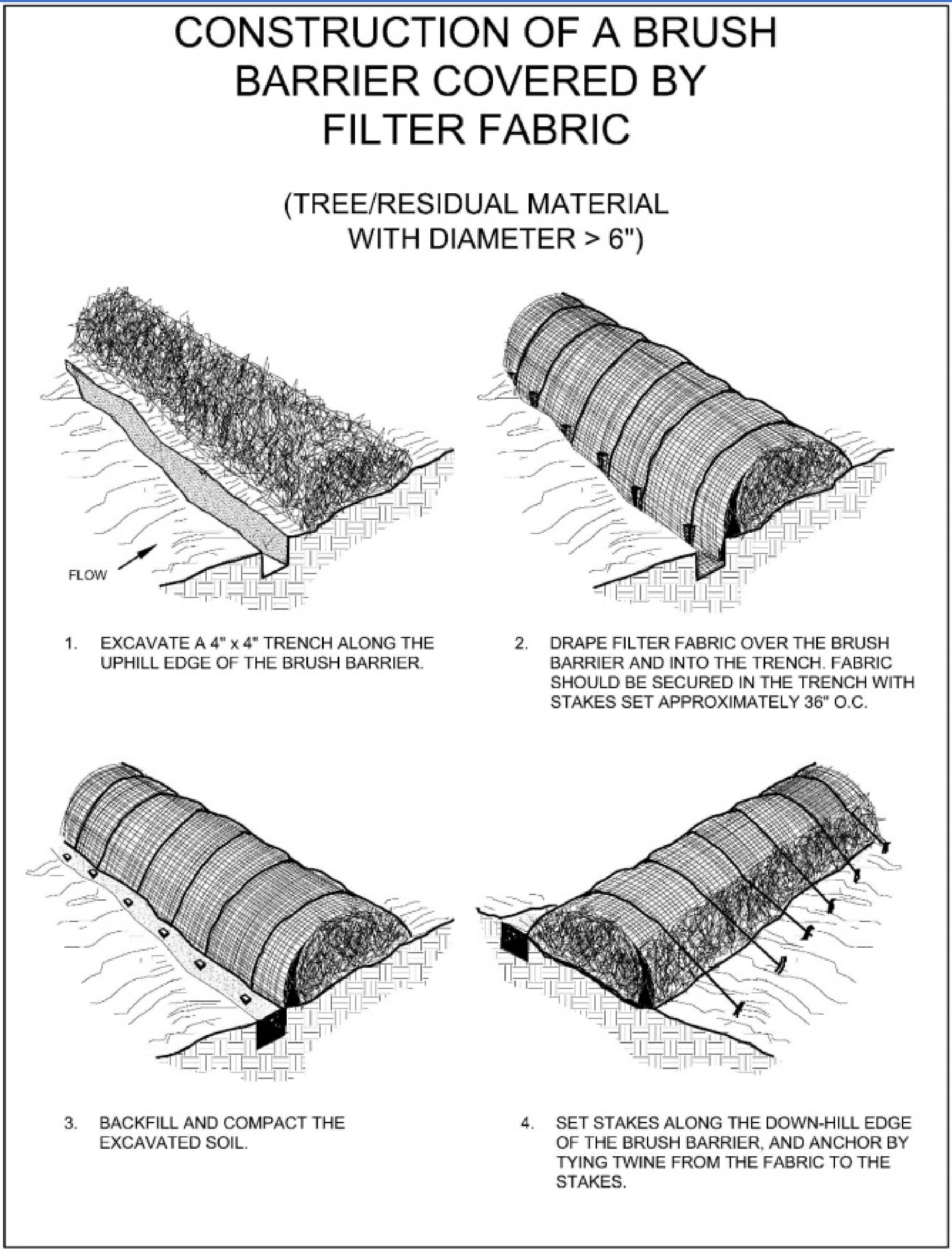
### 6.1 Brush Barrier Without Filter Fabric

1. Construct the height of a brush barrier to a minimum of 3 feet.
2. Construct the width of a brush barrier to a minimum of 5 feet at its base.
3. Construct the barrier by piling brush, stone, root mat, and other material from the clearing process into a mounded row on the contour. Do not use material larger than 6 inches in diameter to create the mound because the non-homogeneity of the mixture can lead to voids where sediment-laden runoff can easily pass.

### 6.2 Brush Barrier With Filter Fabric

1. Use filter fabric that meets the minimum physical requirements noted in Silt Fence (C-PCM-04).
2. Cut the filter fabric into lengths sufficient to lay across the barrier from its upslope base to just beyond its peak. Where joints are necessary, splice the fabric together with a minimum 6-inch overlap and securely seal.
3. Excavate a trench to 6 inches wide and 4 inches deep along the length of the barrier and immediately uphill from the barrier.
4. Drape the lengths of filter fabric across the width of the barrier, with the uphill edge placed in the trench and the edges of adjacent pieces overlapping each other.
5. Secure the filter fabric in the trench with stakes set approximately 36 inches on center.
6. Backfill the trench and compact the soil over the filter fabric.
7. Set stakes into the ground along the downhill edge of the brush barrier and anchor the fabric by tying twine from the fabric to the stakes.

*Figure C-PCM-03-1 Construction of A Brush Barrier Covered by Filter Fabric*




SOURCE: VA. DSWC

## 7.0 Operations and Maintenance Considerations

Inspect brush barriers regularly and after each rainfall to ensure that they retain their initial configuration and filtration function.

- Inspect barriers for scouring on the downslope of berms where ponded overflows occur.
- Inspect barriers and note areas where runoff has blown out or bypassed the barrier.
- Inspect barriers for washouts, undercutting (e.g., animal burrows), and end bypasses along barriers.
- Remove sediment deposits when they reach half the height of the barrier.

Repair or replace filter fabric that has been damaged due to collapse, tearing, decomposition, or other conditions immediately upon discovery.

If blowouts or bypasses occur during more than one significant rain event, then use rock filter outlets along dips and in low corners, amend barrier dimensions for the occurring flow, or use a different practice altogether.

## 8.0 References


PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

USEPA. 2021. Stormwater Best Management Practice – Brush Barrier. EPA-832-F-21-028A. December.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.


# C-PCM-04 Silt Fence

## 1.0 Definition

Silt fence (and its derivatives ***wire-supported (reinforced) and super silt fence***) is a temporary sediment barrier consisting of a synthetic filter fabric entrenched and stretched across and attached to supporting posts.

– CAD C-PCM-04 Construction of a Silt Fence (Without Wire Support)

– CAD C-PCM-04-2 Construction of a Silt Fence (With Wire Support)

## 2.0 Purpose and Applicability of Best Management Practice

Silt fence intercepts and detains small amounts of sediment from disturbed ground areas during construction to prevent sediment from leaving the site. Silt fence decreases the water velocity of sheet flow and low-level channel flows to moderate-level channel flows.

Super silt fence is used to control runoff from some small, disturbed areas where the maximum slope lengths for standard silt fence and wire-supported (reinforced) silt fence cannot be met and space is insufficient for construction of sediment traps or basins.

Silt fence and its derivatives (wire-supported (reinforced) and super silt fence) are not to be used as check dams in any application.

## 3.0 Planning and Considerations

Use silt fence downstream or below disturbed areas where erosion would occur in the form of sheet and rill erosion.

Do not use silt fence where rock or other hard surface prevents the full and uniform depth anchoring of the barrier.

Do not use super silt fences where rock or rocky soil prevent the full and uniform anchoring of the fence or proper installation of the fence posts.

Only use super silt fence where access exists or can be made for the construction equipment required to install and remove the chain link fencing.

Super silt fence chain link and posts may be reused on multiple projects and may present a more cost-effective alternative to silt fence.

Super silt fences can mitigate sheet flow from disturbed areas to sinkholes and other karst features.

Do not use this BMP in areas of concentrated flow.

Reinforced or super silt fence may be used in areas where there is a high potential for physical stress, as at the bottoms of steep fills, where the silt fence may be impacted by loose fill material or dirt clods may roll down the slope face during grading.

Reinforced and super silt fence will resist breakage and overturning from physical impacts much better than regular silt fence and will require much less maintenance.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

9VAC25-875-560

**Erosion Control Efficiency: LOW**

**Sediment Removal Efficiency: MEDIUM**

**Table C-PCM-04-1 Typical Flow Rates and Filtering Efficiencies of Perimeter Controls**

| Material | Flow Rate (gallon/minute/foot) | Total Solids Removal Efficiency (%) | Total Suspended Solids Removal Efficiency (%) | Turbidity Reduction (%) |
|---|---|---|---|---|
| Mulch Filter Berm[a] | 0.47 | 54.8 | 51.3 | 8.1 |
| Straw Bale[a] | 0.46 | 65.1 | 53.8 | 11.8 |
| 8-inch Compost Filter Sock[a] | 0.37 | 84.3 | 75.9 | 28.6 |
| 12-inch Compost Filter Sock[a] | 0.37 | 85.0 | 84.9 | 19.1 |
| Silt Fence | 0.11 | 89.0 | 87.0 | 76.0 |

Footnote:

a. Runoff of 2.9 inches on a 2,500-square-foot watershed to replicate maximum spacing requirements for silt fence typically used for sediment control on disturbed soils for 10% slope (Faucette et al. 2008.).

Source for Mulch Filter Berm, Straw Bale, and Compost Filter Sock: Faucette et al. 2009.

Source for Silt Fence: Faucette et al. 2008.

## 5.0 Design Criteria

Design silt fence and its derivations in accordance with Figure C-PCM-04-1 Maximum Slope Length for Silt Fence.

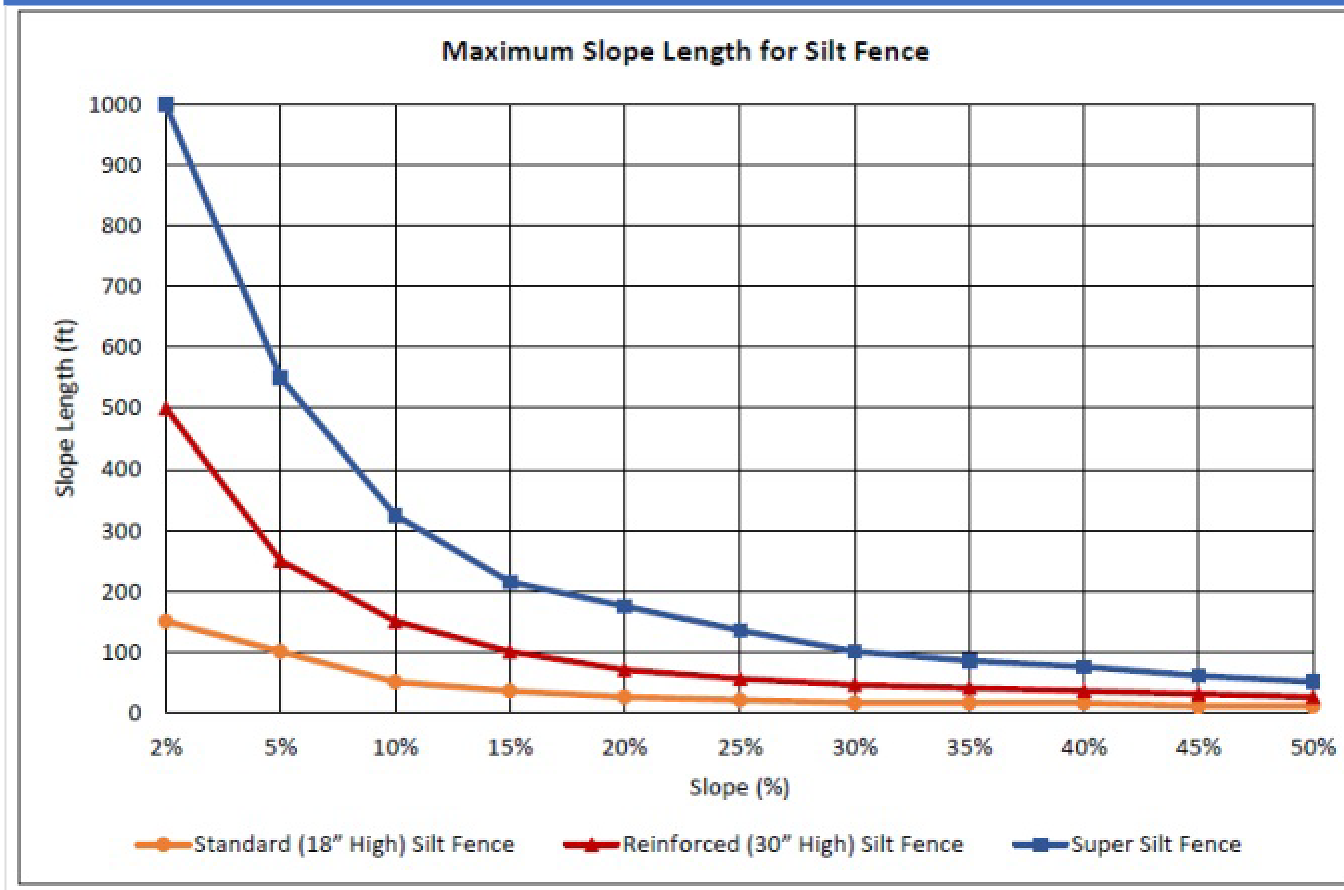
As with straw bale barriers, locate silt fence at least 5 to 7 feet beyond the bases of disturbed slopes with grades greater than 7 percent.

Do not exceed the maximum slope length in existing, temporary, or final grade above any silt fence at any time during the construction, as shown in Table C-PCM-04-2 Maximum Slope Length (feet) Above Fence. The slope length shown is the distance from the fence to the drainage divide or the nearest upslope channel.

If a super silt fence is used to mitigate sheet flow to sinkholes, the fence should be installed around the sinkhole's outer edge ("parapet") within 1 to 2 feet outside the slope in the parapet.

Trenchless silt fence (Specification BMP C-ENV-10) may be used in areas where existing wooded vegetation is to remain and trenched installation would otherwise damage the root ball.

***Figure C-PCM-04-1 Maximum Slope Length for Silt Fence***




*Source: Faucette et al. 2008.*

| Table C-PCM-04-2 Maximum Slope Length (feet) Above Fence | | | |
|---|---|---|---|
| Slope (%) | Standard (18 inches High) Silt Fence | Reinforced (30 inches High) Silt Fence | Super (33 inches High) Silt Fence |
| 2 (or less) | 100 | 500 | 1000 |
| 5 | 100 | 250 | 550 |
| 10 | 50 | 150 | 325 |
| 15 | 35 | 100 | 215 |
| 20 | 25 | 70 | 175 |
| 25 | 20 | 55 | 135 |
| 30 | 15 | 45 | 100 |
| 35 | 15 | 40 | 85 |
| 40 | 15 | 35 | 75 |
| 45 | 10 | 30 | 60 |
| 50 | 10 | 25 | 50 |

Source: Pennsylvania Department of Environmental Protection (PADEP) 2012.

## 6.0 Construction Specifications

| Table C-PCM-04-3 Material Specifications for Silt Fence | |
|---|---|
| **Material Specifications for Silt Fence** | |
| Filter Fabric | Use filter fabric consisting of woven slit film silt fence and is certified by the manufacturer or supplier as conforming to the requirements noted in Table C-PCM-04-4.<br><br>Ensure fabric has the minimum properties required by state-specific or local specifications, whichever is more stringent. Ensure the fabric is in use no longer than the manufacturer's recommended life span and is replaced with new fabric after the life span has been exceeded.<br>Use fabric with a minimum width of 30 inches for standard silt fence or 36 inches or greater for reinforced and super silt fences. Ensure stakes are hardwood or equivalent steel ("U" or "T") stakes.<br><br>Use toe anchor trench measurements of a minimum of 4 inches vertical by 4 inches horizontal to anchor bottom of filter fabric into the ground.<br><br>A silt fence is replaced when clogged with sediment and can no longer be cleaned. Synthetic filter fabric containing ultraviolet ray inhibitors and stabilizers shall be used to provide a minimum of 6 months of expected usable construction life at a temperature range of 0 to 120 degrees Fahrenheit. |
| Stakes | If wooden stakes are used for silt fence construction, ensure the stake has a nominal diameter of 2 inches when oak is used and 4 inches when pine is used. Use wooden stakes with a minimum length of 5 feet.<br><br>If steel posts (standard "U" or "T" section) are used for silt fence construction, ensure the posts have a minimum weight of 1.33 pounds per linear foot and a minimum length of 5 feet. |
| Reinforced Silt Fence | Use wire reinforcement for reinforced silt fence using standard-strength filter fabric with a minimum of 14 gauge and a maximum mesh spacing of 6 inches. |
| Super Silt Fence | Install 2.5-inch-diameter galvanized or aluminum poles set at 10-foot maximum spacing. Install poles at a minimum depth of 24 inches below the ground surface and extend a minimum of 33 inches above ground.<br><br>Ensure chain link is galvanized No. 11.5 Ga. steel wire with 2.25-inch opening, No. 11 Ga. aluminum coated steel wire in accordance with ASTM-A-491, or galvanized No. 9 Ga. steel wire top and bottom with galvanized No. 11 Ga. steel intermediate wires. |

**Table C-PCM-04-4 Physical Properties of Filter Fabric in Standard Silt Fence**

| Physical Property | Test | Requirements |
|---|---|---|
| Grab Strength Tensile | ASTM D 4632 | 124 lbs. |
| Elongation at Failure | ASTM D 4632 | 15% |
| CBR Puncture Resistance | ASTM D 6241 | 325 lbs. |
| Minimum Trapezoidal Tear Strength | ASTM D 4533 | 45 lbs. |
| Apparent Opening Size – U.S. Standard Sieve | ASTM D 4751 | 30 |

| Table C-PCM-04-4 Physical Properties of Filter Fabric in Standard Silt Fence | | |
|---|---|---|
| **Physical Property** | **Test** | **Requirements** |
| Flow Through Rate | ASTM D 4491 | 10 gallons/minute/square foot |
| Minimum Ultraviolet (UV) Residual | ASTM D 4355 | 70% |

**Notes:**

Source: PADEP 2012, Table 4.3, p.75.

ASTM = ASTM International

CBR = California bearing ratio

lbs. = pounds

| Table C-PCM-04-5 Physical Properties of Filter Fabric in High-Performance Silt Fence | | |
|---|---|---|
| **Physical Property** | **Test** | **Requirements** |
| Grab Strength Tensile | ASTM D 4632 | 180 lbs. |
| Elongation at Failure | ASTM D 4632 | 15% |
| CBR Puncture Resistance | ASTM D 6241 | 650 lbs. |
| Minimum Trapezoidal Tear Strength | ASTM D 4533 | 60 lbs. |
| Apparent Opening Size – U.S. Standard Sieve | ASTM D 4751 | 30 |
| Flow Through Rate | ASTM D 4491 | 129 gallons/minute/square foot |
| Minimum Ultraviolet (UV) Residual | ASTM D 4355 | 80% |

**Notes:**

Source: Colonial Construction Materials 2022.

ASTM = ASTM International

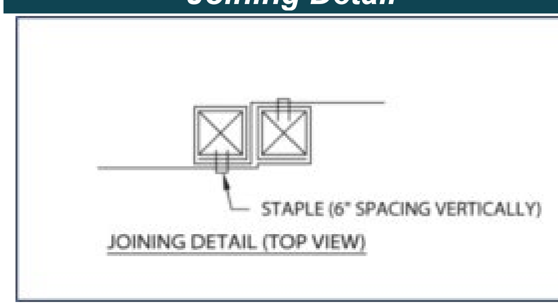
CBR = California bearing ratio

lbs. = pounds

**Installation for Standard and Reinforced Silt Fence**

1. Install silt fence (after trenching) a minimum height of:
   a. 18 inches above the original ground surface for standard silt fence; and
   b. 30 inches above the original ground surface for reinforced silt fence and does not exceed 34 inches above ground elevation.
2. Turn the fence uphill at 45-degree angles at the end of each fence run to prevent run-around bypass.
3. Where silt fence cannot be installed along the contour, J-hooks should be used at the end of each fence run.
4. Purchase the filter fabric in a continuous roll cut to the length of the barrier to avoid the use of joints.

***Figure C-PCM-04-1 Silt Fence Fabric Joining Detail***




*Source: Tahoe Regional Planning Agency 2014*

5. At fabric ends, wrap both ends around the support stake and staple (see Figure C-PCM-04-1). If the fabric comes already attached to the stakes, hold the end stakes together while the fabric is wrapped around the stakes at least one revolution (360 degrees) before driving the stakes.
6. Excavate a trench approximately 4 inches wide and 4 inches deep on the upslope side of the proposed location of the measure.
7. When wire support is used (reinforced silt fence), standard-strength filter fabric may be used. For this type of installation, place posts a maximum of 10 feet apart (see Figure C-PCM-04-2). Fasten the wire mesh fence securely to the upslope side of the posts using heavy-duty wire staples at least 1 inch long, tie wires, or hog rings. Extend the wire into the trench a minimum of 2 inches and do not extend more than 34 inches above the original ground surface. Staple or wire the standard-strength fabric to the wire fence and extend 8 inches of the fabric into the trench. Do not staple the fabric to existing trees.
8. When wire support is not used (standard silt fence or high-performance silt fence), use extra-strength filter fabric. Place posts for this type of fabric a maximum of 6 feet apart (see Figure C-PCM-04-3). Fasten the filter fabric securely to the upslope sides of the posts using 1-inch-long (minimum) heavy-duty wire staples or tie wires and extend 8 inches of the fabric into the trench. . This method of installation is more commonplace than the use of the reinforced silt fence. Do not staple the fabric to existing trees
9. When attaching two silt fences, first place the end post of one fence inside the end post of the other fence. Rotate both posts at least 180 degrees in a clockwise direction to create a tight seal with the fabric material. Drive both posts a minimum of 18 inches into the ground and bury the flap in a trench.
10. If a silt fence is to be constructed across a ditch line or swale, ensure the measure is of sufficient length to eliminate end-flow, and the plan configuration resembles an arc or horseshoe with the ends oriented upslope (see Figure C-PCM-04-3). Use extra-strength filter fabric for this application with a maximum 3-foot spacing of posts.
11. Drive stakes a minimum of 18 inches below ground surface.
12. Backfill and compact the 4-inch by 4-inch trench with soil over the filter fabric.
13. Remove the silt fence when the fence has served its useful purpose, but not before the upslope area has been permanently stabilized.

**Installation for Super Silt Fence**

1. Excavate an 8-inch-deep trench, minimizing the disturbance on the downslope side, with the bottom of the trench at level grade.
2. Install the chain link fence in the downslope side of the trench with the fence on the upslope side of the support poles. Install 2.5-inch- diameter galvanized or aluminum poles set at 10-foot maximum spacing. Install poles at a minimum depth of 24 inches below the ground surface and extend a minimum of 33 inches above ground. A posthole drill may be necessary to install poles appropriately for most sites. Poles do not need to be set in concrete.

3. Fasten chain link fence securely to fence posts with wire ties.
4. Ensure chain link is galvanized No. 11.5 Ga. Steel wire with 2.25-inch opening, No. 11 Ga. Aluminum coated steel wire in accordance with ASTM-A-491, or galvanized No. 9 Ga. Steel wire top and bottom with galvanized No. 11 Ga. Steel intermediate wires. Install No. 7 gage tension wire horizontally through holes at the top of the chain link fence or attach with hog rings, wire fasteners, staples, or preformed clips at 5-foot (maximum) centers.
5. Stretch filter fabric and securely fasten to the fence with wire fasteners, staples, or preformed clips. Extend the fabric a minimum of 33 inches above the ground surface. Ensure the filter fabric width is a minimum of 42 inches.

Super Silt Fence Source: PADEP 2012, p.82

6. Fasten the filter fabric securely to the chain link fence with fasteners, staples, or preformed clips spaced horizontally 24 inches at the ground surface, top, and midsection.
7. When attaching two super silt fences, the overlap joining method should be used. See Figure C-PCM-04-3.
8. Place the fabric toe in the bottom of the trench, then backfill and compact the trench.
9. Remove and properly dispose of super silt fence when the disturbed area tributary to the fence is permanently stabilized.

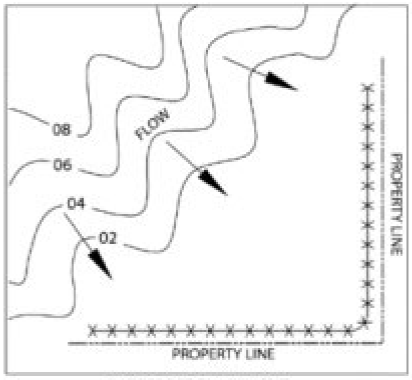
## 7.0 Operations and Maintenance Considerations

Inspect silt fences immediately after each rainfall and at least daily during prolonged rainfall. Make any repairs immediately.

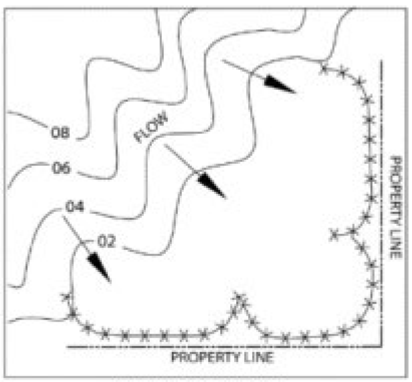
Pay close attention to the repair of damaged silt fence resulting from end runs and undercutting. This is commonly a sign the fence has either been improperly installed or is placed in a less than optimal location. If the fence cannot be relocated, then more frequent inspections will be warranted.

Replace the fabric promptly if the fabric on a silt fence decomposes or becomes ineffective before the end of the expected usable life and the barrier is still necessary.


*Silt Fence Failure*




INCORRECT PLACEMENT
DO NOT LAYOUT PERIMETER CONTROL SILT FENCES ALONG PROPERTY LINES. ALL SEDIMENT-LADEN RUNOFF WILL CONCENTRATE AND OVERWHELM THE SYSTEM.



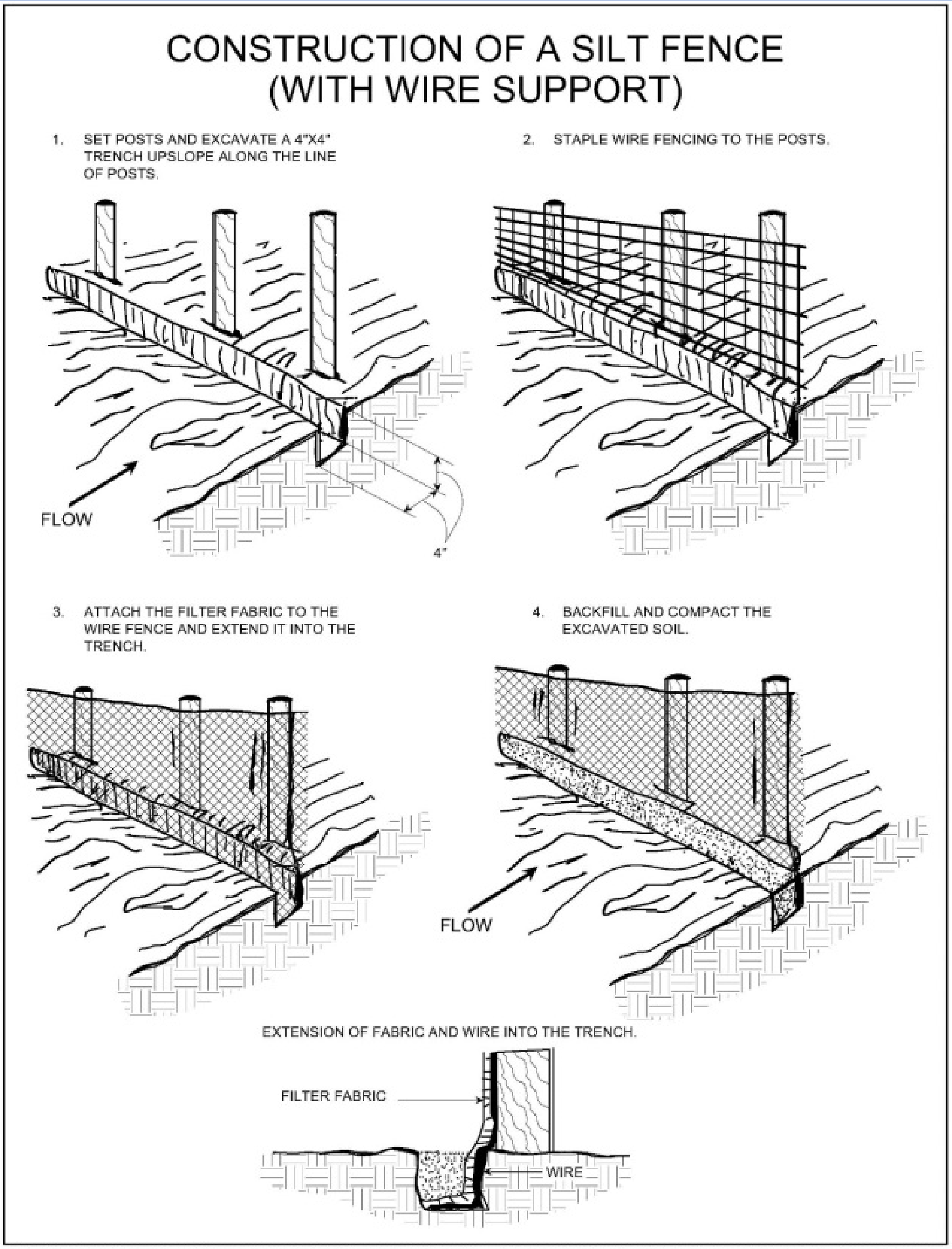

CORRECT PLACEMENT
BREAK-UP SILT FENCE INTO SECTIONS TO PREVENT SEDIMENT-LADEN RUNOFF FROM CONCENTRATING AND OVERWHELMING THE SYSTEM.

Remove trash, floatables, and large sediment deposits after each storm event and when deposits reach approximately one half the height of the barrier.

Dress to conform to existing grade, prepare, and seed any sediment deposits remaining in place after the silt fence is no longer required.

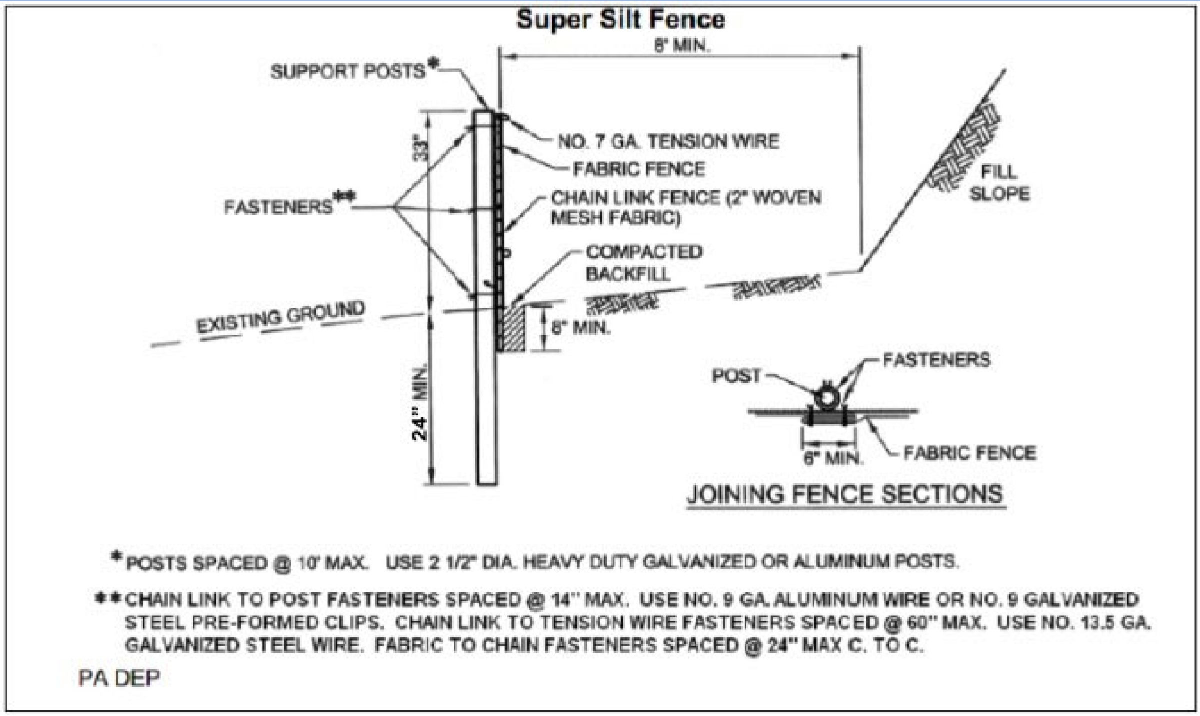
Where silt fence or any of its derivatives have failed because of concentrated runoff, a rock filter outlet (Specification BMP C-SCM-08) must be placed at the location. **Do not reinstall using the compromised practice.**

## *Figure C-PCM-04-2 Construction of Silt Fence with Wire Support Installation*




SOURCE: ADAPTED FROM INSTALLATION OF STRAW AND FABRIC FILTER BARRIERS FOR SEDIMENT CONTROL, SHERWOOD & WYANT

**Figure C-PCM-04-3 Super Silt Fence Installation**




*Source: Adapted from PADEP 2012, Standard Construction Detail # 4-10, p.84.*

## 8.0 References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# C-PCM-05 Compost Filter Sock

## 1.0 Definition

Compost filter sock, also called a filter log, is a temporary sediment control practice consisting of a biodegradable or photodegradable mesh tube filled with a coarse compost media to filter sediment and other pollutants associated with construction and prevent their migration offsite.

*Source: Gilliland Energy 2023*

## 2.0 Purpose and Applicability of Best Management Practice

Compost filter socks can be used in many construction site applications where erosion will occur in the form of sheet erosion. Compost filter socks are a best management practice (BMP) used both at the site perimeter and within the construction areas. These socks may be filled after placement by blowing compost into the tube pneumatically or filled at a staging location and moved into its designed location. Acceptable locations where compost filter socks can be applied include:

- Site perimeters;
- Below disturbed areas subject to sheet runoff with minor sheet or rill erosion;
- Above graded slopes to serve as a diversion berm;
- Check dams;
- Along the toes of stream and channel banks;
- Around area drains or inlets located in a storm drain system;
- Around sensitive trees where trenching of silt fence is not beneficial for tree survival or may unnecessarily disturb established vegetation; and
- On paved surfaces where trenching of silt fence is impossible.

## 3.0 Planning and Considerations

Compost quality is an important consideration when designing a compost filter sock. Use of sanitized, mature, biologically stable compost ensures that the compost filter sock performs according to design, has no identifiable feedstock constituents or offensive odors, and minimizes soluble nutrient loss.

Compost filter socks can be used in conjunction with land-disturbing activities where erosion will occur in the form of sheet erosion and there is no concentrated flow of stormwater flowing to the sock.

In areas with steep slopes and/or rocky terrain, ensure that soil conditions are such that good continuous contact between the sock and the soil is maintained throughout its length. Provide stakes, as necessary, along the length of the sock to secure to the slope and prevent movement.

For use on impervious surfaces, such as road pavement or parking areas, provide proper anchorage to prevent shifting of the sock or separation of the contact between the sock and the pavement.


*Source: GSWCC*

These socks may be filled after placement by blowing compost into the tube pneumatically, filled at a staging location and moved into its designed location, or purchased pre-filled with compost on pallets. Note that straw wattles are not a substitute for compost filter socks, as straw wattles are not the same control measures.

The anticipated functional life of a biodegradable filter sock should be 6 months; for photodegradable socks, it should be 1 year. Projects with disturbances anticipated to last longer than the functional life of a sock should plan to replace the socks periodically or use another type of BMP.

Compost filter socks may also be used for r other filtering or trapping purposes, such as with Inlet Protection (C-SCM-04), Concrete Washout Pit (C-SCM-13), and Temporary Sediment Trap (C-SCM-11).

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any land-disturbing activity and will be made functional before upslope land disturbance takes place.

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

Use compost filter socks with a minimum diameter of 12 inches, unless being used in the following applications, in which case a minimum diameter of 8 inches is required:

- Residential development on lots of 0.25 acre or less or
- Commercial developments of less than 10,000 square feet total lot area, where the life of the project is less than or equal to 6 months.

As with other perimeter controls and sediment barriers, place filter socks parallel to the contour with either end of the sock extended for 8 feet at a 45-degree angle to prevent end-arounds.

Do not exceed the maximum slope lengths above a compost filter sock shown in Table C-PCM-05-1.

When placed, ensure the flat dimension of the sock is at least 1.5 times the nominal diameter.

Do not exceed the maximum drainage area of 0.5 acre for every 100 linear feet of compost filter sock (Keener et al. 2007).

**Table C-PCM-05-1 Design Parameter of Sock Thickness**

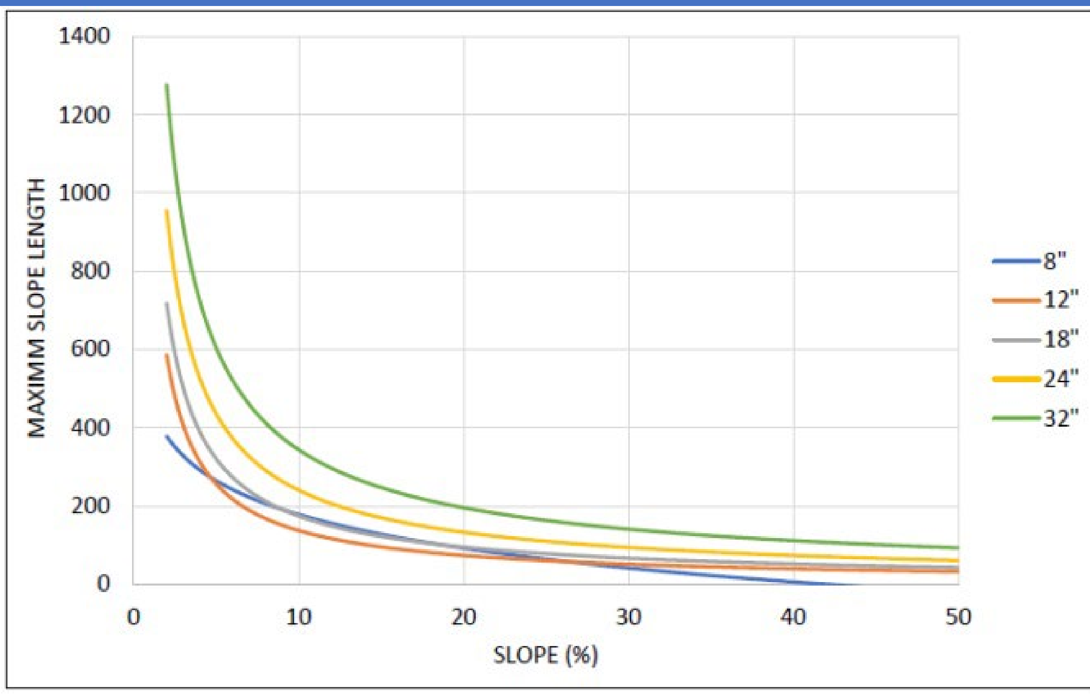
**Maximum Slope Lengths Above Compost Filter Sock**

| Diameter (inches) | Slope (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 20 | 25 | 33 | 50 |
| | Length (feet) | | | | | | |
| 8 | 378 | 264 | 177 | 91 | 64 | 29 | -- |
| 12 | 586 | 256 | 137 | 73 | 60 | 47 | 32 |

| Table C-PCM-05-1 Design Parameter of Sock Thickness | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum Slope Lengths Above Compost Filter Sock | | | | | | | |
| Diameter (inches) | Slope (%) | | | | | | |
| | 2 | 5 | 10 | 20 | 25 | 33 | 50 |
| | Length (feet) | | | | | | |
| 18 | 718 | 321 | 174 | 95 | 78 | 61 | 42 |
| 24 | 956 | 436 | 240 | 133 | 110 | 86 | 60 |
| 32 | 1,277 | 605 | 344 | 195 | 163 | 130 | 93 |

Source: Adapted from Florida Erosion and Control Designer and Reviewer Manual, Pennsylvania Department of Environmental Protection Erosion and Sediment Control Pollution Control Program Manual, North Carolina Erosion and Sediment Control Planning and Design Manual, Filtrexx Federal Specifications for Compost Filter Socks for Sediment & Erosion Control, and the United States Department of Agriculture.

*Figure C-PCM-05-1 Maximum Slope Lengths Above Compost Filter Sock*




## 6.0 Construction Specifications

| Table C-PCM-05-2 Compost Sock Fabric Minimum Specifications | | | | | |
|---|---|---|---|---|---|
| **Material Type** | **3 mil HDPE** | **5 mil HDPE** | **5 mil HDPE** | **Multi-Filament Polypropylene (MFPP)** | **Heavy Duty Multi-Filament Polypropylene (HDMFPP)** |
| **Material Characteristics** | **Photo-degradable** | **Photo-degradable** | **Bio-degradable** | **Photo-degradable** | **Photo-degradable** |
| Sock Diameters (inches) | 12<br>18 | 8<br>12<br>18<br>24<br>32 | 12<br>18<br>24<br>32 | 12<br>18<br>24<br>32 | 12<br>18<br>24<br>32 |
| Mesh Opening (inches) | 0.375 | 0.375 | 0.375 | 0.375 | 0.125 |
| Tensile Strength | 26 psi | 26 psi | 26 psi | 44 psi | 202 psi |
| Ultraviolet Stability % Original Strength (ASTM G-155) | 23% at 1,000 hour | 23% at 1,000 hour | | 100% at 1,000 hour | 100% at 1,000 hour |
| Minimum Functional Longevity | 6 months | 9 months | 6 months | 1 year | 2 years |
| **Two-ply systems** | | | | | |
| Inner Containment Netting | HDPE biaxial net<br>Continuously wound<br>Fusion-welded junctures<br>0.75-inch x 0.75-inch maximum aperture size | | | | |
| Outer Filtration Mesh | Composite polypropylene fabric (woven layer and non-woven fleece mechanically fused via needle punch)<br>0<br>1875-inch maximum aperture size | | | | |
| Sock fabrics composed of burlap may be used on projects lasting 6 months or less. | | | | | |

Source: Filtrexx & JMD

“ = inch(es)

HDPE = high-density polyethylene

psi = pounds per square inch

Source compost that is a well decomposed, weed-free organic matter derived from agriculture, food, stump grindings, and yard or wood/bark organic matter sources with no objectionable odors.

Ensure the compost is aerobically composted.

Ensure the compost product does not resemble the raw material from which it was derived.

Wood and bark chips, ground construction debris, or reprocessed wood products are not acceptable as the organic component of the mix.

Obtain compost with the physical parameters that comply with the standards in Table C-PCM-05-3.

Provide certification that the compost meets the standards in Table C-PCM-05-3.

| Table C-PCM-05-3 Compost Material Standards | |
|---|---|
| Organic Matter Content | 25% - 100% (dry weight basis) |
| Organic Portion | Fibrous and elongated |
| pH | 6.0 - 8.0 |
| Moisture Content | 30% - 60% |
| Particle Size | 99% passing a 2-inch screen and<br>10 - 50% passing a 0.375-inch screen |
| Soluble Salt Concentration | 5.0 Deci Siemens per meter (dS/m; millimho per centimeter [mmhos/cm])<br>maximum |
| Source: SAG / NYS | |

## 7.0 Operations and Maintenance Considerations

Do not permit traffic to cross compost filter socks. Design breaks in the barriers for internal circulation and movement of equipment.

Remove accumulated sediment when it reaches half the above-ground height of the sock and dispose in accordance with the erosion and sediment control plan.

Inspect socks weekly and after each runoff event. Repair damaged socks in the manner required by the manufacturer or replace within 24 hours of inspection notification.

Replace compost filter socks according to the manufacturer's frequency recommendations.

Upon stabilization of the area contributory to the sock, remove the stakes. The compost filter sock may be left in place and vegetated or removed in accordance with the stabilization plan. For removal, the mesh can be cut, and the compost spread as an additional mulch to act as a soil supplement. ***If a rubber-fill sock is used, remove the sock and dispose offsite.***

Improperly Maintained Compost Filter Sock
Source: Michael D. DeVuono, PE

## 8.0 References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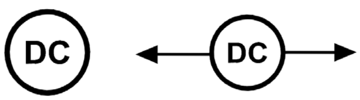
# C-SCM-01 Dust Control

## 1.0 Definition

Dust control is the reduction of movement of dust on the ground surface and in the air during land disturbance, demolition, and construction.




## 2.0 Purpose and Applicability of Best Management Practice

Dust control is used to prevent surface and air movement of dust from exposed soil surfaces and reduce the presence of airborne substances that may pose health hazards, traffic safety problems, or harm animal or plant life.

Dust control applies to areas subject to dust on the ground surface and in the air where on-site and off-site damage is likely to occur if preventive measures are not taken.

## 3.0 Planning and Considerations

Construction inevitably results in the exposure and disturbance of soil. Fugitive dust is emitted both during the activities (i.e., excavation, demolition, vehicle traffic, human activity) and because of wind erosion over exposed earth surfaces. Large quantities of dust are typically generated in “heavy” construction, road and street construction and subdivision, commercial, or industrial development, which involve disturbance of significant areas of the soil surface. Research of construction sites has established an average dust emission rate of 1.2 tons/acre/month for active construction. Earth-moving activities comprise the major source of construction dust emissions, but traffic and disturbance of the soil also generate significant dust emissions.

In planning for dust control, limiting the amount of soil disturbance at any one time should be a key objective. Therefore, phased clearing and grading operations and the use of temporary stabilization in accordance with MS-1 (9VAC25-875-560) can significantly reduce dust emissions. Undisturbed vegetative buffers (minimum 50-foot widths) left between graded and protected areas can also be very helpful in dust control.

Where evaporation rates are high, water application to exposed soils may require near constant attention. If too much water is applied, application may create excess runoff from the site and possibly create conditions under which vehicles could track mud onto public roads.

Use chemical applications sparingly and only on mineral soils (not muck soils) because its misuse can create additional surface water pollution from runoff or contaminate groundwater. Chemical applications might also pose a health risk if excessive amounts are used.

During drought, give special attention to controlling dust by employing vegetative cover, mulch, tillage, and spray-on adhesives as temporary measures during construction. Sprinkling the site with water to control dust is a common practice (although not recommended during extreme drought conditions).

## 4.0 Stormwater Performance Summary

**MS-2** - During construction of the project, soil stockpiles and borrow areas shall be stabilized or protected with sediment trapping measures. The applicant is responsible for the temporary protection and permanent stabilization of all soil stockpiles on site as well as borrow areas and soil intentionally transported from the project site.

9VAC25-875-560

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

No formal design procedure is given for dust control.

## 6.0 Construction Specifications

### 6.1 Temporary Measures Used During Construction

| Table C-SCM-01-1 Design Criteria for Dust Control | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Vegetative Cover | In areas subject to little or no construction traffic, a vegetatively stabilized surface will reduce dust emissions. See Temporary Seeding (BMP C-SSM-09). |
| Mulch | When properly applied, mulch offers a fast, effective means of controlling dust. Mulch is not recommended for areas within heavy traffic pathways. Use binders or tackifiers to tack organic mulches. See Mulching (BMP C-SSM-11). |
| Tillage | This practice is designed to roughen the ground and bring clods to the surface. Use tillage as an emergency measure before wind erosion starts. Begin plowing on the windward side of the site. Chisel-type plows spaced about 12 inches apart, spring-toothed harrows, and similar plows are examples of equipment that may produce the desired effect. |
| Irrigation | Irrigation is the most used dust control practice. The site is sprinkled with water until the surface is wet. Repeat as needed. Irrigation offers fast protection for haul roads and other heavy traffic routes. |
| Spray-On Adhesives | Significant progress has been made in recent years in the development of spray-on adhesive products. Most are effective on “mineral” soils and are ineffective on “muck” soils. These adhesives are derived from a variety of compounds, both organic and synthetic based. Many of the adhesives will withstand heavy traffic loads. The organic compounds include derivatives from pine tar and vegetable gum; synthetic compounds may be acrylic- or petroleum-based. Table C-SCM-01-2 list adhesives and provides corresponding information on mixing and application. |
| Stone | Crushed stone or coarse gravel can be used to stabilize roads or other areas during construction. See Construction Road Stabilization (BMP C-SCM-02). |
| Barriers | A board fence, wind fence, sediment fence, or similar barrier can help to control air currents and blowing soil. Place barriers perpendicular to prevailing air currents at intervals of about 15 times the barrier height. Where dust is a known problem, existing windbreak vegetation should be preserved. |

| Table C-SCM-01-1 Design Criteria for Dust Control | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Calcium Chloride | Apply this chemical by mechanical spreader as loose, dry granules or flakes at a rate that keeps the surface moist but not so high as to cause water pollution or plant damage.<br>Application rates should be strictly in accordance with suppliers' specified rates. |

Table C-SCM-01-2 lists adhesives and provides information on mixing and application.

| Table C-SCM-01-2 Adhesives Used in Dust Control | | | |
|---|---|---|---|
| **Adhesive** | **Water Dilution (adhesive: water)** | **Type of Nozzle** | **Application Rate (gallons/acre)** |
| Anionic asphalt emulsion | 7:1 | Coarse Spray | 1,200 |
| Latex emulsion | 12.5:1 | Fine Spray | 235 |
| Resin in water | 4:1 | Fine Spray | 300 |
| Acrylic emulsion (non-traffic) | 7:1 | Coarse Spray | 450 |
| Acrylic emulsion (traffic) | 3.5:1 | Coarse Spray | 350 |

| Table C-SCM-01-4 Permanent Methods of Dust Control | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Permanent Vegetation | The application of Permanent Seeding (BMP C-SSM-09) and saving existing trees and large shrubs can help reduce movement of soil and air at construction sites. |
| Stone | Crushed stone or coarse gravel can be used as a permanent cover, which will control soil emissions. |

## 7.0 Operations and Maintenance Considerations

Maintain dust control measures through dry weather until all disturbed areas have been stabilized.

Because the success of dust controls depends on specific site and weather conditions, inspection and maintenance requirements are unique for each site. However, dust control measures involving application of either water or chemicals require more monitoring than structural or vegetative controls to remain effective.

Inspect structural controls for deterioration regularly to ensure the controls are still achieving its intended purpose.

## 8.0 References

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

# C-SCM-02 Construction Road Stabilization

## 1.0 Definition

Construction road stabilization is the stabilization of temporary construction access routes, onsite vehicle transportation routes, and construction parking areas.

## 2.0 Purpose and Applicability of Best Management Practice

This specification applies to temporary or permanent access roads and parking areas for use by construction traffic. Additionally, this specification applies to (but is not limited to) streets and highways, parking areas, and other traffic areas immediately after grading to reduce erosion caused by vehicles during wet weather conditions.

This construction best management practice (BMP) is used to:

1. Reduce the erosion of temporary roadbeds caused by construction traffic during wet weather.
2. Reduce the erosion and subsequent regrading of permanent roadbeds between the time of initial grading and final stabilization.
3. Reduce ground compaction from vehicular traffic.
4. Reduce excess disturbance to root zones and shrubs within ecologically sensitive environments (e.g., wetlands, streams, riparian buffers, forested grounds).

## 3.0 Planning and Considerations

Areas graded for construction vehicle transport and parking purposes are especially susceptible to erosion. The exposed soil surface is continually disturbed, leaving no opportunity for vegetative stabilization. Such areas also tend to collect and transport runoff waters along their surfaces. During wet weather, these exposed areas often become muddy and can generate significant quantities of sediment-laden runoff that may pollute downgradient streams or cause sediment to be transported offsite on the wheels of construction vehicles. During wet weather, dirt roads can be unusable.

Construction of a conventional haul road through forested and/or soft ground results in additional ground disturbance and a potential source of sediment into adjacent streams and waterways.

Both stone and temporary timber deck mats are suitable stabilization materials for a construction access road.

If construction or project access roads are located within 50 feet of and drain to  a sinkhole or other karst feature capable of conveying water underground, the edge of the road near the karst feature should be protected using super silt fence (Specification BMP C-PCM-04).

To avoid erosion, compaction, and runoff problems when siting a construction access route or parking area, follow the planning steps recommended by American Electric Power Service Corporation (AEP 2018, p.72) and: :

1. Coordinate with resources agencies (e.g., Virginia Department of Conservation and Recreation, Virginia Department of Wildlife Resources, Virginia Department of Historic Resources) to determine the appropriate areas for access routes, taking into consideration aquatic resources and sensitive areas including karst resources (AEP 2018).
2. Evaluate information from the Natural Resources Conservation Service (NRCS) Web Soil Survey, U.S. Geological Survey, National Wetlands Inventory, and other available resources to determine the most appropriate areas for access routes and/or parking based on areas of erodible soils, karst topography, wet or rocky areas, and areas with seasonally high water tables.
3. Evaluate the site topography to locate natural benches and flatter slopes and use these areas for access routes and/or parking. Avoid long, steep road grades and narrow valleys.
4. Evaluate aquatic resources in the area to minimize stream and/or wetland crossings. Where crossings are unavoidable, consider the following:
    a. Cross at right angles to minimize the length of the crossing.
    b. Cross where the resource is narrowest and upland areas are most stable.
    c. Minimize the number of crossings.
    d. Leave a buffer zone of undisturbed ground between the road and resource, where the road runs parallel to the resource.
    e. Divert water from the road with a temporary diversion to prevent water running directly into the resource.
5. Where possible, use switchbacks to lessen the road grade on steeper sloped areas.
6. Locate roads and/or parking areas on stable geology that includes well-drained soils and rock formations that tend to dip into the slope. Avoid slumps and slide-prone areas characterized by steep slopes, highly weathered bedrock, clay beds, concave slopes, hummocky topography, or rock layers that dip parallel to the slope.
7. Ridge tops can be good places for roads if proper drainage can be constructed. Be aware that conditions may change when constructing during the dry season. Be prepared to add culverts after construction when hidden springs and streams start back up in the winter and spring.
8. If possible, build roads on the drier south- or west-facing slopes.

## 4.0 Stormwater Performance Summary

**MS-4: First-Step Measures** – When used appropriately, low-volume construction access roads and driveways will preserve the existing land conditions and topography and reduce erosion. Low-volume access roads and their culverts, diversions, outlet protection, and other used measures shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-17: Vehicular Tracking and Construction Entrances** – Where construction vehicle access routes intersect paved or public roads, provisions shall be made to minimize the transport of sediment by vehicular tracking onto the paved surface. Where sediment is transported onto a paved or public road surface, the road surface shall be cleaned thoroughly at the end of each day. Sediment shall be removed from the roads by shoveling or sweeping and transported to a sediment control disposal area. Street washing shall be allowed only after sediment is removed in this manner. This provision shall apply to individual development lots as well as to larger land-disturbing activities.

9VAC25-875-560

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: LOW**

## 5.0 Design Criteria

| Table C-SCM-02-1 Design Criteria for Construction Road Stabilization | |
|---|---|
| **Design Criteria for Construction Road Stabilization** | |
| Road Cross- Sections | Five road cross-sections are typically used in road construction: (1) crowned fill; (2) crowned turnpike; (3) outslope; (4) inslope with ditch; and (5) crowned and ditched (Figure C-SCM-02-1).<br>The choice of which cross-section to use depends on the drainage needed, soil stability, slope, and the expected volume of traffic on the road. The cross-sections can be used in combination as the terrain changes or as drainage issues are encountered.<br>• **Crowned Fill Section:** Use on flat ground where water standing on a road surface may be a problem.<br>• **Crowned Turnpike Section:** Use on low ground roads where fill is not available.<br>• **Outslope:** Use on moderate slopes for low-volume roads and stable soils. Outsloping can be more dangerous in wet and snowy weather.<br>• **Inslope with Ditch Section:** Use on steep hills, areas with fine-textured soils, winter logging roads, and where drainage is necessary.<br>• **Crowned and Ditched Section:** Use on high-volume roads on steep side hills. |
| Road Width | Construct roadbeds to be a minimum of 14 feet wide for one-way traffic and 20 feet wide for two-way traffic. |
| Alignment (Natural Resources Conservation Service 2021) | Adapt the gradient and horizontal alignment to the intensity of use, the mode of travel, the type of equipment and load weights, and the level of development. Frequent grade changes generally cause fewer erosion problems than long, continuous gradients.<br>Design horizontal curves and switchbacks with sufficient radius for trucks and other large vehicles to negotiate easily. Provide a radius no less than 35 feet for standard vehicles and 50 feet for tractor-trailers. Design the lengths of vertical curves, in feet, to use a minimum 'K' value of 10 in the design. |
| Road Grade | Road grade is the single most important factor in planning a low-volume road. Keep road grades to a minimum. If possible, do not exceed 10%. Exceeding these grades typically results in the transport of gravel from the roadbed and generally makes for poorly stabilized conditions. On steeper road grades, ruts form more easily and runoff velocities are higher, which causes gullies and rill erosion along the roadbed. |

| Table C-SCM-02-1 Design Criteria for Construction Road Stabilization | |
|---|---|
| **Design Criteria for Construction Road Stabilization** | |
| Road Embankment Side Slopes (Pennsylvania Department of Environmental Protection [PADEP] 2012) | Construct all cuts and fills to be 2H:1V or flatter to the extent possible. Minimize cuts and fills where possible. Long and/or high cut/fill slopes are often difficult to stabilize. In soils with low shear strength, these slopes also pose an increased potential for slope failures. Avoid cuts deeper than 3 feet and fill slopes higher than 5 feet where possible. Stabilize cut and fill slopes as soon as possible, but no more than seven (7) calendar days, after reaching final grade in accordance with Permanent Seeding (Specification BMP C-SSM-10) and Soil Stabilization Blankets and Matting (Specification BMP C-SSM-05). |
| Drainage Ditches | Provide drainage ditches as needed. The design and construction of drainage ditches shall be in accordance with Stormwater Conveyance Channel (Specification BMP C-ECM-09). |
| Stabilization | Clear the roadbed or parking surface of all vegetation, roots, and other objectionable material.<br><br>**Stone:** Apply a 6-inch course of Virginian Department of Transportation (VDOT) #1, #2, or #3 Coarse Aggregate immediately after grading or the completion of utility installation within the right-of-way. For additional stability, filter fabric may be applied to the roadbed surface before coarse aggregate placement. Design specifications for filter fabric are provided in Temporary Stone Construction Entrance (Specification BMP C-SCM-03). In “heavy duty” traffic situations, place stone at an 8- to 10-inch depth to avoid excessive dissipation or maintenance needs.<br><br>**Timber Mat Stabilization:** Typical timber matting will be manufactured hardwood board (usually oak or poplar), laminated pine board, plastic composite, or similar. Dimensions shall vary by manufacturer. Use timber matting on low gradient roads in wet areas. |

| Table C-SCM-02-1 Design Criteria for Construction Road Stabilization | |
|---|---|
| Design Criteria for Construction Road Stabilization | |
| Ditch Relief or Cross-Drain Culvert (PADEP 2012) | Ditch relief or cross-drain culverts are used on crowned or ditched roads to minimize the potential for erosion of roadside ditches as well as flooding of the roadway by reducing the volume of flow conveyed by the ditch. It is important to provide additional culverts at intervals along the roadway where runoff is being conveyed by a ditch.<br><br>Place ditch relief culverts with slopes of 2% to 4% to help keep the culvert clean and ensure water flow. Install culverts between 25 to 45 degrees to the centerline of the ditch to minimize turbulence at the inlet.<br><br>Size and space culverts according to Table C-SCM-02-2 for temporary culverts and Table C-SCM-02-3 for permanent culverts or size the culverts for the 10-year storm event based on the drainage area to the culvert.<br><br>The minimum diameter for any culvert is 12 inches unless other regulatory conditions apply. Otherwise, size the culvert to pass the flow from the 10-year storm event without overtopping the construction road. Extend the culvert 12 inches beyond the base of the road fill on both sides. Firmly pack fill around the culvert, especially the bottom half. Cover the top of the culvert with at least 12 inches of fill, more if heavy loads are anticipated on the road.<br><br>To be sure that no water bypasses the inlet, install a control backstop of earth, riprap, sandbags, or half-culvert sections on the downhill level of the inlet.<br>Do not discharge onto the side of a road fill. Provide suitable outlet stabilization; see Outlet Protection (Specification BMP C-ECM-15) and, where appropriate, Inlet Protection (Specification BMP C-SCM-04). |
| Temporary Right-of- Way Diversion | Temporary right-of-way diversions (Specification BMP C-ECM-07) may be used on construction access roads to direct surface water off the road into a constructed outlet but are not recommended for high-volume roads due to difficulty of moving equipment over the diversions (18 inches high with a 6-foot base width) and the need for continual maintenance due to damage from traffic. Temporary right-of-way diversions are useful on infrequently used roads.<br><br>Temporary right-of-way diversions used on active access roads will often require reinforcement with a log, steel pipe, or other support to maintain the integrity of the diversion between maintenance operations. Do not use temporary right-of-way diversions on in-sloping roadways where there is no opportunity to discharge runoff to either side. |

| Table C-SCM-02-1 Design Criteria for Construction Road Stabilization | |
|---|---|
| **Design Criteria for Construction Road Stabilization** | |
| Turnout (PADEP 2012) | Turnouts are channels that drain water away from roads or roadside ditches into well- vegetated areas. Turnouts are typically located along crowned roadways where runoff cannot sheet flow off the roadway. Like ditch relief culverts, the purpose of turnouts is to minimize the volume of water in a roadside ditch. Locate turnouts to take advantage of natural drainage courses or buffer areas where possible.<br><br>Grade the approach to a turnout on a 2% to 3% slope to allow constant drainage. Ensure that the spoil from turnout construction is not allowed to form a dam at the end of the turnout. Do not discharge water from a turnout directly into a stream or waterbody.<br><br>An excavated sump at the end of the turnout can effectively pond and settle out sediment before discharging to a vegetated buffer; however, discharges from a turnout should be handled as other concentrated discharges.<br><br>Where a suitable vegetative filter strip is not available to remove sediment, install a compost filter sock, rock filter, or other sediment removal BMP at the outlet of the turnout. Design discharges from a turnout to minimize erosion.<br><br>Consult Outlet Protection (Specification BMP C-ECM-15) for design guidance.<br><br>Stabilize the turnout as soon as possible after grading in accordance with Permanent Seeding (Specification BMP C-SSM-10) and Soil Stabilization Blankets and Matting (Specification BMP C-SSM-05). |
| Stream or Wetland Crossing | Refer to Stable Wetland Crossing (Specification BMP C-ENV-06) for temporary wetland crossing design specifications and Temporary Vehicular Stream Crossing (Specification BMP C-ENV-03) for temporary stream crossing design specifications.<br><br>Construction roads should not be constructed within sinkholes (as defined by a closed topographic depression) or over cave entrances. |

Source: AEP 2018, unless otherwise specified.

| Table C-SCM-02-2 Sizing and Spacing of Ditch Relief Culverts for Temporary Access Roads | | | | | | |
|---|---|---|---|---|---|---|
| **Sizing and Spacing of Ditch Relief Culverts for Temporary Access Roads** | | | | | | |
| **Road Grade (%)** | **Culvert Spacing[a] (feet)** | **Length of Upslope Drainage (feet)** | | | | |
| | | **<300** | **300 – 400** | **400 – 500** | **500 – 600** | **>600** |
| | | **Minimum Culvert Size (inches)** | | | | |
| 2 | 300 | 12 | 15 | 15 | 15 | 18 |
| 3 | 235 | 12 | 15 | 15 | 15 | 18 |
| 4 | 200 | 12 | 15 | 15 | 15 | 18 |
| 5 | 180 | 12 | 12 | 15 | 15 | 15 |

| Table C-SCM-02-2 Sizing and Spacing of Ditch Relief Culverts for Temporary Access Roads | | | | | | |
|---|---|---|---|---|---|---|
| Sizing and Spacing of Ditch Relief Culverts for Temporary Access Roads | | | | | | |
| 6 | 165 | 12 | 12 | 12 | 15 | 15 |
| 7 | 155 | 12 | 12 | 12 | 12 | 15 |
| 8 | 150 | 12 | 12 | 12 | 12 | 15 |
| 9 | 145 | 12 | 12 | 12 | 12 | 15 |
| 10 | 140 | 12 | 12 | 12 | 12 | 15 |
| 12 | 135 | 12 | 12 | 12 | 12 | 15 |

**Note:**

a. Culvert spacing may be adjusted slightly to take advantage of natural drainage courses.

Source: PADEP 2012, Table 3.3, p.31.

| Table C-SCM-02-3 Recommended Spacing of Ditch Relief Culverts (18-inch diameter Corrugated Metal Pipe) for Permanent Access Roads | | | | | |
|---|---|---|---|---|---|
| Recommended Spacing of Ditch Relief Culverts (18-inch diameter Corrugated Metal Pipe) for Permanent Access Roads | | | | | |
| | Soil Type in Ditch | | | | |
| Road Grade (%) | Gravels, Sandy Gravels, Aggregate Surfacing | Silty Gravels, Clayey Gravels | Plastic and Non-Plastic Inorganic Clays | Inorganic Silts, Silty or Clayey Sands | Sands, Silty Sands, & Gravelly Sands |
| | Maximum Culvert Spacing Feet[a] | | | | |
| 2 | 390 | 315 | 245 | 170 | 95 |
| 4 | 335 | 275 | 210 | 145 | 85 |
| 6 | 285 | 230 | 180 | 125 | 75 |
| 8 | 240 | 195 | 150 | 105 | 65 |
| 10 | 200 | 160 | 125 | 90 | 55 |
| 12 | 160 | 130 | 105 | 75 | 45 |
| 14 | 130 | 110 | 85 | 60 | 35 |

**Note:**

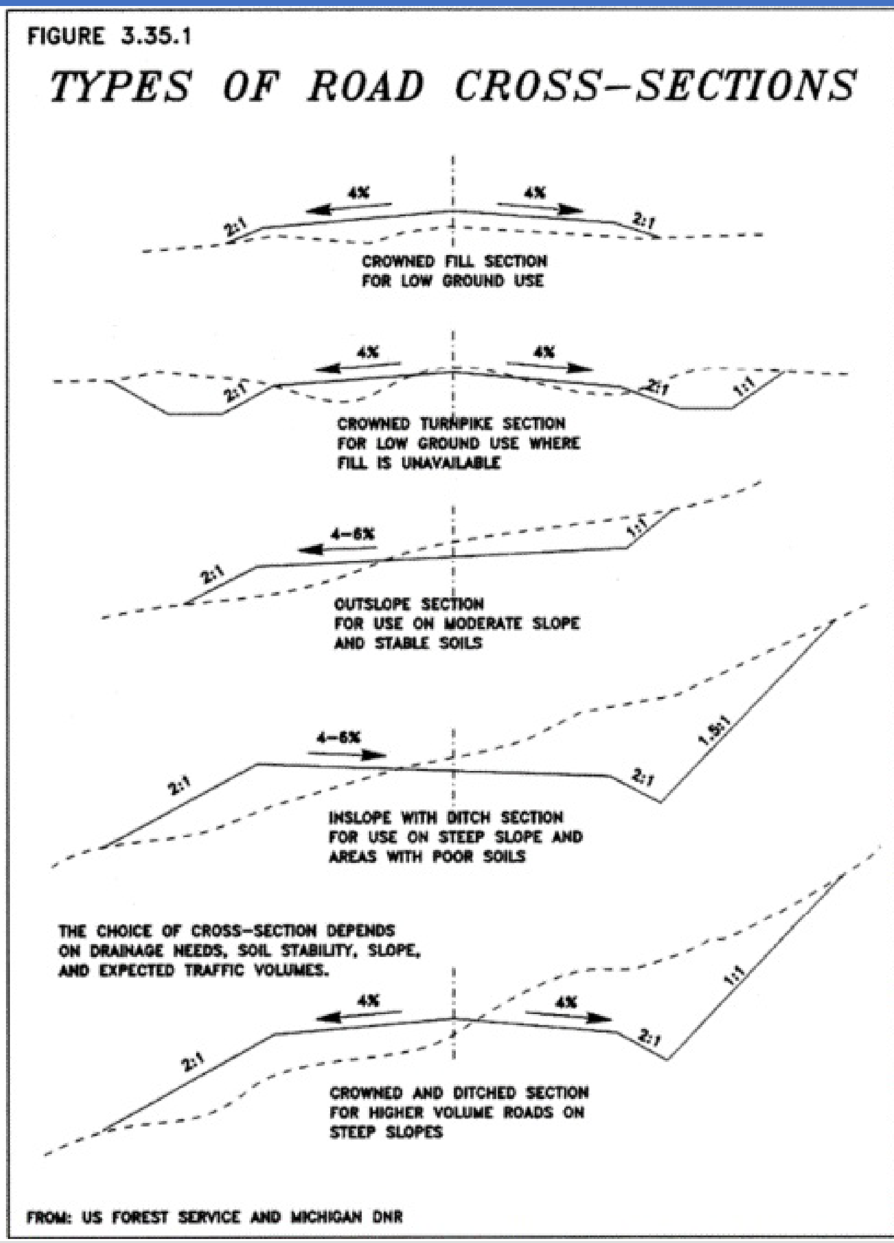
a. Culvert spacing may be adjusted slightly to take advantage of natural drainage courses.

Source: PADEP 2012, Table 3.4, p.32.

## 6.0 Construction Specifications

Before construction, install the appropriate erosion and sediment controls downgradient of the construction access road grading, including Compost Filter Socks (Specification BMP C-PCM-05), Silt Fence (Specification BMP C-PCM-04), Temporary Sediment Trap (Specification BMP C-SCM-11), Temporary Sediment Basin (Specification BMP C-SCM-12), and other structures. Upon completion of roadway or parking area grading, immediately stabilize cut and fill slopes.

***Figure C-SCM-02-1 Types of Cross Road Sections***




*Source: AEP 2018, Appendix B. AEP Erosion and Sediment Control Details: West Virginia BMP 3.35 – Access Road/Low Volume Road/Driveway, p.3.35-9.*

## 7.0 Operations and Maintenance Considerations

Inspect roadways and parking areas weekly and after each rainfall event. Inspect roadways and cut/fill slopes for gully or rill erosion or sloughing and scour in the ditches. If temporary right-of-way diversions or broad-based dips are used, ensure that the measures have been maintained and are deep enough to capture road surface runoff. If runoff overruns these measures, repair immediately. Inspect culverts, roadside ditches, and outlets and restore flow capacity as needed (AEP 2018).

*Example of Poorly Maintained Vehicular Route Stabilization*

Ensure that the proper cross-section is available, and outlets are stable. Fill low areas in travel treads and re-grade, as needed, to maintain road cross-section. Repair or replace surfacing materials as needed (AEP 2018).

Inspect roadside ditches and other drainage structures to ensure that the measures do not become clogged with silt or other debris. Remove accumulated debris as necessary to maintain flow capacity (AEP 2018).

Inspect timber mats to ensure the mats are installed correctly and functioning properly. Remove accumulated sediment as needed to ensure that it is not transported offsite. Immediately replace any severely damaged mats (Wetland Studies and Solutions, Inc. 2020; Dominion Energy 2019).

Inspect seeded areas adjacent to the roads and parking areas to ensure that vegetation is maintained (AEP 2018).

## 8.0 References


AEP. 2018. FY 2018 General Erosion and Sediment Control and Stormwater Management Specifications for the Construction and Maintenance of Electric Utility Lines. American Electric Power Service Corporation Environmental Services. March, revised. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/bmp-design-specifications.

Dominion Energy. 2019. Erosion and Sedimentation Control and Stormwater Management Control Standards and Specifications for Dominion Energy Electric Distribution. March. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/bmp-design-specifications.

Natural Resources Conservation Service. 2020. Conservation Practice Standard: Access Road, Code 560. National Standard 560-CPS-1. United States Department of Agriculture, Natural Resources Conservation Service. September. Available online at: https://www.nrcs.usda.gov/resources/guides-and-instructions/access-road-ft-560-conservation-practice-standard.

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

Virginia Department of Environmental Quality. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

Wetland Studies and Solutions, Inc. 2020. Erosion and Sediment Control Standards for Wetland and Stream Bank Construction Projects. WSSI #21698.01. Revised September 17. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/bmp-design-specifications.

# C-SCM-03 Temporary Stone Construction Entrance

## 1.0 Definition

A temporary stone construction entrance is a pad with a fabric filter liner underneath the stone located at points of vehicular ingress and egress on a construction site. There are several types of track-out controls that minimize the amount of sediment, such as dirt or mud, leaving or being tracked out from the construction site attached to vehicles.

– CAD C-SCM-03-1 Stone Construction Entrance

## 2.0 Purpose and Applicability of Best Management Practices

Construction entrances provide an opportunity for significant removal of mud from construction vehicle tires before they enter a public road, and, just as important, the soil adjacent to the paved surface can be kept intact. Temporary stone construction entrances reduce the tracking of mud onto paved public roads by motor vehicles or runoff and provide a stable entry to or exit from the construction site.

This practice applies where traffic leaves a construction site and moves directly onto a public road or other paved area.

## 3.0 Planning and Considerations

A fabric filter liner is used as a “separator” to minimize the dissipation of aggregate into the underlying soil due to construction traffic loads. If the action of the vehicles traveling over the gravel pad is not sufficient to remove most of the mud, or there exists an especially sensitive traffic situation on the adjacent paved road, wash the tires before the vehicle enters the public road. If washing is necessary, make provisions to intercept the wash water and trap the sediment so it can be collected and stabilized.

*Stone Construction Entrance with Washrack*

Use construction entrances in conjunction with stabilization of construction roads (see Construction Road Stabilization [BMP C-SCM-02]) to reduce the amount of mud picked up by construction vehicles and better remove mud. Encourage vehicles (other than construction equipment) to remain in stabilized areas where possible to avoid mud accumulation on vehicles’ tires that will regularly enter and leave the site. Other innovative techniques for accomplishing the same purpose (such as a bituminous entrance) can be used, but only after specific plans and details are submitted and approved by the appropriate certified plan reviewer.

## 4.0 Stormwater Performance Summary

**MS-17: VEHICULAR TRACKING AND CONSTRUCTION ENTRANCES** – Provisions shall be made to minimize the transport of sediment from the site onto the paved surface.

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

9VAC25-875-560

**Erosion Control Efficiency: MODERATE**

**Sediment Removal Efficiency: MODERATE**

## 5.0 Design Criteria

| Table C-SCM-03-1 Design Criteria for Temporary Stone Entrance | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Aggregate Size | Use Virginia Department of Transportation (VDOT) #1, #2, or #3 Coarse Aggregate (1.5- to 3.5-inch stone) or American Association of State Highway and Transportation Officials (AASHTO) #1 Course Aggregate (2.5- to 3.5-inch stone). |
| Entrance Dimensions | Construct the aggregate layer to be a minimum of 6 inches thick and place a minimum 3 inches of aggregate in a cut section to give the entrance added stability and help secure the fabric filter separator.<br><br>Extend the entrance to the entire width of the vehicular ingress and egress area and have a minimum 12-foot width.<br><br>Construct the entrance length at a minimum of 70 feet except for smaller construction projects (total disturbance area of less than 1 acre) or sites with entrance constraints.<br><br>For these project sites, the minimum length is the greater of either 30 feet or a length sufficient for all on-site equipment to make at least two tire revolutions when crossing the trackout surface.<br><br>Where site conditions warrant that it may be necessary to extend the length or width of the rock to ensure the effectiveness of the entrance. |
| Mountable Berm & Culvert Pipe | Where access to the site crosses a roadside ditch, stream channel, or natural drainage course, provide a suitable means of conveying the flow past the entrance (e.g., an appropriately sized culvert pipe). Size the pipe to convey the runoff generated by the 2-year, 24-hour frequency storm at a minimum. The minimum permissible pipe size is 6 inches.<br><br>For such installations, install a mountable berm above the pipe to avoid crushing the pipe. Construct the 3-foot-wide mountable berm centered above the pipe with 5H:1V side slopes and 6 inches higher than the elevation of the rest of the construction entrance. |
| Filter Fabric | Use filter fabric that is a woven fabric consisting only of continuous-chain polymeric filaments or yarns of polyester. Use filter fabric inert to commonly encountered chemicals and hydrocarbons, mildew and rot-resistant, and conforms to the physical properties noted in Table 1. |

| Table C-SCM-03-1 Design Criteria for Temporary Stone Entrance | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Washing | If most mud is not removed by the vehicles traveling over the stone, wash the vehicles' tires before entering the public road. Carry wash water away from the entrance to an approved settling area or sediment removal device (e.g., sediment basin or trap, silt fence, or compost filter sock) to remove sediment. Prevent all sediment from entering storm drains, ditches, or watercourses.<br><br>Use a wash rack to make washing more convenient and effective for washing mud from the tires of the work vehicles only. A reinforced concrete or metal wash rack are both viable options to reduce the presence of sediment from work vehicles leaving the construction site (PA DEP 2012).<br><br>Wash racks are unsuitable for complete truck washing and only apply to washing the vehicle tires. If there is a need for a full wash of vehicles, refer to standard detail Concrete Washout Pit (C-SCM-13). Additionally, ensure that wash racks immediately discharge to a sediment removal device (e.g., sediment basin or trap, silt fence, or compost filter sock) before the water enters waterbodies (PA DEP 2012). |
| Location | Locate the entrance to provide for maximum use by all construction vehicles. Locate the entrance on level ground at an appropriate site distance. Avoid locating the entrance on steep slopes and ensure the entrance drains transversely to prevent runoff from the entrance flowing into the adjacent roadway.<br><br>Entrance configurations off the paved road may be modified to allow tractor trailers or longer delivery vehicles adequate area to safely exit the paved road onto the construction entrance and re-enter onto the paved road from the construction entrance. |

| Table C-SCM-03-2 Construction Specifications for Filter Fabric Liner Under Aggregate Stone | | | |
|---|---|---|---|
| **Fabric Properties[1]** | **Light-Duty Entrance[2] (Graded Subgrade)** | **Heavy-Duty Entrance[3] (Rough Graded)** | **Test Method** |
| Grab Tensile Strength (lbs.) | 200 | 315 | ASTM D4632 |
| Grab Tensile Elongation (%) | 15 | 15 | ASTM D4632 |
| Trapezoidal Tear (lbs.) | 75 | 113 – 120 | ASTM D4533 |
| CBR Puncture Strength (lbs.) | 700 | 900 | ASTM D6241 |
| Apparent Opening Size | 40 | 40 | ASTM D4751 |

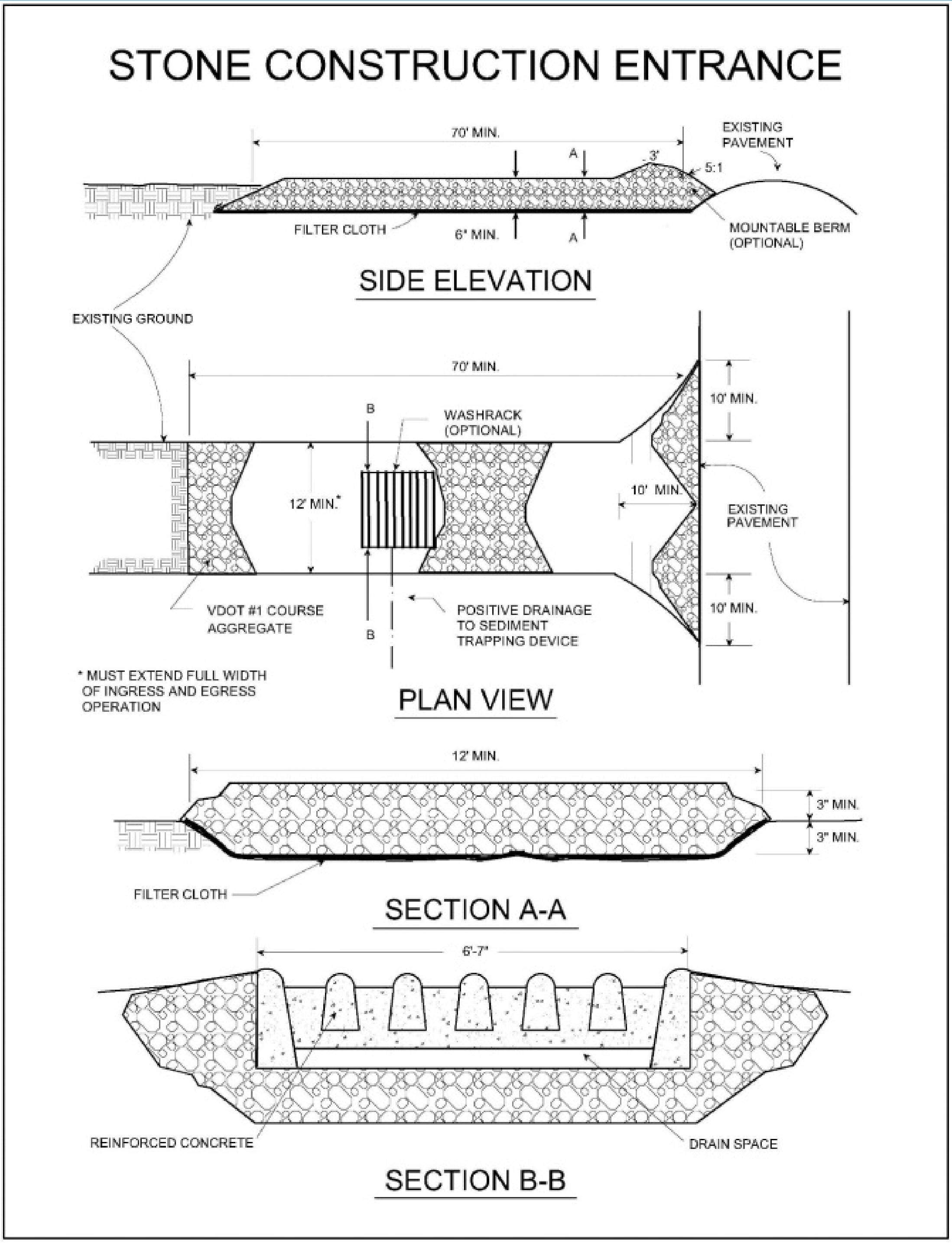
| Table C-SCM-03-2 Construction Specifications for Filter Fabric Liner Under Aggregate Stone | | | |
|---|---|---|---|
| Fabric Properties[1] | Light-Duty Entrance[2] (Graded Subgrade) | Heavy-Duty Entrance[3] (Rough Graded) | Test Method |

1. Only use fabrics not meeting these specifications when design procedure and supporting documentation are supplied to determine aggregate depth and fabric strength.
2. **Light-Duty Entrance:** Sites that have been graded to subgrade and where most travel would be by single-axle vehicles and an occasional multi-axle truck. Examples of fabrics that can be used are: Mirafi 500X, Skaps SW200, Geotex 200 ST, or equivalent.
3. **Heavy-Duty Entrance:** Sites with only rough grading and where most travel would be by multi-axle vehicles. Examples of fabrics that can be used are: Mirafi 600X, Skaps SW315, Geotex 315 ST, or the equivalent.

## 6.0 Construction Specifications

1. Excavate the entrance area to a minimum of 3 inches and clear the area of all vegetation, roots, and other objectionable material.
2. Construct any drainage facilities according to specifications. Provide for the conveyance of surface water under the entrance through culverts.
3. Place the filter fabric underlayment atop the entire width and length of the entrance.
4. Following the filter fabric installation, place the stone to the specified dimensions (including the construction of the mountable berm) as necessary.
5. If wash racks are used, install wash racks according to manufacturer's specifications. Ensure the wash rack can convey sediment-laden water immediately to a sediment control treatment device before entering a water body.
6. Confirm the length and width of the construction entrance before setting up erosion control measures and perimeter control measures.

**Figure C-SCM-03-1 Stone Construction Entrance**




SOURCE: ADAPTED FROM 1983 MARYLAND STANDARDS FOR SOIL EROSION AND SEDIMENT CONTROL, AND VA. DSWC

*Source: Maryland Water Resources Administration et al. 1983*

## 7.0 Operations and Maintenance Considerations

Inspect the construction entrance weekly and immediately after each rainfall.

Maintain the entrance to prevent tracking or flow of dirt, mud, or sediment onto public rights-of-way, including periodic top dressing with additional stone and repair or cleanout of structures that trap sediment or both. Maintain a stockpile of rock at the site for top dressing purposes.

*Improperly Maintained Stone Construction Entrance-Stones Dislodged Spilling into Adjoining Roadway*

Mud and soil particles will eventually clog the voids in the stone and compromise the effectiveness of the construction entrance. When this occurs, top dress the pad with new stone. Complete stone replacement is necessary when the pad becomes wholly clogged with sediment and the topdressing is no longer effective at removing accumulated sediment from tires.

Immediately remove all materials spilled, dropped, washed, or tracked from vehicles onto roadways or storm drains. Do not use water trucks to remove materials dropped, washed, or tracked onto roadways under any circumstances.

Immediately remove stones from the adjoining roadway that construction traffic dislodged from the entrance.

Maintain the area under the wash rack free of accumulated sediment. Repair or replace the wash rack if it becomes damaged.

## 8.0 References

Maryland Water Resources Administration, Soil Conservation Service, and State Soil Conservation Committee. 1983. Maryland Standards and Specifications for Soil Erosion and Sediment Control. April.

# C-SCM-04 Inlet Protection

## 1.0 Definition

Inlet protection is a sediment filter or an excavated impounding area around a storm drain drop inlet or curb inlet.

– CAD C-SCM-04 Culvert Inlet Sediment Trap

– CAD C-SCM-04-1 Silt Fence Drop Inlet Protection

– CAD C-SCM-04-2 Gravel and Wire Mesh Drop Inlet Sediment Filter

– CAD C-SCM-04-3 Block and Gravel Drop Inlet Sediment Filter

– CAD C-SCM-04-4 Excavated Drop Inlet Sediment Trap

– CAD C-SCM-04-5 Gravel Curb Inlet Sediment Filter

– CAD C-SCM-04-6 Curb Inlet Protection With 2-inch x 4-inch Wooden Weir

– CAD C-SCM-04-7 Block & Gravel Curb Inlet Sediment Filter

## 2.0 Purpose and Applicability of Best Management Practice

The purpose of inlet protection is to prevent sediment from entering storm drainage systems before permanent stabilization of the disturbed area. Every storm drain inlet, catch basin, curb inlet, or similar drainage structure receiving sediment-laden runoff should be protected by a combination of upstream erosion control and temporary inlet protection. This practice will significantly reduce sediment loads and will help prevent floatable waste materials and other construction wastes from entering stormwater systems (City of Knoxville 2018).

*Properly Installed Inlet Protection*

Inlet protection applies to disturbed tributary areas that have yet to be permanently stabilized and where ponding water will not endanger highways, street traffic, houses, buildings, parks, or other facilities. Small drainage areas, typically smaller than 1 acre, that have impervious surfaces and do not permit the construction of a sediment trap or sediment basin are the most applicable for installing inlet protection.

## 3.0 Planning and Considerations

Storm sewers made operational before stabilization of the associated drainage areas can convey large amounts of sediment to natural drainageways. In extreme sediment loading, the storm sewer itself may clog and lose a significant portion of its capacity. To avoid these problems, it is necessary to prevent sediment from entering the system at the inlets.

Inlet protection can be accomplished using pre-manufactured proprietary devices or on-site construction. Self-constructed devices generally consist of filtering (geotextile fabric and aggregate) securely anchored and supported against the weight of ponded water by some support (e.g., wood boards, concrete blocks, wire mesh, the inlet structure itself). This can be accomplished in many ways. Inlet protection structures that pond water onto streets, parking lots, or driveways should be designed to have some method for allowing excess water from large storms to bypass or overflow. Inspect the means of filtering (generally clean aggregate or filter fabric) regularly to see if sediments and silt clog the material. Pre-manufactured proprietary devices are compatible with most types of inlets and typically consist of either fabric tubes with aggregate or other filter material or fabric sacks placed underneath an inlet grate to trap sediment. Stormwater runoff may bypass protected inlets on slopes. A berm or other type of wall can capture some of the flow. Design inlets downstream, particularly sump inlets, with an overflow to handle large storms. Best management practice (BMP) selection is site- and inlet type-specific.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

9VAC25-875-560

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

| Table C-SCM-04-1 Design Criteria for Materials | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Drainage Area | No greater than 1 acre per inlet. |
| Proprietary Devices | Size/order proprietary devices to fit the inlet grate or curb opening. |
| Construction | Construct the inlet protection device so that:<br>• It will facilitate cleanout and disposal of trapped sediment and minimize interference with construction.<br>• It will not cause excessive inconvenience or damage to adjacent areas or structures. |
| Stone Filtering | If using stone as the principal ponding/filtering medium, a range of stone sizes is offered; use Virginia Department of Transportation (VDOT) #3, #357, or #5 Coarse Aggregate.<br>Attempt to obtain the greatest amount of filtering action possible using smaller-sized stones while not creating significant ponding problems.<br>In all designs that use stone with a wire mesh support as a filtering mechanism, the stone can be completely wrapped with the wire mesh to improve stability and provide for easier cleaning. |
| Filter Fabric | Filter fabric may be added to devices that use “coarse aggregate” stone to significantly enhance sediment removal. Secure the filter fabric, meeting the physical requirements noted for “extra strength” provided in Table C-PCM-04-3, between the stones and the inlet (on wire mesh if it is present). As a result of the significant increase in filter efficiency provided by the fabric, a more comprehensive range of stone sizes (VDOT #1, #2, or #3 Coarse Aggregate) may be used with such a configuration. The larger stone will help keep larger sediment masses from clogging the cloth. Notably, significant ponding may occur at the inlet if filter cloth is used in this manner. |

## 6.0 Construction Specifications

Inlet protection can be classified based on the type of inlet on which the protection is being installed. Inlet protection specifications and details are broken down below based on inlet types and whether the protection is to be self-constructed or a pre-manufactured proprietary device. Refer to the manufacturer’s standards, specifications, product materials, and installation details for all proprietary devices so that they are installed and maintained according to the manufacturer’s specifications.

| Table C-SCM-04-2 Drop Inlet Self-Constructed Specifications | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Silt Fence Drop Inlet Sediment Filter | 1. Ensure the silt fence conforms to the construction specifications for "extra strength" provided in Table C-PCM-04-3 and is cut from a continuous roll to avoid joints.<br>2. For stakes, use 2-inch x 4-inch wood (preferred) or equivalent metal at a minimum length of 3 feet. If metal stakes are used, install protective caps.<br>3. Space stakes evenly around the perimeter of the inlet a maximum of 3 feet apart and securely drive them into the ground approximately 18 inches deep (see Figure C-SCM-04-1).<br>4. To provide stability to the installation, frame with 2-inch x 4-inch wood strips around the crest of the overflow area at a maximum of 1.5 feet above the drop inlet crest.<br>5. Place the bottom 12 inches of the fabric in a trench (see Figure C-SCM-04-1) and backfill the trench with 12 inches of compacted soil.<br>6. Fasten filter fabric securely with staples or wire to the stakes and frame. Joints must be overlapped to the next stake.<br>7. It may be necessary to build a temporary dike on the downslope side of the structure to prevent bypass flow.<br><br>*Failed Silt Fence Inlet Protection (Drop Inlet)* |
| Gavel and Wire Mesh Drop Inlet Sediment Filter | 1. Lay wire mesh over the drop inlet so that the wire extends at least 1 foot beyond each side of the inlet structure. Use wire mesh with 0.5-inch openings. If more than one mesh strip is necessary, the strips should be overlapped by a minimum of 1 foot.<br>2. Place coarse aggregate atop the wire mesh (see Figure C-SCM-04-2) at a depth of at least 12 inches over the entire inlet opening. Extend the stone beyond the inlet opening at least 18 inches on all sides.<br>3. If the stone filter becomes clogged with sediment so that it no longer adequately performs its function, pull the stones away from the inlet and clean the stone or replace the stone or both.<br>Note: This filtering device has no overflow mechanism; therefore, ponding is likely especially if sediment is not removed regularly. Do not use this device where overflow may endanger an exposed fill slope. Consider the possible effects of ponding on traffic movement, nearby structures, working areas, adjacent property, and other situations. |

| Table C-SCM-04-2 Drop Inlet Self-Constructed Specifications | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Block and Gravel Drop Inlet Sediment Filter | 1. Place concrete blocks lengthwise on their sides in a single row around the perimeter of the inlet, with the ends of adjacent blocks abutting and holes running horizontally. Depending on design needs, the barrier's height can vary by stacking combinations of 4-inch, 8-inch, and 12-inch-wide blocks. Ensure the barrier of blocks is at least 12 inches high and no greater than 24 inches high.<br>2. Place wire mesh over the outside vertical face (webbing) of the concrete blocks to prevent the stones from washing through the holes in the blocks. Use wire mesh with 0.5-inch openings.<br>3. Pile the stones against the wire to the top of the block barrier (see Figure C-SCM-04-3).<br>4. If the stone filter becomes clogged with sediment so that it no longer performs its function adequately, pull the stones away from the blocks and clean and replace the stones. |
| Excavated Drop Inlet Sediment Trap | 1. Size the excavated trap to provide a minimum storage capacity of 134 cubic yards per acre of drainage area. Construct a trap to be no less than 1 foot and no more than 2 feet deep, measured from the top of the inlet structure. Construct side slopes to be steeper than 2H:1V (see Figure C-SCM-04-4).<br>2. The slope of the basin may vary to fit the drainage area and terrain. Observe to check trap efficiency and modify as necessary to ensure satisfactory sediment trapping. Where an inlet is located to receive concentrated flows, such as in a highway median, it is recommended that the basin have a rectangular shape in a 2H:1V ratio, with the length oriented in the direction of the flow.<br>3. Remove sediment and restore the trap to its original dimensions when the sediment has accumulated to one-half the design depth of the trap. Deposit removed sediment in a suitable area so that it will not erode. |
| Trench Drain Inlet Filter | 1. For use where existing or proposed slot or trench drain storm inlets will be operational before project completion, and the corresponding drainage area of less than 0.5 acres is permanently stabilized.<br>2. Place filter fabric underneath the grate system with a minimum of 4 inches of filter fabric extended past the outer edge of the grate.<br>3. Check for tears and accumulated sediment and perform maintenance or replace fabric as needed. |

| Table C-SCM-04-2 Drop Inlet Self-Constructed Specifications | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Yard Drain Inlet Filter | 1. For use where existing or proposed yard drain inlets 15 inches in diameter or less will be operational before project completion and permanently stabilize the corresponding drainage area of less than 0.5 acre.<br>2. Place filter fabric underneath the grate system with a minimum of 4 inches of filter fabric extended past the outer edge of the grate.<br>3. Remove accumulated sediment and debris from the surface and vicinity of the unit to prevent ponding.<br>4. Replace the filter fabric immediately if any rips/tears are noticed. |

| Table C-SCM-04-3 Curb Inlet Self-Constructed Specifications | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Gravel Curb Inlet Sediment Filter | 1. Place wire mesh with 0.5-inch openings over the curb inlet opening so that at least 12 inches of wire extends beyond the inlet opening on both sides, and at least 12 inches of wire extends across the concrete gutter from the inlet opening, as depicted on Figure C-SCM-04-5.<br>2. Pile the stone against the wire to anchor it against the gutter and inlet opening, cover the inlet opening completely, and extend a minimum of 18 inches beyond the inlet opening on both sides.<br>3. If the stone filter becomes clogged with sediment so it no longer performs its function adequately, pull the stone away from the block and clean and replace the stone filter.<br><br>*Failed Inlet Protection (Curb Inlet)* |
| Curb Inlet Protection with Wooden Weir | 1. Attach a continuous piece of wire mesh (30-inch minimum width x inlet throat length plus 4 feet) to the 2-inch x 4-inch wooden weir (with a total length of throat length plus 2 feet) as shown in Figure C-SCM-04-6. Ensure that the wood is "construction grade" lumber.<br>2. Place a piece of approved "extra-strength" filter cloth of the same dimensions as the wire mesh over the wire mesh and securely attach it to the 2-inch x 4-inch weir.<br>3. Securely nail the 2-inch x 4-inch weir to the 9-inch-long vertical spacers between the weir and inlet face at a maximum 6-foot spacing.<br>4. Place the assembly against the inlet throat, and nail 2-foot (minimum) 2-inch by 4- inch board lengths to the top of the weir at spacer locations. Extend these 2-inch x 4- inch anchors across the inlet tops and hold in place by sandbags or alternate weight.<br>5. Place the assembly so that the end spacers are a minimum of 1 foot beyond both ends of the throat opening.<br>6. Form the wire mesh and filter cloth to the concrete gutter and against the face of the curb on both sides of the inlet. Place coarse aggregate atop the wire mesh and filter fabric to prevent water from entering the inlet under or around the filter cloth.<br>7. Inspect this type of protection frequently and replace the filter cloth and stone when it becomes clogged with sediment.<br>8. Ensure that storm flow does not bypass the inlet by installing temporary earth or sandbag dikes directing flow into the inlet. |

| Table C-SCM-04-3 Curb Inlet Self-Constructed Specifications | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Block and Gravel Curb Inlet Sediment Filter | 1. Place two concrete blocks on their sides abutting the curb at either side of the inlet opening.<br>2. Cut a 2-inch by 4-inch stud and place it through the outer holes of each spacer block to help keep the front blocks in place.<br>3. Place concrete blocks on their sides across the front of the inlet and abutting the spacer blocks as depicted in Figure C-SCM-04-7.<br>4. Place wire mesh over the outside vertical face (webbing) of the concrete blocks to prevent the stone from washing through the holes in the blocks. Use wire mesh with 0.5-inch openings.<br>5. Pile VDOT #3, #357, or #5 coarse aggregate against the wire to the barrier's top, as shown in Figure C-SCM-04-7.<br>6. If the stone filter becomes clogged with sediment so that it no longer performs its function adequately, pull the stone away from the blocks and clean or replace the stone filter. |

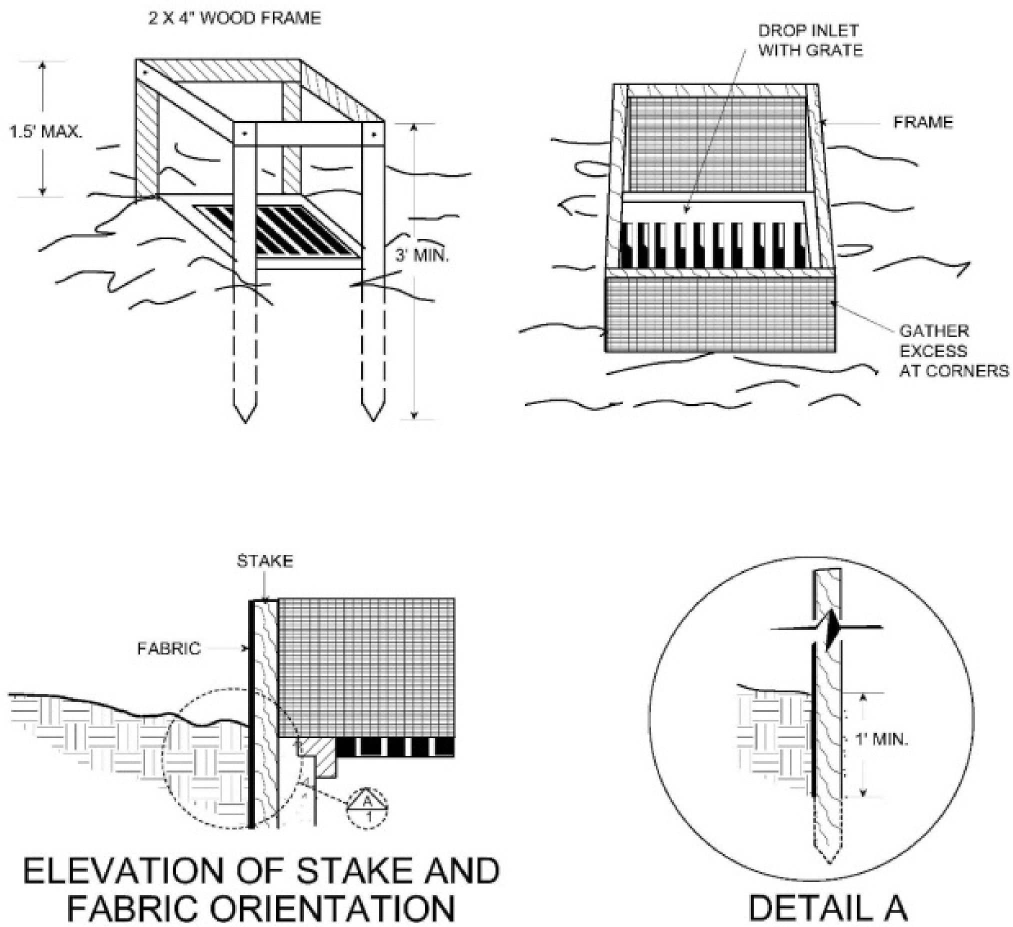
## 7.0 Operations and Maintenance Considerations

Routine inspection and maintenance are critical to ensuring the adequate performance of inlet protection. Include the following activities as part of any maintenance program (Minnesota Pollution Control Agency 2023):

- Inspect all inlet protection devices at least twice weekly (72 hours or more between each inspection) and after every significant rainfall event (0.25 inch or more).
- During extended rainfall events, inspect inlet protection devices at least once every 24 hours.
- Replace clogged aggregate or filter fabric immediately.
- Look for damage or tears to fabric caused by large flows.
- Inspect downstream inlets, pipes, and other infrastructure after severe storms to check for bypassed material.
- Remove sediment from temporary inlet protection methods when sediment reaches depths of 2 or 3 inches. More frequent sediment removal is required from paved areas such as streets or parking lots.
- Remove all inlet protection devices within 30 days after the site is stabilized, or when the inlet protection is no longer needed.
- Bring the disturbed area to final grade and appropriately stabilize all bare areas around the inlet with vegetation.
- Clean storm drainage system of sediment and debris before final inspection.
- In karst areas, inspect excavated drop inlet sediment traps regularly and after each precipitation event for subsidence. Subsidence is a criterion of failure. As such, mitigate subsidence immediately using the appropriate engineering practice.

**_Figure C-SCM-04-1 Silt Fence Drop Inlet Protection_**

SILT FENCE DROP INLET PROTECTION




SPECIFIC APPLICATION

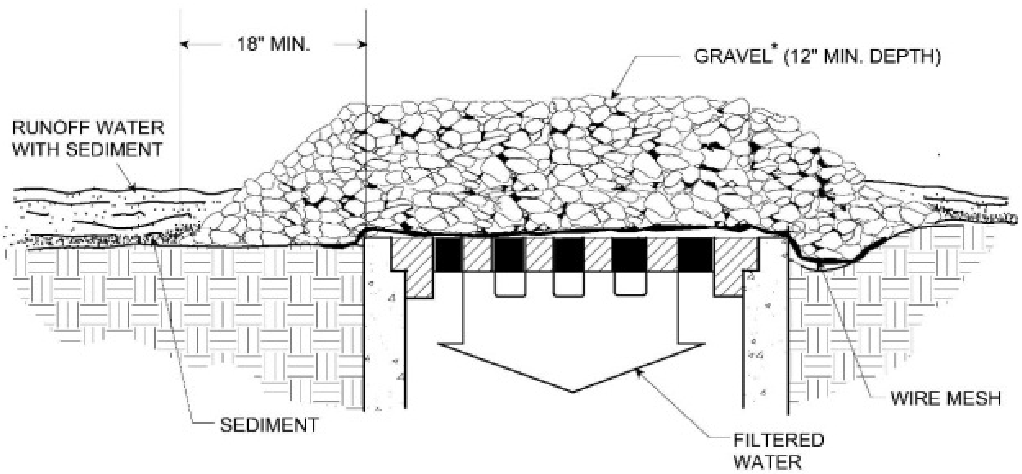
THIS METHOD OF INLET PROTECTION IS APPLICABLE WHERE THE INLET DRAINS A RELATIVELY FLAT AREA (SLOPE NO GREATER THAN 5%) WHERE THE INLET SHEET OR OVERLAND FLOWS (NOT EXCEEDING 1 C.F.S.) ARE TYPICAL. THE METHOD SHALL NOT APPLY TO INLETS RECEIVING CONCENTRATED FLOWS, SUCH AS APPLY TO INLETS RECEIVING CONCENTRATED FLOWS, SUCH AS IN STREET OR HIGHWAY MEDIANS.

SOURCE: N.C. EROSION AND SEDIMENT CONTROL PLANNING AND DESIGN MANUAL, 1988 PLATE. 3.07-1

*Source: North Carolina Sediment Control Division et al. 2013*

### *Figure C-SCM-04-2 Gravel and Wire Mesh Drop Inlet Sediment Filter*

## GRAVEL AND WIRE MESH DROP INLET SEDIMENT FILTER



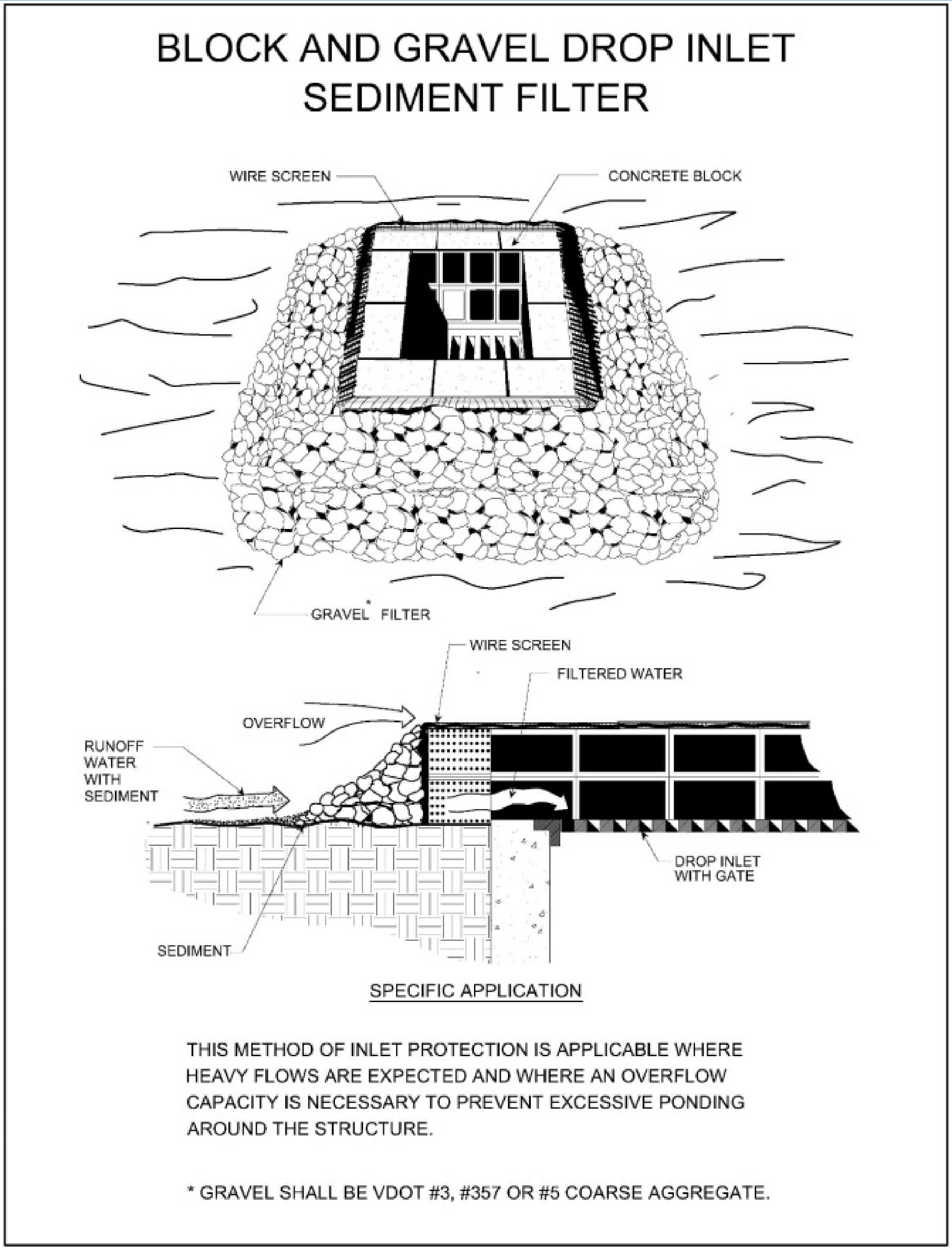

SPECIFIC APPLICATION

THIS METHOD OF INLET PROTECTION IS APPLICABLE WHERE HEAVY CONCENTRATED FLOWS ARE EXPECTED BUT NOT WHERE PONDING AROUND THE STRUCTURE MIGHT CAUSE EXCESSIVE INCONVENIENCE OR DAMAGE TO ADJACENT STRUCTURES AND UNPROTECTED AREAS.

* GRAVEL SHALL BE VDOT #3, #357 OR #5 COARSE AGGREGATE.

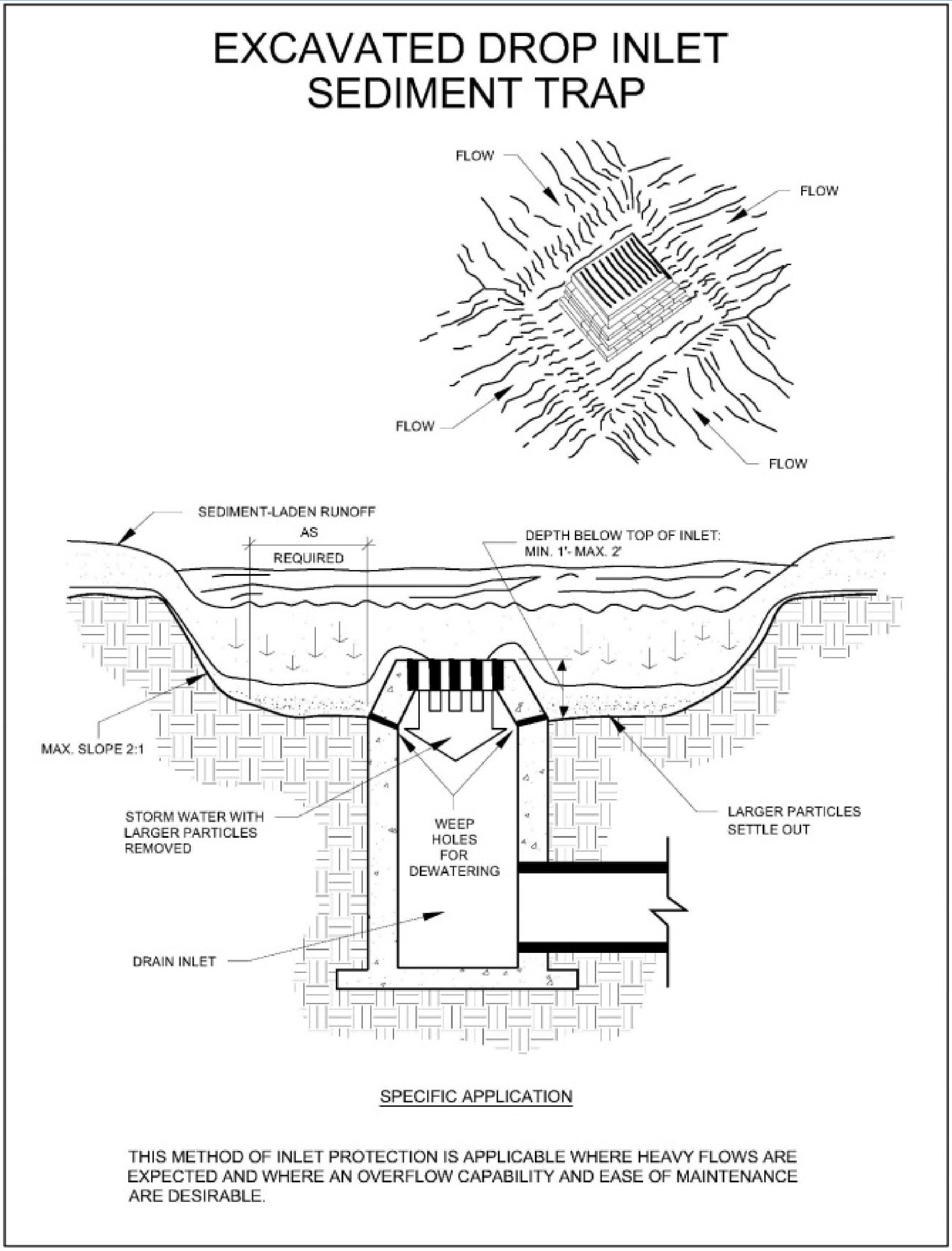
SOURCE: VA. DSWC

***Figure C-SCM-04-3 Block and Gravel Drop Inlet Sediment Filter***




SOURCE: VA. DSWC

## *Figure C-SCM-04-4 Excavated Drop Inlet Sediment Trap*

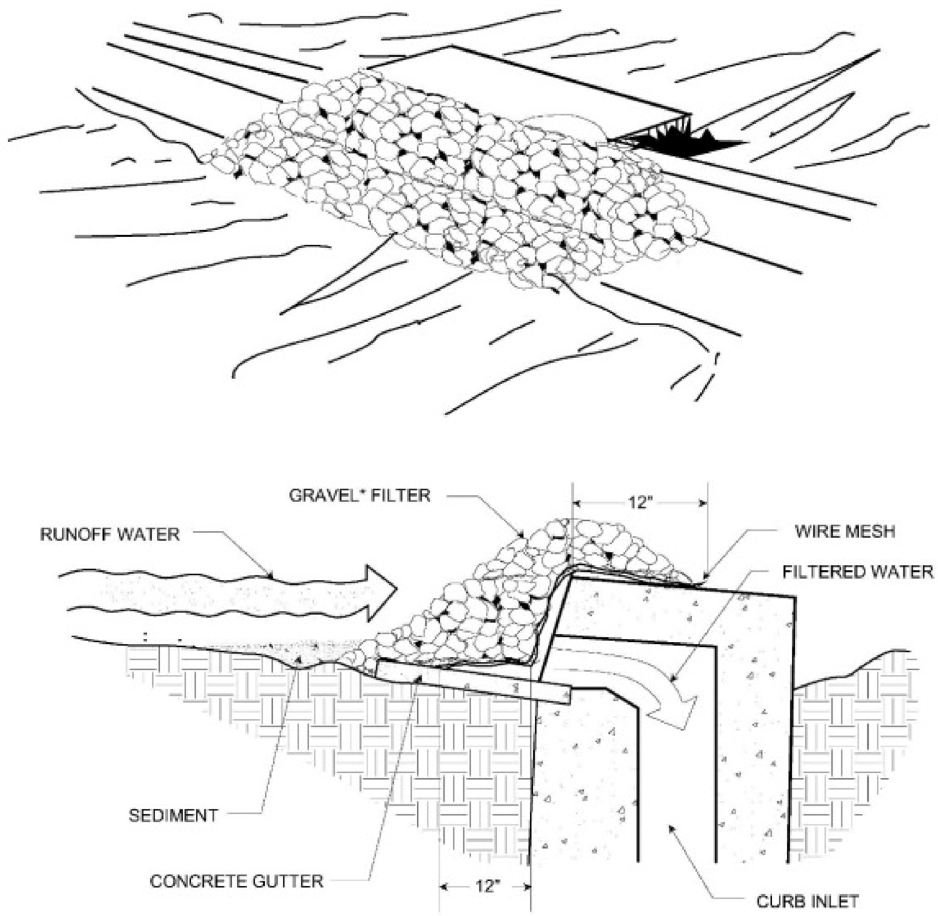



SOURCE: MICHIGAN SOIL EROSION AND SEDIMENT CONTROL GUIDEBOOK, 1975, AND USDA-SCS

*Source: Peterson et al. 1975*

## *Figure C-SCM-04-5 Gravel Curb Inlet Sediment Filter*

# GRAVEL CURB INLET SEDIMENT FILTER



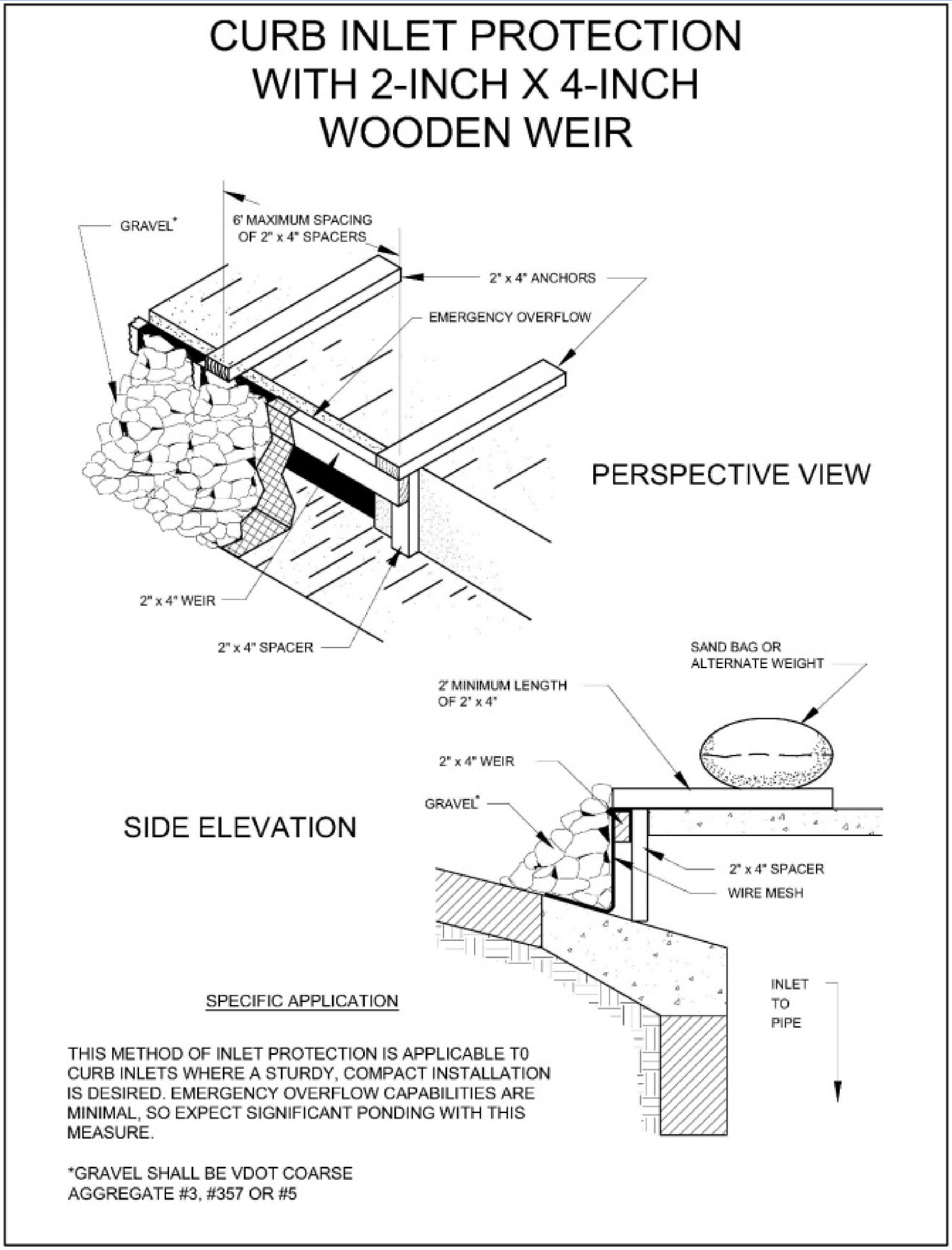

SPECIFIC APPLICATION

THIS METHOD OF INLET PROTECTION IS APPLICABLE AT CURB INLETS WHERE PONDING IN FRONT OF THE STRUCTURE IS NOT LIKELY TO CAUSE INCONVENIENCE OR DAMAGE TO ADJACENT STRUCTURES AND UNPROTECTED AREAS.

* GRAVEL SHALL BE VDOT #3, #357 OR 5 COARSE AGGREGATE.

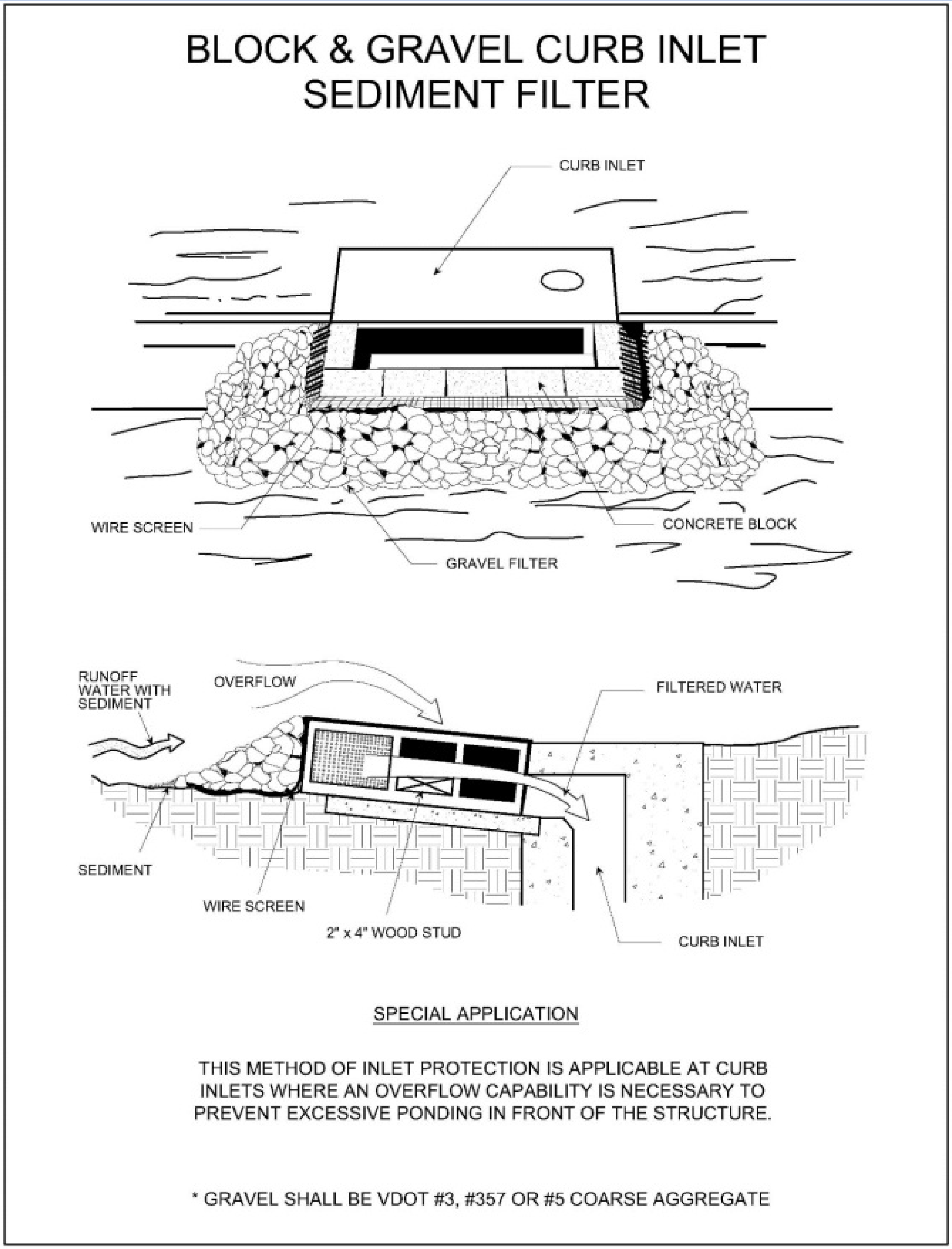
SOURCE: VA. DSWC

***Figure C-SCM-04-6 Curb Inlet Protection with 2-Inch x 4-Inch Wooden Weir***




SOURCE: USDA SCS

**Figure C-SCM-04-7 Block and Gravel Curb Inlet Sediment Filter**




SOURCE: VA. DSWC

## 8.0 References

City of Knoxville. 2018. Best Management Practices (BMP) Manual. January.

Minnesota Pollution Control Agency. 2023. Minnesota Stormwater Manual – Sediment Control Practices – Storm Drain Inlet Protection. Located at: https://stormwater.pca.state.mn.us/index.php/Sediment_control_practices_-_Storm_drain_inlet_protection. February 15.

Peterson, A., Reznik, R., Hedin, S., Hendges, M. and D. Dunlap. 1975. Guidebook of Best Management Practices for Michigan Watersheds. Reprinted October 1998.

Virginia Department of Environmental Quality (VDEQ). 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-SCM-05 Culvert Inlet Protection

## 1.0 Definition

Culvert inlet protection is a sediment filter located at the inlets of culverts.

– CAD C-SCM-05-1 Silt Fence Culvert Inlet Protection

– CAD C-SCM-05-2 Culvert Inlet Sediment Trap

## 2.0 Purpose and Applicability of Best Management Practice

Culvert inlet protection prevents sediment from entering, accumulating in, and being transported by a culvert and associated drainage system before the permanent stabilization of a disturbed project area.

Culvert inlet protection also controls erosion at culvert inlets during the phase of a project in which elevation and drainage patterns change, causing original control measures to be ineffective or in need of removal.

Use culvert inlet protection where a culvert is to be made operational before permanent stabilization of the disturbed drainage area or to control erosion/remove sediment from water before flowing into an existing culvert.

Different types of structures apply to different conditions (see Figure C-SCM-05-1 and Figure C-SCM-05-2).

## 3.0 Planning and Considerations

Conduct pre-construction subsurface investigation of culvert inlets to identify any subsurface voids, conduits, or openings in the bedrock.

When construction on a project reaches a stage in which upstream areas are stabilized culverts, other storm sewer appurtenances are installed and many areas are brought to a desired grade, the erosion control measures used in the early stages normally need to be modified or may need to be removed altogether. At that time, there is a need to protect the points at which runoff will leave the area via culverts and drop or curb inlets from sedimentation.

Culverts made operational before stabilization of the associated drainage areas can convey large amounts of sediment to natural drainageways. In case of extreme sediment loading, the pipe or pipe system itself may clog and lose a major portion of its capacity. Use one of the methods noted in this section to prevent sediment from entering the culvert to avoid these problems.

Construct the culvert inlet protection so that:

1. It will facilitate cleanout and disposal of trapped sediment and minimize interference with construction.

2. Any resultant ponding of stormwater will not cause excessive inconvenience or damage to adjacent areas or structures.

See Figure C-SCM-05-1 and Figure C-SCM-05-2 for graphic depictions of inlet protection.

## 4.0 Stormwater Performance Summary

**MS-10: INLET PROTECTION** – All storm sewer inlets made operable during construction will be protected so that sediment-laden water cannot enter the conveyance system without first being filtered or otherwise treated to remove sediment.

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

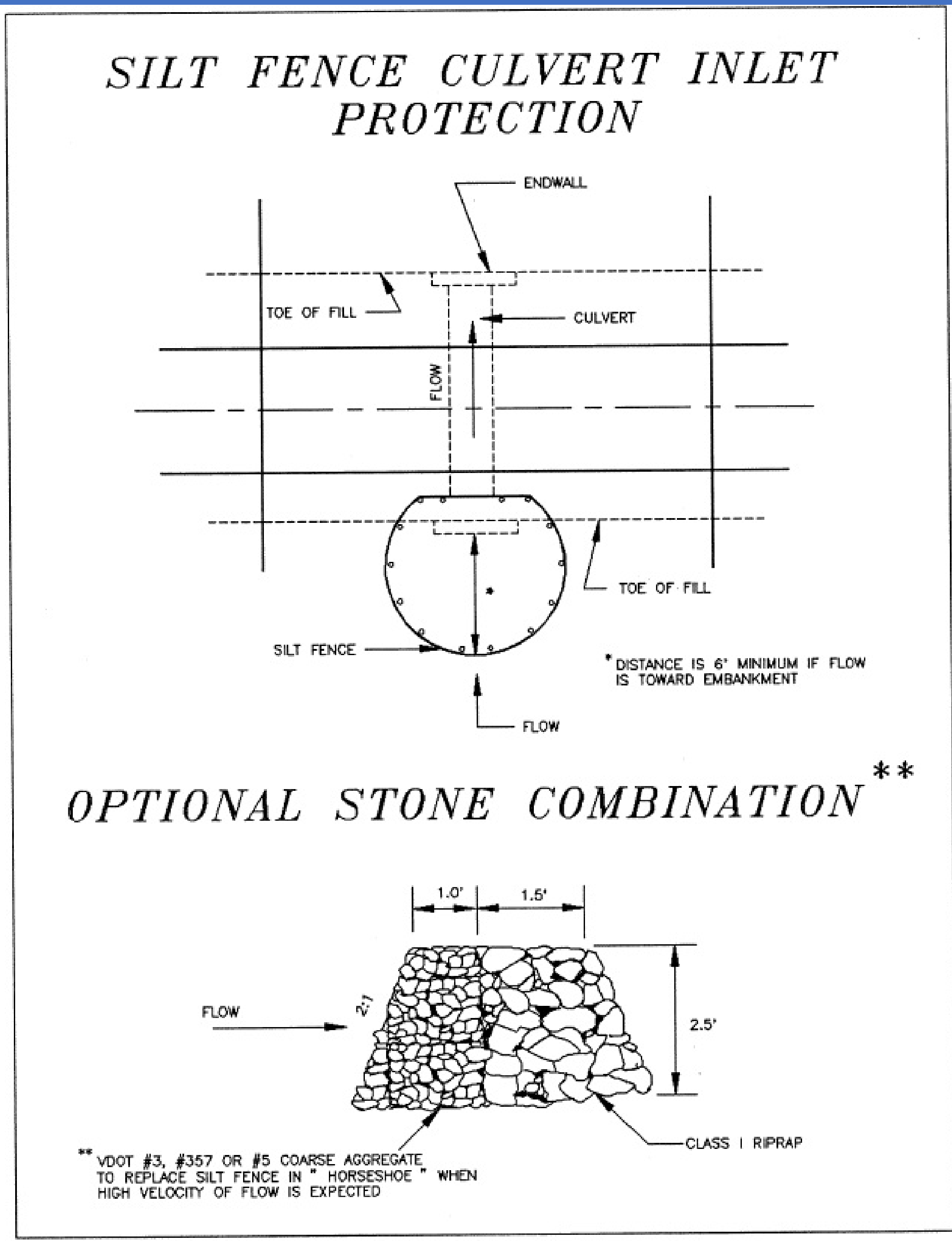
### 5.1 Silt Fence Culvert Inlet Protection

1. No formal design is required; however, design areas tributary to silt fence culvert inlet protection to comply with slope length and gradient requirements specified in Silt Fence (C-PCM-04).
2. Silt fence culvert inlet protection has an expected maximum usable life of 3 months.
3. Design the maximum area draining to this practice not to exceed 1 acre.

### 5.2 Culvert Inlet Sediment Trap

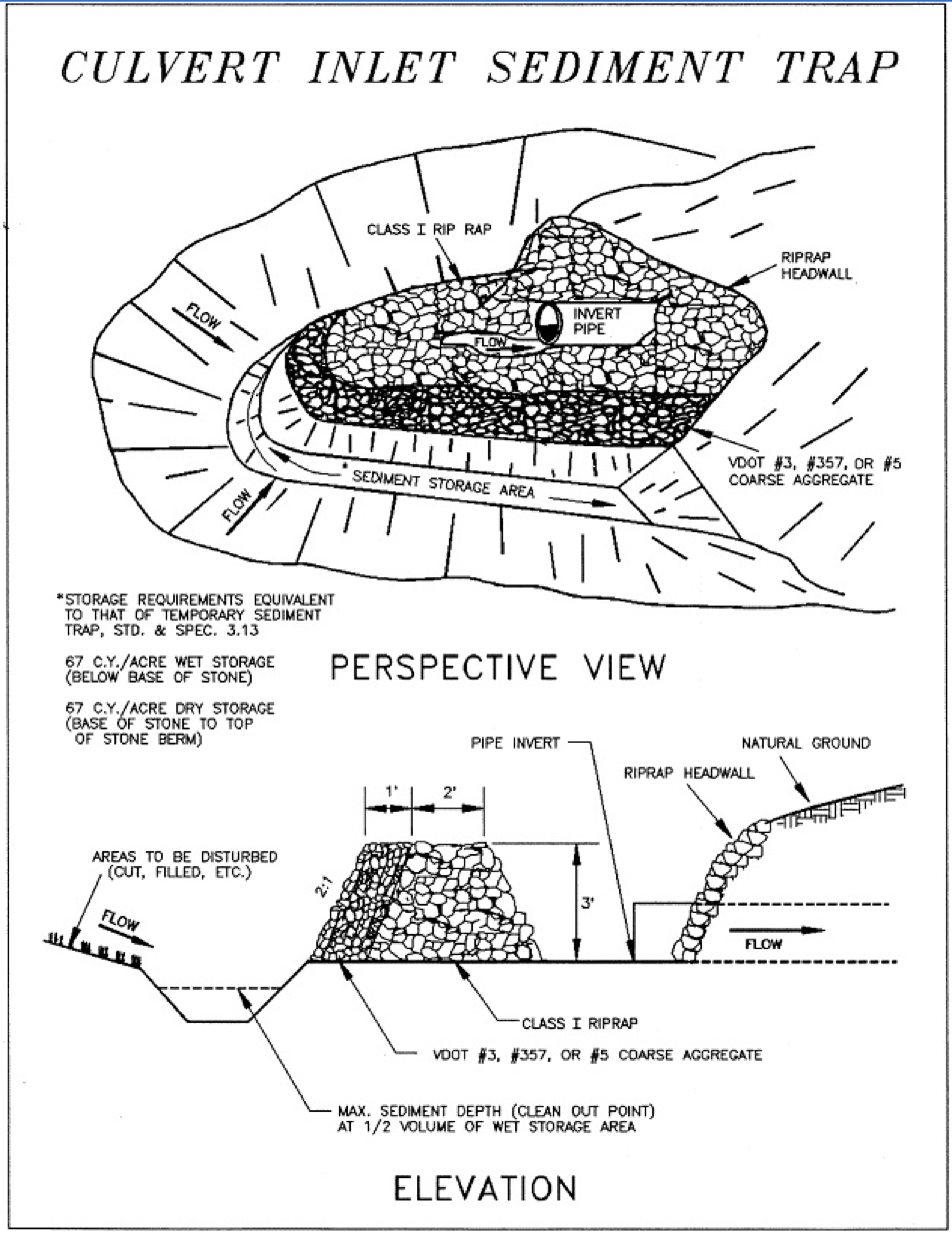
1. Align runoff storage requirements with information outlined under Temporary Sediment Trap (C-SCM-11).
2. Culvert inlet sediment traps have a maximum expected useful life of 18 months.
3. Design the maximum area draining to the trap not to exceed 3 acres.
4. Design the maximum height of the stone berm to be 3 feet.
5. Design the side slopes of the stone berm section not to exceed 2H:1V.
6. Design the side slopes of excavated areas to be no steeper than 1H:1V. Design the maximum depth of excavation within the wet storage area to be 4 feet to facilitate cleanout and for site safety considerations.
7. Design the stone berm to be a combination of coarse aggregate and riprap, with the smaller stone being Virginia Department of Transportation (VDOT) #3, #357, or #5 Coarse Aggregate (smaller stone sizes will enhance filter efficiency) and riprap being Class I. Design the top width of the coarse aggregate to be 1 foot and the top width of the riprap to be 2 feet.
8. Place the filter fabric that meets the physical requirements noted in Riprap (C-ECM-13) at the stone-soil interface to act as a separator.

#### *Figure C-SCM-05-1 Silt Fence Culvert Inlet Protection*




*Source: Adapted from VDOT Standard Sheets and Va. DSWC*

**Figure C-SCM-05-2 Culvert Inlet Sediment Trap**




*Source: North Carolina Sediment Control Commission et al. 2013*

## 6.0 Construction Specifications

### 6.1 Silt Fence Culvert Inlet Protection

1. Construct the silt fence specifications to comply with Silt Fence (C-PCM-04).
2. Construct the height of the silt fence (in front of the culvert opening) to be a minimum of 16 inches and not to exceed 34 inches.
3. Use extra-strength filter fabric with a maximum stake spacing of 3 feet to construct the measure.
4. Place the silt fence approximately 6 feet from the culvert in the direction of incoming flow, creating a circular shape as shown in Figure C-SCM-05-1. The silt fence should extend above and around the top of the culvert.
5. If the silt fence cannot be installed properly, or the flow or velocity of flow to the culvert protection is excessive and may breach the structure, use the stone combination noted in Figure C-SCM-05-1.
6. Compost filter sock or straw wattles may be used in lieu of a silt fence. Use one row of 18-inch-diameter compost filter sock or smaller compost filter sock or straw wattles stacked to form a minimum height of 16 inches. Stake the stacked compost filter sock or straw wattles in accordance with the Compost Filter Sock Outlet in the Temporary Sediment Trap (C-SCM-11).

**6.2 Culvert Inlet Sediment Trap**

1. The geometry of the design will be a "horseshoe" shape around the culvert inlet (see Figure C-SCM-05-2).
2. The toe of the riprap (composing the sediment filter dam) should be no closer than 24 inches from the culvert opening to provide an acceptable emergency outlet for flows from larger storm events.
3. All other Construction Specifications documented within the Temporary Sediment Trap (C-SCM-11) also apply to this practice.
4. The proper installation of the culvert inlet sediment trap is a viable substitute for the installation of the temporary sediment trap.

## 7.0 Operations and Maintenance Considerations

Inspect the structure after each rain event and make repairs as needed.

Replace or clean aggregate when inspection reveals that clogged voids are causing ponding problems that interfere with on-site construction.

Remove sediment and restore the impoundment to its original dimensions when sediment has accumulated to one half the design depth. The deposit removed sediment in a suitable area so that it would not erode and cause further sedimentation problems. In karst areas, sinkholes may form in the vicinity of inlet protection and capture site runoff into groundwater. Inspect inlets for subsidence features and repair any subsidence features identified using the appropriate sinkhole repair BMP.

Remove temporary structures when they have served their useful purpose, but not before the upslope area has been permanently stabilized.

## 8.0 References

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

Virginia Department of Environmental Quality (VDEQ). 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-SCM-06 Wood Chip Filter Berm

## 1.0 Definition

A wood chip filter berm is a construction best management practice (BMP) constructed of mounded wood chips placed perpendicular to sheet flow to control erosion by reducing slope length in disturbed areas and retaining sediment. Wood chip berms may be constructed from processed woody material from initial site clearing operations (PA DEP 2012).

*Source: MPCA 2023*

## 2.0 Purpose and Applicability of Best Management Practice

Use wood chip filter berms on wooded or rocky slopes where staking and trenching of other BMPs is difficult or impossible.

Wood chip filter berms do not require trenching and disturb less soil during installation than silt fence or straw bale barriers.

## 3.0 Planning and Considerations

Large obstructions (e.g., tree limbs, boulders) should be removed before placement of the wood chips. Once the tributary drainage area is permanently stabilized, the wood chip filter berm may be leveled or left in place.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any land-disturbing activity and will be made functional before upslope land disturbance.

**Erosion Control Efficiency: LOW**

**Sediment Removal Efficiency: MODERATE**

## 5.0 Design Criteria

Do not place Wood chip filter berms in areas of concentrated flow. They should be aligned parallel to existing contours and below all disturbed areas.

Typically, the use of wood chip filter berms does not include use within 50 feet of receiving surface waters.

The maximum slope length above a wood chip filter berm should not exceed those identified in Table C-SCM-06-1.

**Table C-SCM-06-1 Maximum Slope Length for Wood Chip Filter Berms**

| Slope - Percent | Maximum Slope Length (ft) Above Barrier |
|---|---|
| 2 (or less) | 150 |
| 5 | 100 |
| 10 | 50 |
| 15 | 35 |
| 20 | 25 |
| 25 | 20 |
| 30 | 15 |
| 35 | 15 |
| 40 | 15 |
| 45 | 10 |
| 50 | 10 |
| >50 | Not Permitted |

*Source: PADEP 2012*

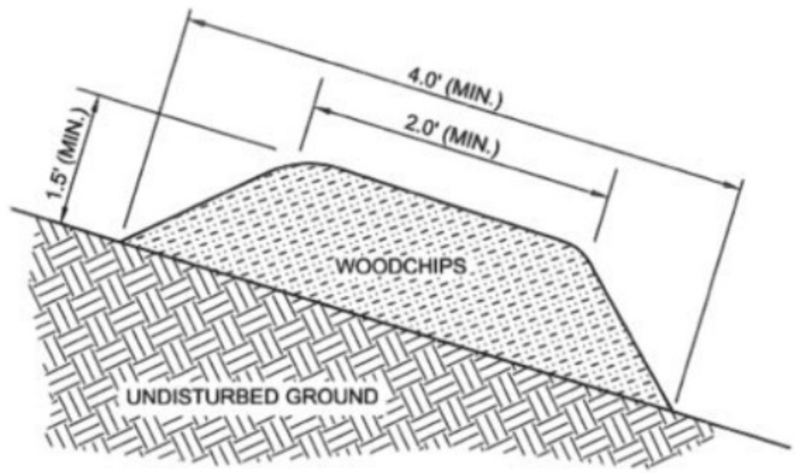
## 6.0 Construction Specifications

Before placement of the berm, obstructions such as tree limbs and large rocks will be removed.

Wood chip filter berms will be placed at the existing level grade. Both ends of the berm will be extended at least 8 feet upslope to 45 degrees to the main berm alignment.

Wood chip berms will not be located in areas of concentrated flow or used to construct sediment traps or other impoundments.

***Figure C-SCM-01-1 Wood Chip Filter Berm Minimum Dimensions***




## 7.0 Operations and Maintenance Considerations

Berms must be inspected weekly and after each runoff event.

Sediment must be removed when accumulations reach half the height of the berm.

Damaged or deteriorated portions of the berm must be replaced immediately upon inspection.

Berms may be leveled when the tributary area has been permanently stabilized or left in place.

## 8.0 References

Minnesota Pollution Control Agency. 2023. Minnesota Stormwater Manual – Sediment Control Practices – Stabilized Earth/Soil Berm. February 15. Located at: https://stormwater.pca.state.mn.us/index.php?title=Sediment_control_practices_-_Stabilized_earth/soil_berm

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

# C-SCM-07 Rock Check Dams

## 1.0 Definition

Rock check dams are small temporary stone dams constructed across a swale, channel, or drainage ditch.

– CAD C-SCM-07-1 Rock Check Dam

– CAD C-SCM-07-2 Spacing Between Check Dams

## 2.0 Purpose and Applicability of Best Management Practice


*A Rock Check Dam Under Dry Conditions*
*Source: Earth Tek, Inc. 2014.*

Rock check dams minimize the erosion rate of a swale, channel, or ditch by reducing the velocity of concentrated stormwater flows. This practice also traps sediment generated from adjacent areas or the ditch, mainly by ponding the stormwater runoff. Field experience has shown that they perform more effectively than silt fences or straw bales in the effort to stabilize "wet weather" ditches.

This sing a combination of stone sizes, is limited to use in small open channels. Do not use rock check dams in a live stream, as the objective is to protect the live watercourse. Some specific applications include:

1. Temporary ditches or swales that, because of their short length of service, cannot receive a non-erodible lining but still need protection to reduce erosion;
2. Either temporary ditches or swales that need protection during the establishment of grass linings; and
3. As an aid in the sediment trapping strategy for a construction site. This practice is not a substitute for major perimeter trapping measures such as a Temporary Sediment Trap (C-SCM-11) or a Temporary Sediment Basin (C-SCM-12).

## 3.0 Planning and Considerations

It is usually better to establish a protective vegetative lining before flow is confined or to install a structural channel lining than to install check dams; however, where this is not feasible, check dams are useful.

Check dams installed in grass-lined channels may kill the vegetative lining if submergence after rain events is too long and/or silting is excessive.

If check dams are used in grass-lined channels that will be mowed, take care to remove all the stone when the dam is removed including any stone that has washed downstream.

## 4.0 Stormwater Performance Summary

**MS-11: OUTLET PROTECTION** – Before any newly constructed stormwater conveyance channel can be made operational, adequate outlet protection and any required temporary or permanent channel lining will be installed in both the conveyance channel and receiving channel.

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: MODERATE**

## 5.0 Design Criteria

There is no formal design required to construct stone check dams; however, there are some general considerations required when proposing the use of check dams for sediment trapping and flow velocity reduction practices.

| Table C-SCM-07-1 Design Criteria for Rock Check Dams | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Drainage Area | Ensure the drainage area of the channel or swale being protected does not exceed:<br>• 2 acres when Virginia Department of Transportation (VDOT) #1 Coarse Aggregate is used alone.<br>• 10 acres when a combination of Class I riprap (added for stability) and VDOT #1 Coarse Aggregate is used.<br>Refer to Figure C-SCM-07-1 for orientation of stone and a cross-sectional view of the measure. Extend the stone to the tops of channel banks. |
| Spacing | Design the maximum spacing between the dams so that the toe of the upstream dam is at the same elevation as the top of the downstream dam (see Figure C-SCM-07-2).<br>Adjust and compute spacing based on the proposed slope of the channel/swale. |
| Height/ Weir | Ensure the maximum height of the check dam is 2 feet at the center of the channel/ swale. Design the center of the check dam to be a minimum of 6 inches (0.5 foot) lower than the outer edges at natural ground, providing a weir for open flow over the dam.<br>Compute the depth of flow at the weir for the 2-year, 24-hour storm. |
| Side Slopes | In the direction of the flow, install the side slopes of the rocks in the rock check dam to be a maximum of 2H:1V (see Figure C-SCM-07-1) to prevent scouring of the material and maximize the efficiency of the control measure. |
| Filter Fabric | A filter fabric may be used as a separator between the graded stone and the soil base and abutments. The filter fabric will prevent the migration of soil particles from the subgrade into the graded stone. Set the filter fabric into the subgrade soils. Place the filter fabric immediately adjacent to the subgrade without any voids and extend 3 feet beyond the downstream toe of the dam to prevent scour.<br>Refer to Riprap (C-ECM-13) for required physical properties of the filter fabric. |

## 6.0 Construction Specifications

1. For added stability, the base of the check dam can be keyed into the soil approximately 6 inches.
2. Place the stone according to the configuration shown on Figure C-SCM-07-1. Hand or mechanical placement is necessary to achieve complete coverage of the channel or swale and to ensure that the center of the dam is lower than the edges.
3. Alternative proprietary solutions may be used in place of the non-proprietary design included in this Chapter. Refer to the Virginia Department of Transportation List 58, Standard EC-16 Temporary Check Dam list of approved materials.

## 7.0 Operations and Maintenance Considerations

Inspect the check dam measure every 7 calendar days and within 24 hours after each rainfall event.

Inspect check dams for sediment accumulation after each runoff-producing storm event. Remove sediment when it reaches one half of the original height of the measure.

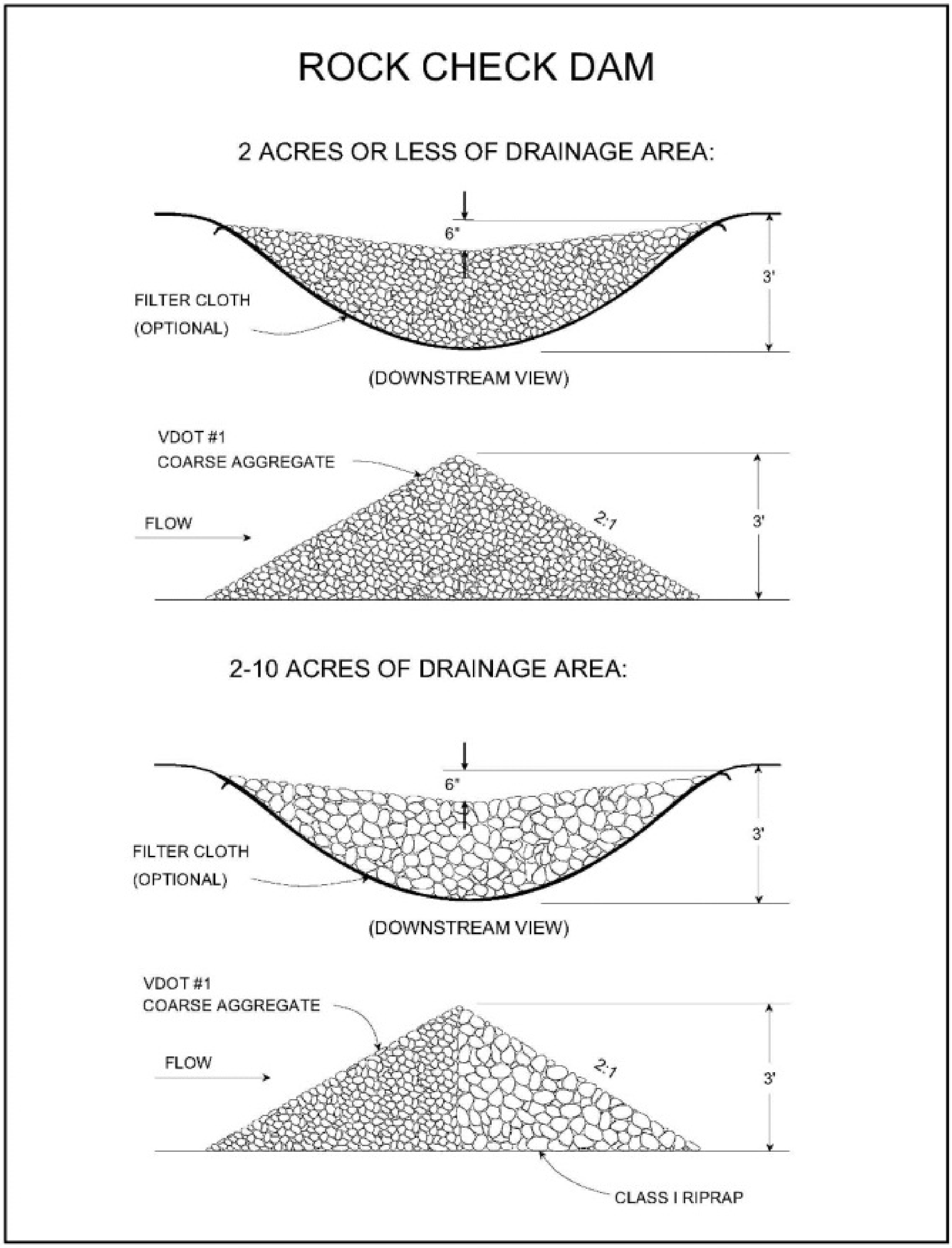
After removal of sediment, inspect the base of the check Improperly Installed or Maintained Rock Check Dam Failing Under Wet Conditions dam for end run breakthroughs, scouring, end runs, and any removal of rock from higher-velocity flow.

Immediately address any damages to the integrity of the check dam and review and modify the design as necessary to prevent future damages. Remove accumulated trash or other debris that may restrict or divert flow over the center of the check dam.

*Improperly Installed or Maintained Rock Check Dam Failing Under Wet Conditions*

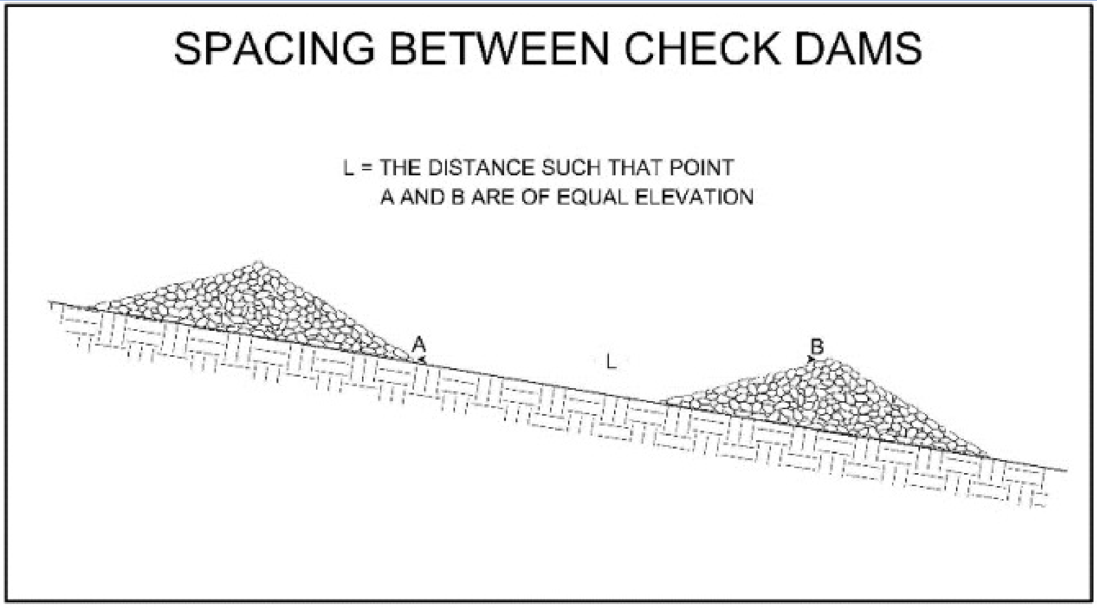
Unless the check dams are designed and constructed to be incorporated into a permanent stormwater management control, remove check dams when their useful life concludes. In temporary ditches and swales, remove check dams and fill in the ditch when they are no longer needed. In permanent structures, remove check dams when all upstream areas are stabilized. In the case of grass-lined ditches, remove check dams after upstream areas are stabilized and when the grass has matured sufficiently to protect the ditch or swale. Repair the area in which the check dam has been removed as needed to provide a continuous flow line in the channel. Seed and mulch the area beneath the check dams immediately after they are removed. The use of filter fabric underneath the stone will make the removal of the stone easier.

## *Figure C-SCM-07-1 Rock Check Dam*




SOURCE: VA. DSWC

*Figure C-SCM-07-2 Spacing between Rock Check Dams*




SOURCE: VA. DSWC

## 8.0 References

Earth Tek, Inc. 2014. Earth Tek Erosion Control Specialists. Located at: http://www.earthtekcos.com/

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-SCM-08 Rock Filter Outlet

## 1.0 Definition

A rock filter outlet is a berm constructed of riprap and stone aggregate where unanticipated concentrated flow to a perimeter control (e.g., silt fence or straw bale barrier) has caused the perimeter control to fail.

## 2.0 Purpose and Applicability of Best Management Practice

Rock filter outlets are an additional perimeter control measure used when silt fence or straw bale barriers have failed due to sheet flow and/or shallow concentrated flow to a common low area along the alignment of the perimeter control, and where a sediment trap may not be warranted.

## 3.0 Planning and Considerations

If small areas of concentrated flow are identified at the perimeter of the site that may cause perimeter controls to be undermined or overtopped, use rock filter outlets at these concentrated flow points.

Additionally, if a buildup of sediment-laden runoff to a perimeter control is observed after installation, use a rock filter outlet to provide higher flow-through rates.

Rock filter outlets are installed where flow concentrates, typically in combination with silt fence or straw bale barriers, to prevent spillover or bypass of the perimeter control.

Because rock filter outlets are typically placed at points of failure or compromise in a perimeter control, efforts to break up the area tributary to the failure may result in more optimal performance of the rock filter outlet and the perimeter control to which it is ancillary.

## 4.0 Stormwater Performance Summary

### 4.1 MS-4: FIRST-STEP MEASURES

Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment will be constructed as a first step in any land-disturbing activity and will be made functional before upslope land disturbance takes place.

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: Low**

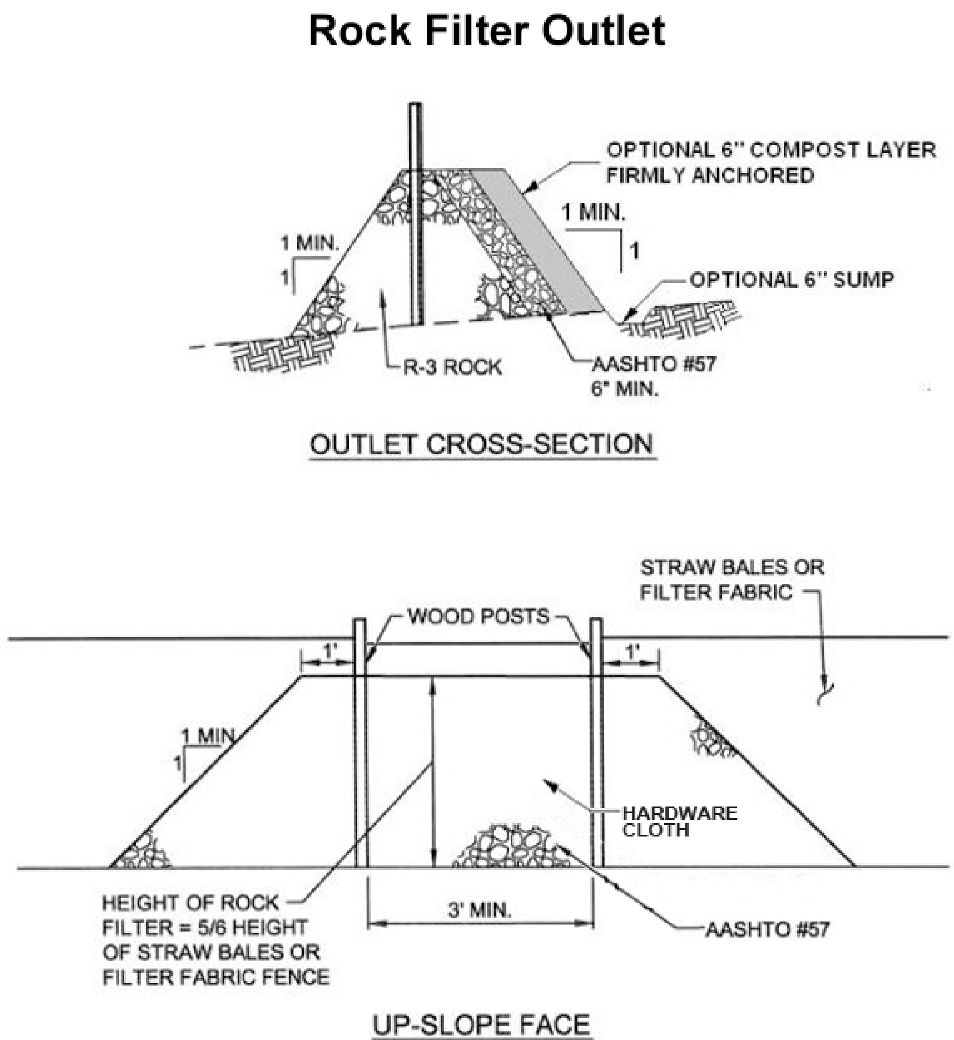
## 5.0 Design Criteria

| Table C-SCM-08-1 Rock Filter Outlet Design Criteria | |
|---|---|
| Material | Construct the rock filter outlet of Class A1 riprap with a 6-inch-thick layer of Virginia Department of Transportation (VDOT) #3, #357, or #5 coarse aggregate on the upslope face of the rock filter. |
| Drainage Area | Do not allow more than 0.25 acre of surface area to drain to a rock filter outlet. |
| Side Slopes | The minimum side slope of the rock filter is 1H:1V. |
| Top Length | The minimum top width of the rock filter is 5 feet with 1 foot extending beyond the silt fence or straw bale barriers on both sides such that a minimum of 3 feet of the rock filter is between the two sections of silt fence or straw bale barriers. |
| Top Width | The minimum top width is 1 foot. |
| Height | Construct the rock filter to be a minimum of five sixths the height of the silt fence filter fabric or straw bale barriers. |
| Sump | Install an optional 6-inch-deep sump on the upslope side of the rock filter outlet to provide additional sediment removal capacity. |

## 6.0 Construction Specifications

1. Where a silt fence or straw bale barrier has been compromised or a failure has occurred, cut a 3-foot section out of the silt fence or remove a 3-foot section of the straw bale barrier. Install two new posts at each end of the newly cut silt fence and attach the filter fabric to the newly installed support posts. Install support stakes in the remaining portions of the straw bale barrier where a section was removed.
2. Install the riprap portion of the rock filter outlet, and then place the layer of coarse aggregate on the upslope side.

***Figure C-SCM-08-1 Rock Filter Outlet Detail***




## 7.0 Operations and Maintenance Considerations

Inspect rock filter outlets immediately after each rainfall and at least daily during prolonged rainfall. Make any required repairs immediately.

Remove sediment when accumulations reach one third the height of the outlet.

Replace clogged riprap and coarse aggregate as necessary to maintain the functionality of the rock filter.

Replace any dislodged or dislocated riprap or coarse aggregate immediately.

Inspect vicinity for subsidence, and repair promptly if found.

Remove and dispose of the rock filter outlet following stabilization of disturbed areas upslope of the outlet.

## 8.0 References

PADEP. 2012. Erosion and Sediment Pollution Control Program Manual. Final. Technical Guidance Number 363-2134-008. March. Available online at: http://www.depgreenport.state.pa.us/elibrary/GetFolder?FolderID=4680.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-SCM-09 Turbidity Curtain

## 1.0 Definition

A turbidity curtain is a floating geotextile material that minimizes sediment transport from a disturbed area adjacent to or within a body of water.

– CAD C-SCM-09-1 Turbidity Curtain

– CAD C-SCM-09-2 Turbidity Curtain Type III

– CAD C-SCM-09-3 Turbidity Curtain Typical Layouts

## 2.0 Purpose and Applicability of Best Management Practice

The purpose of a turbidity curtain is to provide sedimentation protection for a watercourse from upslope land disturbance or from dredging or filling within the watercourse.

Turbidity curtains apply to non-tidal and tidal watercourses where intrusion into the watercourse by construction and subsequent sediment movement are unavoidable.

## 3.0 Planning and Considerations

Soil loss into a watercourse results in long-term suspension of sediment. In time, the suspended sediment may travel long distances and affect widespread areas. A turbidity curtain is designed to deflect and contain sediment and provide enough residence time so that soil particles will fall out of suspension and not travel to other areas.

Select the type of turbidity curtain to be used based on the flow conditions within the water body – whether it be a flowing channel, lake, pond, or a tidal watercourse. The specifications contained herein pertain to minimal and moderate flow conditions in which the velocity of flow may reach 5 feet per second (or a current of approximately 3 knots). Where there are greater flow velocities or currents, consult a qualified engineer and product manufacturer.

Consider the direction of water movement in channel flow situations. Turbidity curtains are not designed to act as water impoundment dams and cannot be expected to stop the flow of a significant volume of water. Turbidity curtains are designed and installed to trap sediment, not to halt the movement of the water itself. For most situations, do not install turbidity curtains across channel flows.

In tidal or moving water conditions, make provisions to allow the volume of water contained within the curtain to change. Take measures to prevent the curtain from submerging because the volume of water contained within the curtain will be much greater at high tide verses low tide due to the bottom of the curtain being weighted and external anchors frequently added. In addition to allowing for slack in the curtain to rise and fall, allow water to flow through the curtain if it is to remain in roughly the same spot and to maintain the same shape. Normally, this is achieved by constructing part of the curtain from a heavy woven filter fabric. The fabric allows the water to pass through the curtain but retains the sediment pollutants. Consider the volume of water that must pass through the fabric and sediment particle size when specifying fabric permeability.

Sediment deflected and settled out by the curtain may be removed if directed by the on-site inspector or the certified plan reviewer. However, consider the probable outcome of removal, as it may create more of a sediment problem by resuspending particles and by accidental dumping of the material by the equipment involved. It is, therefore, recommended that the soil particles trapped by a turbidity curtain only be removed if there has been a significant change in the original contours of the affected area in the watercourse. Regardless of the decision made, allow soil particles to settle for a minimum of 6 hours before their removal by equipment or before removal of a turbidity curtain.

It is imperative that the intended function of the other controls in this chapter, to keep sediment out of the watercourse, be the strategy used in every erosion control plan. However, when proximity to the watercourse precludes successful mitigation of sediment loss, the use of the turbidity curtain during land disturbance is essential.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-12: WATERCOURSE CONSTRUCTION** – When work in a live watercourse is performed, precautions shall be taken to minimize encroachment, control sediment transport, and stabilize the work area to the greatest extent possible during construction. Non-erodible material shall be used for the construction of causeways and cofferdams. Earthen fill may be used for these structures if armored by non-erodible cover materials.

**MS-14: OTHER WATERCOURSE REGULATIONS** – All applicable federal, state, and local regulations pertaining to working in or crossing live watercourses shall be met.

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**Erosion Control Efficiency: LOW**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

| Table C-PCM-09-1 Design Criteria for Turbidity Curtains | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Types | Use Type I configuration (see Figure C-SCM-09-1) in areas that are sheltered from wind and waves.<br>Use Type II configuration (see Figure C-SCM-09-1) in areas where there may be small to moderate current running (up to 2 knots or 3.5 feet per second) and/or wind and wave action can affect the curtain.<br>Use Type III configuration (see Figure C-SCM-09-2) in areas where considerable current (up to 3 knots or 5 feet per second) may be present, where tidal action may be present, and/or where the curtain is potentially subject to wind and wave action. |
| Location | Install turbidity curtains parallel to the direction of flow of a moving body of water. Do not place turbidity curtains across the main flow of a significant body of moving water. |
| Alignment | Typical alignments of turbidity curtains are illustrated on Figure C-SCM-09-3. The number and spacing of external anchors may vary depending on current velocities and potential wind and wave action; follow manufacturer's recommendations. |
| Span | Attempt to avoid an excessive number of joints in the curtain; a minimum continuous span of 50 feet between joints is a good “rule of thumb.”<br>For stability reasons, a maximum span of 100 feet between joints (anchor or stake locations) is also a good rule to follow.<br>The ends of the curtain, floating upper, and weighted lower should extend well up into the shoreline, especially if high water conditions are expected. The ends should be secured firmly to the shoreline (preferably to rigid bodies such as trees or piles) to fully enclose the area where sediment may enter the water. |

| Table C-PCM-09-1 Design Criteria for Turbidity Curtains | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Length | Where the watercourse is not subject to tidal action and/or significant wind and wave forces, extend the turbidity curtains the entire depth of the watercourse.<br><br>In tidal and/or wind and wave action situations, do not allow the curtain to be long enough to touch the bottom. Make sure a minimum 1-foot “gap” exists between the weighted lower end of the skirt and the bottom at “mean” low water. Movement of the lower skirt over the bottom due to tidal reverses or wind and wave action on the floatation system may fan and stir sediments that have already settled out.<br><br>In tidal and/or wind and wave action situations, it is seldom practical to extend a turbidity curtain depth lower than 12 feet below the surface, even in deep water. Curtains installed deeper will be subject to very large loads with consequent strain on curtain materials and the mooring system. In addition, a curtain installed in such a manner can “billow up” towards the surface under the pressure of the moving water, which will result in an effective depth significantly less than the skirt depth.<br><br>When sizing the length of the floating curtain, allow an additional 10 to 20 percent variance in the straight-line measurements. This will allow for measuring errors, make installation easier, and reduce stress from potential wave action during high winds.<br><br>When there is a specific need to extend the curtain to the bottom of the watercourse in tidal or moving water conditions, a heavy woven pervious filter fabric may be substituted for the normally recommended impervious geotextile. This creates a “flow-through” medium, which significantly reduces the pressure on the curtain and will help to keep it in the same relative location and shape during the rise and fall of tidal waters. |

## 6.0 Construction Specifications

| Table C-SCM-09-2 Material Specifications for Turbidity Curtains | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Barriers | Use barriers with a bright color (yellow or “international” orange are recommended) that will attract the attention of nearby boaters. |
| Floatation | Use floatation devices that are flexible, buoyant units contained in an individual floatation sleeve or collar attached to the curtain (see Figure C-SCM-09-2).<br><br>Ensure the buoyancy provided by the floatation units is sufficient to support the weight of the curtain and maintain a freeboard of at least 3 inches above the water surface level |
| Curtain | Ensure the curtain fabric meets the minimum requirements in Table C-SCM-09-3. Ensure seams in the fabric are either vulcanized welded or sewn and develop the full strength of the fabric. |

| Table C-SCM-09-2 Material Specifications for Turbidity Curtains | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Load Lines | Use load lines fabricated into the bottoms of all floating turbidity curtains. For Type II and Type III, use load lines fabricated into the top and bottom of the fabric. Use a top load line consisting of woven webbing or vinyl-sheathed steel cable that has a break strength of more than 10,000 pounds. Use a supplemental (bottom) load line consisting of a chain incorporated into the bottom hem of the curtain of sufficient weight to serve as ballast and hold the curtain in a vertical position. Provide additional anchorage as necessary. Ensure the load lines have connecting devices suitable for developing the full breaking strength for connecting to load lines in adjacent sections (see Figure C-SCM-09-1 and Figure C-SCM-09-2, which portray this orientation). |
| External Anchors | External anchors may consist of wooden or metal stakes (2- x 4-inch or 2.5-inch minimum diameter wood or 1.33 pounds/linear foot steel) when Type I installation is used. When using Type II or Type III installations, use bottom anchors. |
| Bottom Anchors | Ensure bottom anchors are sufficient to hold the curtain in the same position relative to the bottom of the watercourse without interfering with the action of the curtain. The anchor may dig into the watercourse bottom (grappling hook, plow, or fluke-type) or may be weighted (mushroom type) and attached to a floating anchor buoy via an anchor line. The anchor line would then run from the buoy to the top load line of the curtain. When used with Type III installations, ensure these lines contain enough slack to allow the buoy and curtain to float freely with tidal changes without pulling the buoy or curtain down and check the lines regularly to make sure they do not become entangled with debris. As previously noted, anchor spacing will vary with current velocity and potential wind and wave action; follow manufacturer's recommendations. See orientation of external anchors and anchor buoys for tidal installation on Figure C-SCM-09-2. |

| Table C-SCM-09-3 Material Specifications for Curtain Fabric | |
|---|---|
| **Physical Property** | **Requirement** |
| Thickness (mils) | 45 |
| Weight (oz./sq. yd.) | |
| Type I | 18 |
| Type II | 18 or 22 |
| Type III | 22 |
| Woven Geotextile Grab Tensile Strength (lbs.) | 200 |
| UV Inhibitor | Must be included |

**6.1 Installation**

1. In the calm water of lakes or ponds (Type I installation), it is usually sufficient to merely set the curtain end stakes or anchor points (using anchor buoys if bottom anchors are employed), then tow the curtain in the furled condition out and attach it to the stakes or anchor points. Subsequently, any additional stakes or buoyed anchors required to maintain the desired location of the curtain may be set and these anchor points made fast to the curtain. Cut the furling lines to drop the curtain skirt.
2. In rivers or other moving water (Type II and Type III installations), it is important to set all curtain anchor points. Take care to ensure that anchor points are of sufficient holding power to retain the curtain under the existing current conditions before putting the furled curtain into the water. Again, employ anchor buoys on all anchors to prevent the current from submerging the floatation at the anchor points. If the moving water into which the curtain is being installed is tidal and will subject the curtain to currents in both directions as the tide changes, it is important to provide anchors on both sides of the curtain for two reasons:
    a. Curtain movement will be minimized during tidal current reversals.
    b. The curtain will not overrun the anchors and pull them out when the tide reverses. When the anchors are secure, secure the furled curtain to the upstream anchor point and then sequentially attach to each subsequent downstream anchor point until the entire curtain is in position. At this point, and before unfurling, assess the "lay" of the curtain and make any necessary adjustments to the anchors. Finally, when the location is ascertained to be as desired, cut the furling lines to drop the skirt.
3. Always attach anchor lines to the floatation device, not to the bottom of the curtain. The anchoring line attached to the floatation device on the downstream side will support the curtain. Attaching the anchors to the bottom of the curtain could cause premature failure due to the stresses imparted on the middle section of the curtain.
4. Turbidity curtains may be installed across channel flows when there is a danger of silt buildup in the middle of a watercourse, thereby blocking access or creating a sand bar. Curtains have been used effectively in large areas of moving water by forming a very long-sided, sharp "V" to deflect clean water around a work site, confine a large part of the silt-laden water to the work area inside the "V," and direct much of the silt toward the shoreline. Take care not to install the curtain perpendicular to the water current.
5. See Figure C-SCM-09-3 for typical installation layouts.

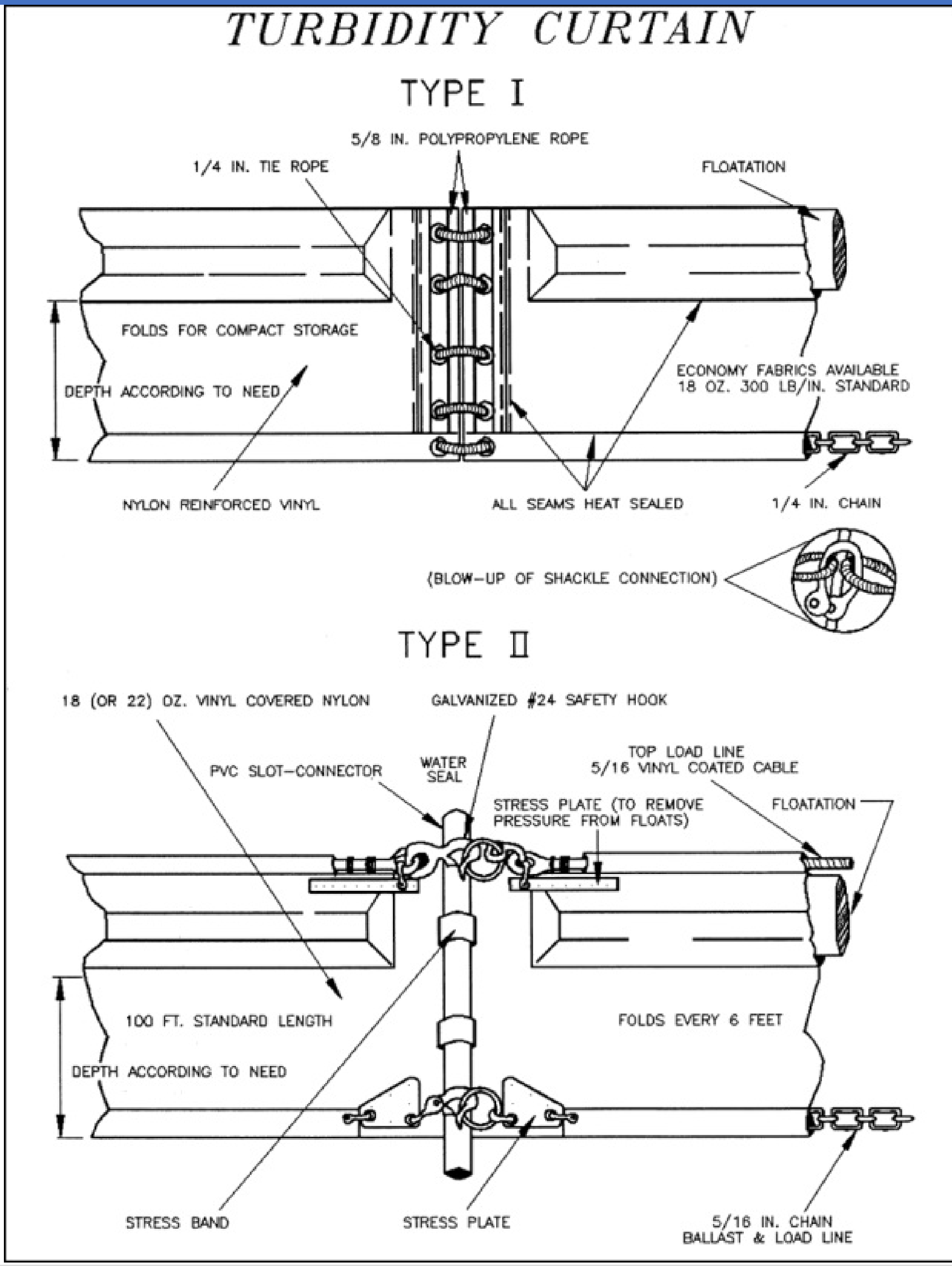
**6.2 Removal**

1. Take care to protect the skirt from damage as the turbidity curtain is dragged from the water.
2. The site selected to bring the curtain ashore should be free of sharp rocks, broken cement, debris, and other hazards to minimize damage when hauling the curtain over the area.
3. If the curtain has a deep skirt, it can be further protected by running a small boat along its length with a crew installing furling lines before attempting to remove the curtain from the water.

## 7.0 Operations and Maintenance Considerations

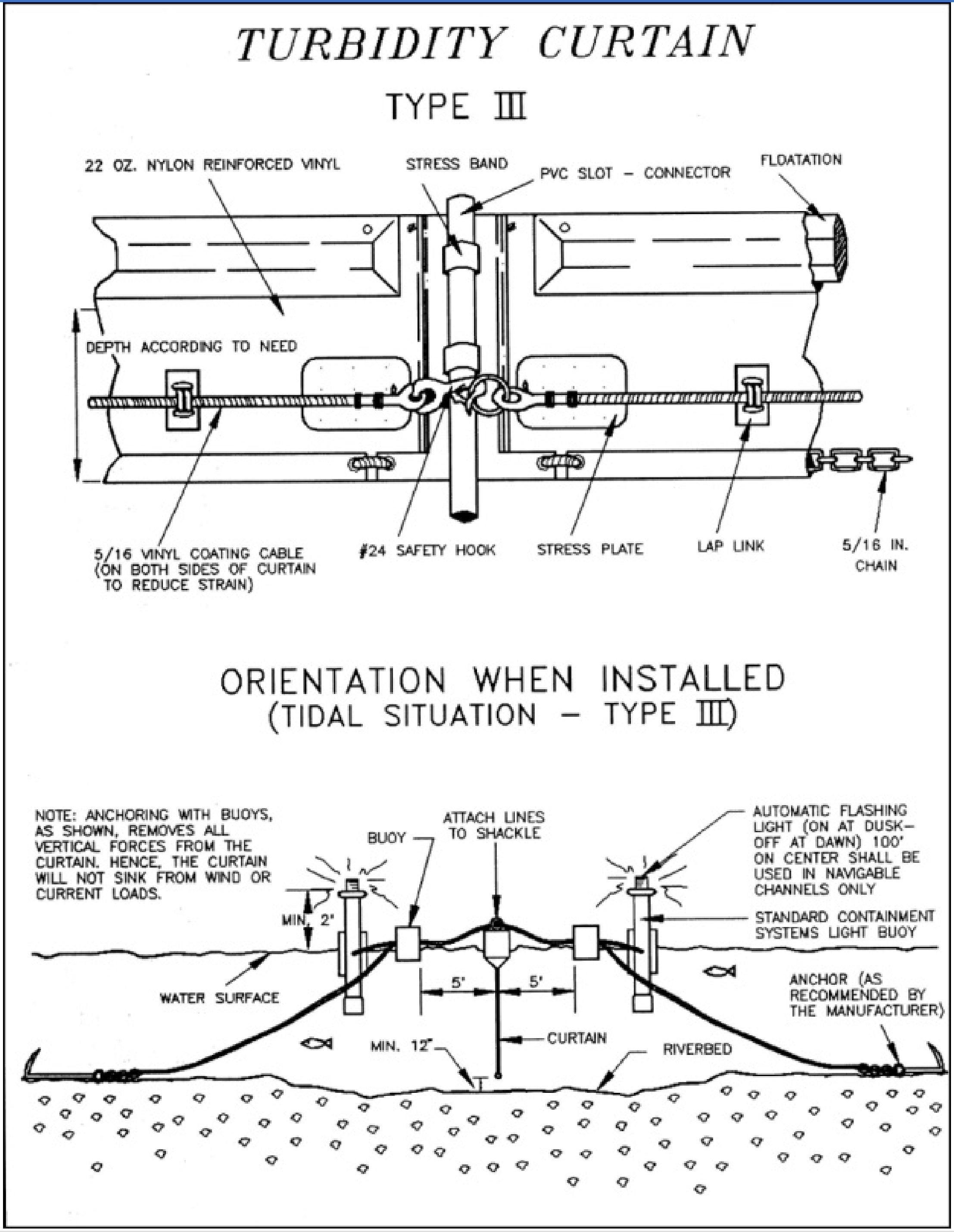
1. Maintain the filter curtain during the project to ensure the continuous protection of the watercourse.
2. Repair the geotextile fabric as necessary using repair kits available from the manufacturer. Follow the manufacturer's instructions to ensure the adequacy of the repair.
3. When the curtain is no longer required, remove the curtain and related components to minimize turbidity. Ensure the remaining sediment is sufficiently settled before removing the curtain. Sediment may be removed and the original watercourse depth (or plan elevation) restored. Transport any spoils to an upland area and stabilize the spoils.

**Figure C-SCM-09-1 – Turbidity Curtain Type I & II**



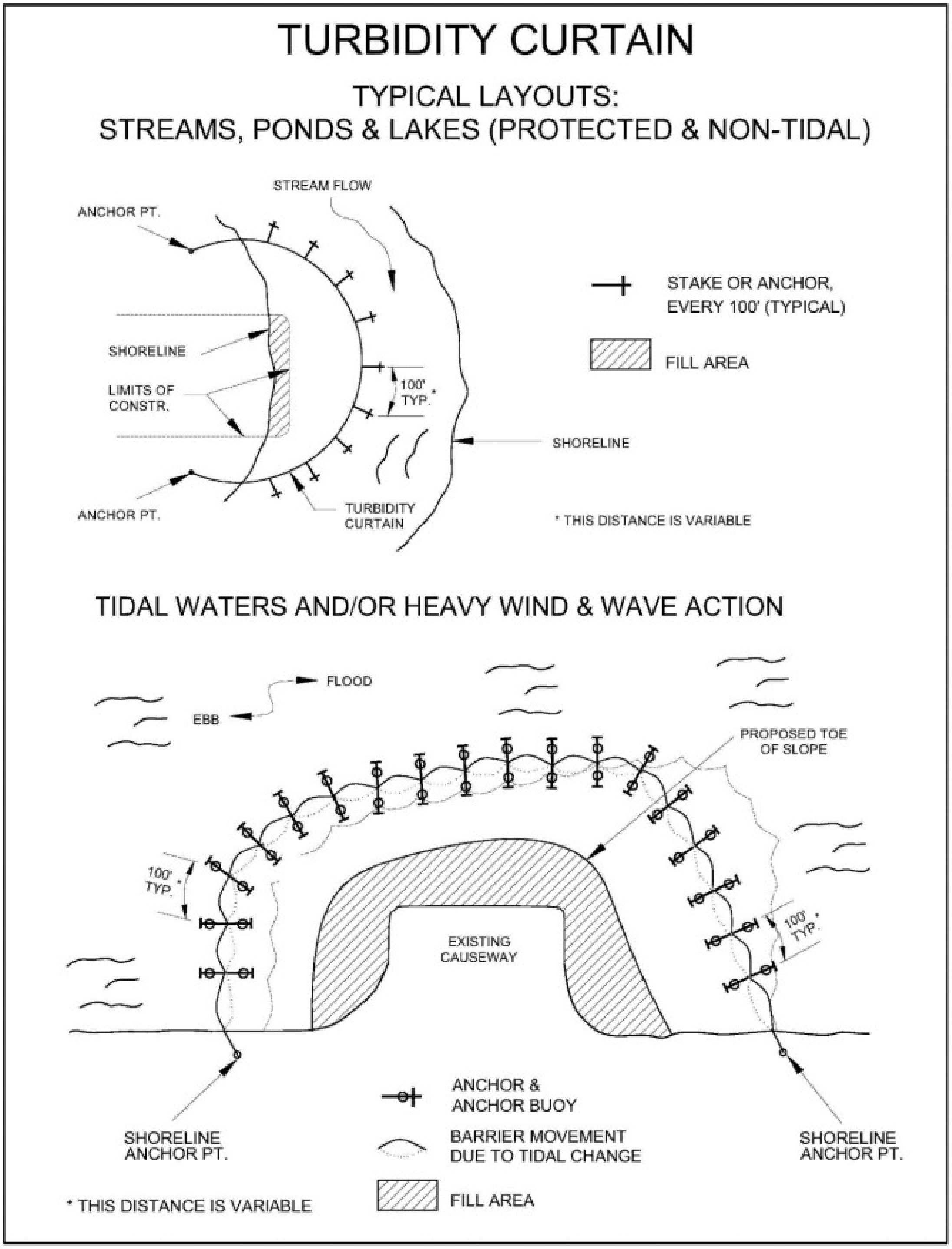

*Source: American Boom and Barrier Corp. product literature*

**Figure C-SCM-09-2 Turbidity Curtain Type III**




*Source: Adapted from American Boom and Barrier Corp. and Virginia Department of Transportation (VDOT) Standard Sheets*

**Figure C-SCM-09-3 Turbidity Curtain Typical Layouts**




SOURCE: ADAPTED FROM FLORIDA DEPARTMENT OF TRANSPORTATION ROAD AND DESIGN SPECIFICATIONS

## 8.0 References


VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

# C-SCM-10 Dewatering Structure

## 1.0 Definition

A dewatering structure is a temporary settling and filtering device used to process water discharged from dewatering activities.

– CAD C-SCM-10-1 Portable Sediment Tank

– CAD C-SCM-10-2 Filter Box

– CAD C-SCM-10-3 Straw Bale/Silt Fence Pit

## 2.0 Purpose and Applicability of Best Management Practice

Dewatering structures filter sediment-laden water before the water is discharged off site.

Dewatering structures are appropriate where sediment-laden water needs to be removed from a construction site by means of pumping.

## 3.0 Planning and Considerations

Water pumped from a construction site usually contains a large amount of sediment. A dewatering structure is designed to remove the sediment before releasing the water off site.

This practice includes several types of dewatering structures that have different applications depending on site conditions and types of operation. Other innovative techniques for accomplishing the same purpose are encouraged, but only after specific plans and details are submitted to and approved by the certified plan reviewer.

A dewatering structure may not be needed if there is a non-sloping, well-stabilized, vegetated area on site to which water may be discharged. A relatively flat, well-stabilized, vegetated area is required so that it can filter sediment and withstand the velocity of the discharged water without eroding.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance.

**MS-6: TRAPS AND BASINS** – Sediment traps and basins shall be designed and constructed based on the total drainage area they serve.

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**Erosion Control Efficiency: LOW**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

| Table C-SCM-10-1 Design Criteria for Dewatering Structures | |
|---|---|
| **Parameter** | **Notes on Proper Use** |
| Size | Size and operate a dewatering structure to allow pumped water to flow through the filtering device without overtopping the structure.<br>Use the following formula to determine the storage volume of the dewatering structure:<br>***Pump discharge (gpm) x 16 = cubic feet of storage required*** |
| Location | Locate dewatering structure away and downhill from stockpiles or excavation spoil piles. Do not place dewatering structure where treated water will be allowed to flow back into the workspace.<br>Ensure a minimum filtering length of 75 feet is available downgradient of the dewatering structure so that the existing well-established vegetated area can adequately filter sediment. |
| Lining | An excavated basin (applicable to “Straw Bale/Silt Fence Pit”) may be lined with filter fabric to help reduce scour and to prevent the inclusion of soil from within the structure. |
| Additional Criteria | Design criteria more specific to each dewatering device are provided on Figure C-SCM-10-1, Figure C-SCM-10-2, Figure C-SCM-10-3, Figure C-SCM-10-4, and Figure C-SCM-10-5. |

gpm = gallons per minute

## 6.0 Construction Specifications

| Table C-SCM-10-2 Material Specifications for Dewatering Structures | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Portable Sediment Tank (Figure C-SCM-10-1) | Construct the structure with steel drums, sturdy wood, or other material suitable for handling the pressure exerted by the associated volume of water.<br><br>Use sediment tanks with a minimum depth of 2 feet.<br>Locate the sediment tank for easy cleanout and disposal of the trapped sediment and to minimize interference with construction.<br>Once the water level nears the top of the tank, the pump must be shut off while the tank drains and additional capacity is made available.<br>Design the tank to allow for emergency flow over the top of the tank.<br>Clean out the tank once one third of the original capacity is depleted due to sediment accumulation. Clearly mark the tank showing the cleanout point. |
| Filter Box (Figure C-SCM-10-2) | Ensure the box selected is made of steel, sturdy wood, or other materials suitable to handle the pressure requirements imposed by the associated volume of water. Fifty-five- gallon drums welded top to bottom are normally readily available and, in most cases, will suffice.<br>Make the bottom of the box porous by drilling holes (or some other method). Place Virginia Department of Transportation (VDOT) #3 Coarse Aggregate over the holes at a minimum depth of 12 inches. Place metal “hardware” cloth between the aggregate and the holes if holes are drilled larger than most of the stone.<br>Due to the fast flow rate of sediment-laden water through the aggregate, direct the effluent over a well-vegetated strip of at least 50 feet after leaving the base of the filter box.<br>Once the water level nears the top of the box, shut off the pump while the box drains and additional capacity is made available. Design/construct the box to allow for emergency flow over the top of the box.<br>Clean out the box once one third of the original capacity is depleted due to sediment accumulation. Clearly mark the box showing the cleanout point. If the stone filter does become clogged with sediment so that it no longer adequately performs its function, pull the stones away from the inlet and clean and replace the stone.<br>Note: Using a filter box only allows for minimal settling time for sediment particles; therefore, it should only be used when site conditions restrict the use of other methods. |

| Table C-SCM-10-2 Material Specifications for Dewatering Structures | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Straw Bale/Silt Fence Pit (Figure C-SCM-10-3) | Ensure the pit consists of straw bales, silt fence, a stone outlet (a combination of VDOT Class AI Riprap and VDOT #25 or #26 Aggregate), and a wet storage pit oriented as shown on Figure C-SCM-10-3. For the straw bale pit, use a filter fabric to line the face of the straw bales that conforms to the requirement identified in Riprap (BMP C-ECM-13).<br><br>In calculating the capacity, include the volume available from the floor of the excavation to the crest of the stone weir. In any case, ensure the excavation is a minimum of 3 feet below the base of the perimeter measures (straw bales or silt fence).<br><br>Install the perimeter measures as per the guidelines in Straw Bale Barrier (C-PCM-02) and Silt Fence (C-PCM-04).<br><br>Once the water level approaches the crest of the stone weir (emergency overflow), shut off the pump while the structure drains down to the elevation of the wet storage. The wet storage pit may be dewatered only after a minimum of 6 hours of sediment settling time. Pump this effluent across a well-vegetated area or through a silt fence or compost filter sock before allowing it to enter a watercourse.<br><br>Once the wet storage area becomes filled to one half of the excavated depth, remove and dispose of accumulated sediment. Once the device has been removed, ground contours will be returned to original condition. |

| Table C-SCM-10-2 Material Specifications for Dewatering Structures | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Pumped Water Filter Bag (Figure C-SCM-10-4) | Use low-volume filter bags made from non-woven monofilament geotextile material sewn with high-strength, double-stitched "J" type seams. Use filter bags capable of trapping particles larger than 150 microns.<br><br>Use high-volume filter bags made from woven monofilament that meet the requirements included in Table C-SCM-10-3.<br>Provide a suitable means of accessing the bag with machinery required for disposal purposes.<br>Replace filter bags when they become half full of sediment. Keep spare bags available for replacement of those that have failed or are filled. Place bags on straps to facilitate removal unless bags come with lifting straps already attached.<br>Locate bags in a well-vegetated (grassy) area and discharge onto stable, erosion-resistant areas. Where this is not possible, provide a geotextile underlayment and flow path. Bags may be placed on filter stone to increase discharge capacity. Do not place bags on slopes greater than 5%. For slopes exceeding 5%, clean rock or other non-erodible and non-polluting material may be placed under the bag to reduce slope steepness.<br><br>No downslope sediment barrier is required for most installations. Install Silt Fence (BMP C-PCM-04) or Compost Filter Sock (BMP C-PCM-05) below bags located within 50 feet of any receiving surface water or where a grassy area is not available. |

*Source: Cascade Geotecnical 2023.*

| Table C-SCM-10-2 Material Specifications for Dewatering Structures | |
|---|---|
| **Approach** | **Notes on Proper Use** |
| Sump Pit (Figure C-SCM-10-5) | Locate sump at a low point in the work area and away from construction activity. Where runoff from a work area flows directly to the sump area, attach a pumped water filter bag at the discharge point unless pumping to a sediment basin or sediment trap.<br>Excavate the pit to three times the pipe diameter and a minimum of 4 feet deep. Place a minimum of 6 inches of clean 0.75- to 1.5-inch stone on the bottom of the pit.<br>Use a 12-inch or larger corrugated metal pipe, high-density polyethylene (HPDE) or polyvinyl chloride (PVC) pipe with 1-inch-diameter perforations, 6 inches on center. Cap the bottom of the pipe with a watertight seal.<br>Wrap pipe with 0.25-inch galvanized hardware cloth and wrap non-woven geotextile over the hardware cloth.<br>Place the pipe vertically into the pit and extend the pipe a minimum of 6 inches above the top of stone.<br>Backfill the pit around the pipe with 0.75- to 1.5-inch stone and extend stone a minimum of 6 inches above the anticipated water surface elevation.<br>Set pump intake inside standpipe.<br>Pump discharge water to a stable area below disturbances from the work zone.<br>If the system clogs, remove perforated pipe and replace geotextile and stone. Keep point of discharge free from erosion. |

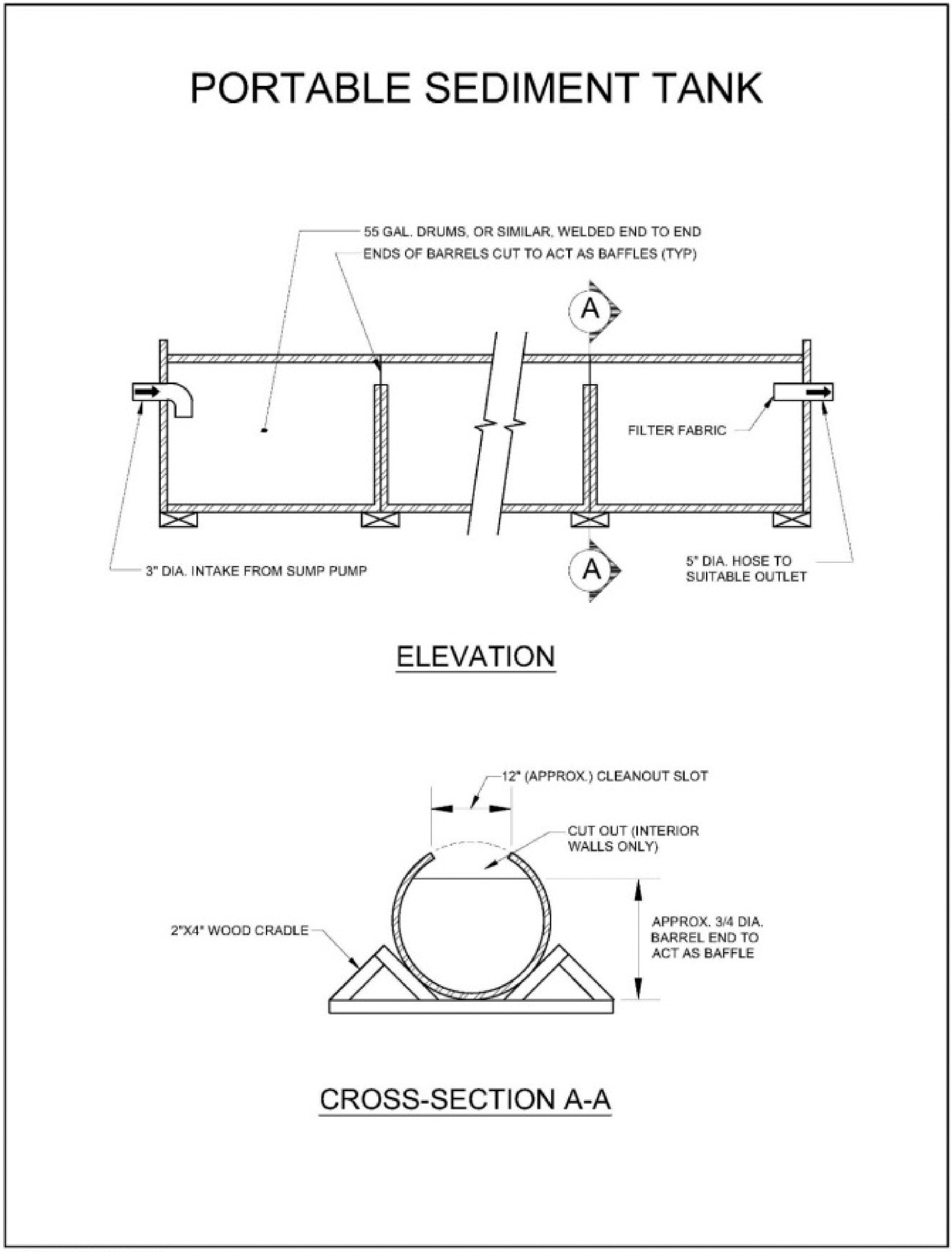
| Table C-SCM-10-3 Material Specifications for Pumped Water Filter Bag | | |
|---|---|---|
| **Property** | **Test Method** | **Minimum Standard** |
| Avg. Wide Width Strength | ASTM D-4884 | 60 lb/in |
| Grab Tensile | ASTM D-4632 | 205 lb |
| Puncture | ASTM D-4833 | 110 lb |
| Mullen Burst | ASTM D-3786 | 350 psi |
| UV Resistance | ASTM D-4355 | 70% |
| AOS % Retained | ASTM D-4751 | 80 Sieve |

## 7.0 Operations and Maintenance Considerations

1. Inspect the filtering devices daily and repair or replace once the sediment buildup prevents the structure from functioning as designed.
2. Remove the accumulated sediment from the dewatering device, spread on site, and stabilize or dispose of at an approved disposal site as per approved plan.

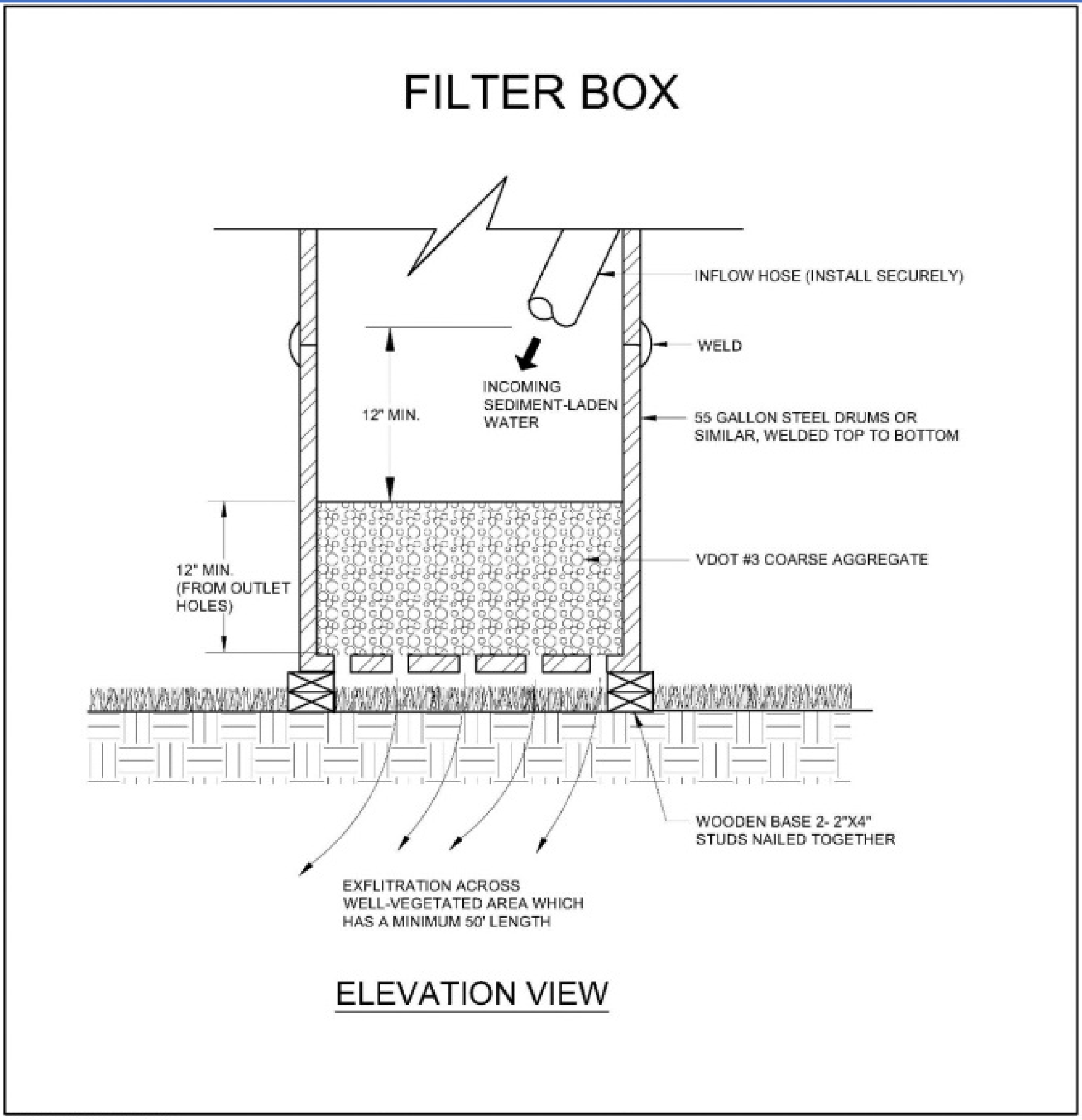
3. Monitor the dewatering structure during operation to ensure that the discharge is not causing erosion. Provide Soil Stabilization Blankets and Matting (BMP C-SSM-05) or Compost Filter Socks (BMP C-PCM-05) as needed to maintain stabilized areas downstream of structure.

**Figure C-SCM-10-1 Portable Sediment Tank**



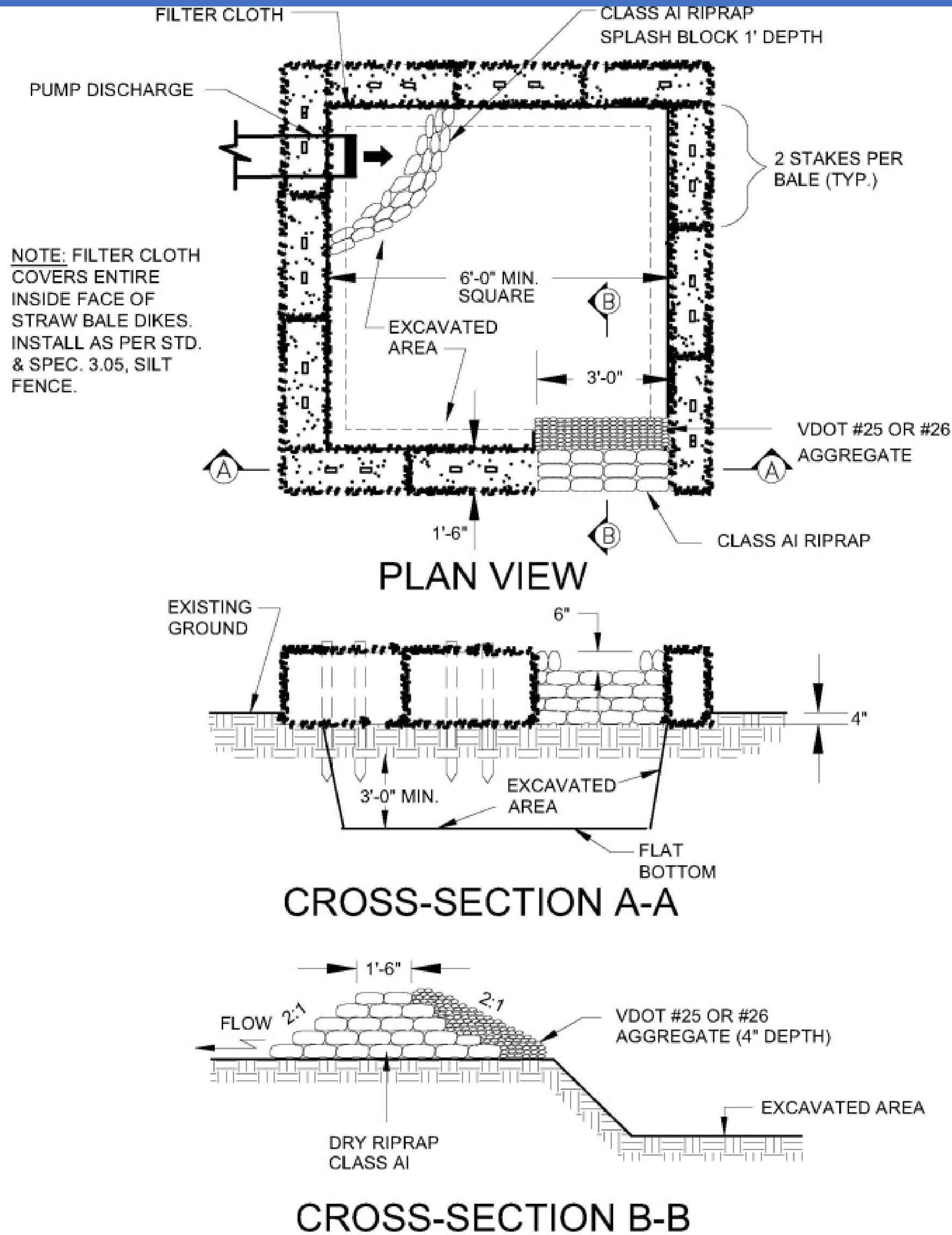

SOURCE: USDA - SCS

## *Figure C-SCM-10-2 Filter Box*



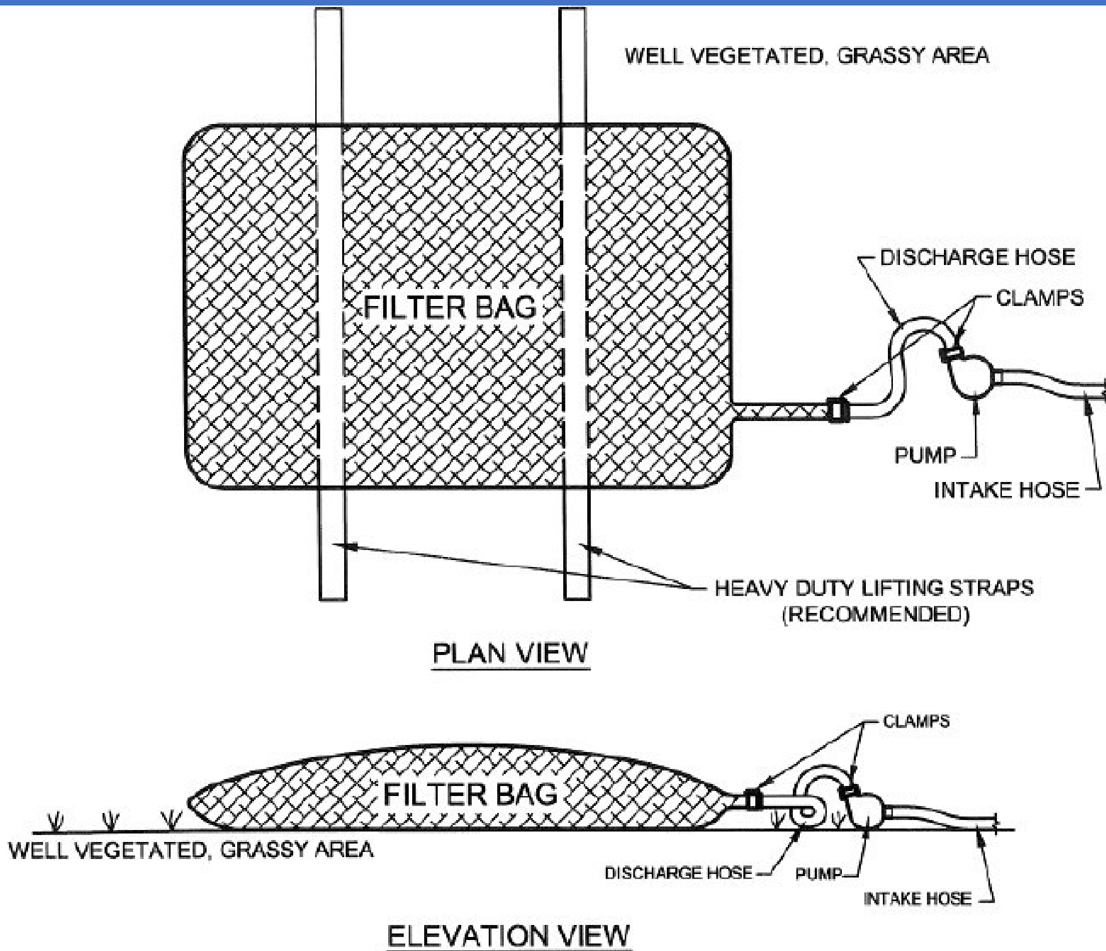

SOURCE: VA. DSWC

## *Figure C-SCM-10-3 Straw Bale/Silt Fence Pit*



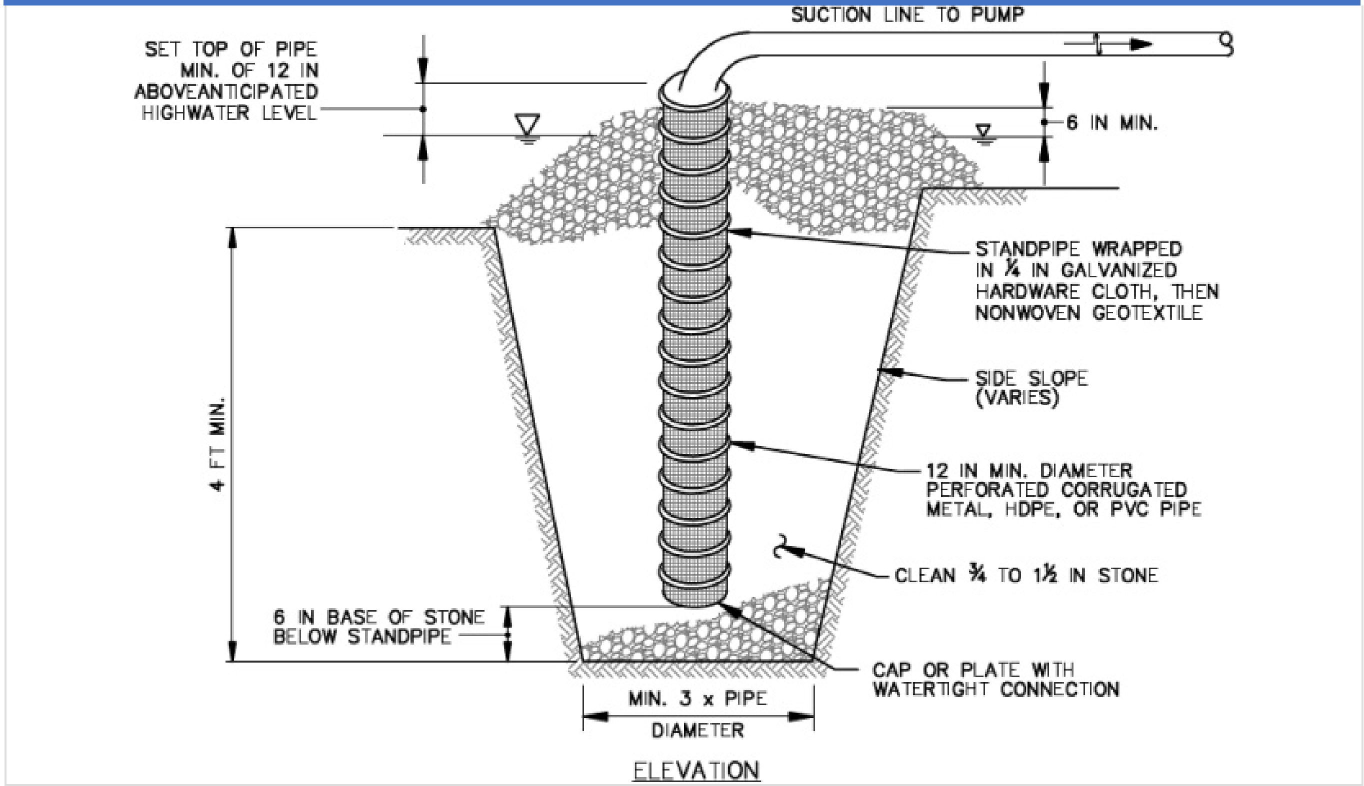

*Source: Va. DSWC*

### *Figure C-SCM-10-4 Filter Bag*




*Source: PADEP 2012*

## Figure C-SCM-10-5 Sump Pit




*Source: Maryland Water Management Administration et al. 2011*

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# C-SCM-11 Temporary Sediment Trap

## 1.0 Definition

A temporary sediment trap is a temporary ponding basin formed by constructing an embankment, often earthen or composed of compost filter sock, with a stone outlet.

– CAD C-SCM-11-1 Minimum Top Width (W) Required for Sediment Trap Embarkments According to Height of Embankment (Feet)

– CAD C-SCM-11-2 Temporary Sediment Trap

## 2.0 Purpose and Applicability of Best Management Practice

Temporary sediment traps are used to detain sediment-laden runoff from small, disturbed areas long enough to allow much of the sediment to settle out to protect water quality in receiving streams, lakes, drainage systems, and adjacent property.

Use a temporary sediment trap:

- Along the contour of the site, below the disturbed areas where the total contributing drainage area per trap is less than 3 acres;
- Where the sediment trap will be used no longer than 18 months (the maximum useful life is 18 months); and
- Where the sediment trap may be constructed either independently or in conjunction with a Temporary Diversion Dike (BMP C-ECM-04).

## 3.0 Planning and Considerations

Select locations for sediment traps during site evaluation. Note natural drainage divides and select trap sites so that runoff from potential sediment-producing areas can easily be diverted into the traps. Ensure the total contributing drainage area for each trap does not exceed 3 acres.

Construct temporary sediment traps, along with other perimeter controls intended to trap sediment, as a first step in any land-disturbing activity and make it functional before upslope land disturbance.

In most cases, excavation will be required to attain the necessary sediment trap storage volume. Additionally, periodic sediment removal will be necessary to maintain the required sediment trap storage volume. Plans should detail how excavated sediment is to be disposed of, such as by use in fill areas on site or removal to an approved off-site location.

Judiciously consider variations in the design to ensure that the minimum storage requirements and structural integrity noted in this specification are maintained.

Avoid locating traps on steep or unstable slopes where possible. Where not possible, address how failure of the trap will be avoided in the design. Do not locate sediment traps within stream channels or in wetlands.

Avoid placing sediment traps where they will impede active construction. Locate sediment traps to maximize their effective lifespan treating runoff from the construction.

Compost filter sock traps may be used for some locations if the installation procedure for such a trap is followed and the type of sock is suitable for the length of time for which the trap will be in use.

Outlet the sediment trap onto stabilized (preferable undisturbed) ground, into a watercourse, stabilized channel, or into a storm drain system. Maximize the distance between inlet and outlet to the longest length practicable.

Outlet protection must be designed in accordance with Outlet Protection (BMP C-ECM-15). The area below the outlet must not be obstructed to allow free flow from the trap when it is discharging. The drainage path must not be impeded with silt fence or other control measures that do not have the capacity the pass the discharge flows without damage.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-6: TRAPS AND BASINS** – Sediment traps and sediment basins shall be designed and constructed based upon the total drainage area to be served by the trap or basin.

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**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: High**

## 5.0 Design Criteria

| Table C-SSM-11-1 Design Criteria for Temporary Sediment Trap | |
|---|---|
| Drainage Area | Design the sediment trap so that the total contributing drainage area for each trap is less than 3 acres. If the contributing drainage area is 3 acres or greater, refer to Temporary Sediment Basin (BMP C-SCM-12). |
| Length of Use | A temporary sediment trap must remain in service, through proper upkeep, performance, and maintenance, until the contributing drainage area is stabilized or managed by a replacement best management practice (BMP). |
| Trap Capacity | Design the sediment trap to have an initial storage volume of 134 cubic yards/acre of drainage area. Where runoff computations are used, use runoff coefficients or curve numbers corresponding to a bare earth condition.<br><br>Permanent Pool or Wet Storage:<br><br>Half of the storage volume (67 cubic yards/acre) is reserved for a permanent pool (wet storage volume) to provide a stable settling medium.<br><br>Measure the wet storage volume from the low point of the excavated area to the base of the stone outlet structure.<br><br>Calculate the wet storage volume as follows:<br><br>$V_1 = 0.85 \times A_1 \times D_1$<br>Where:<br>$V_1$ = wet storage volume (cubic feet)<br>$A_1$ = surface area of the flooded area at the base of the stone outlet (square feet)<br>$D_1$ = maximum depth measured from the low point in the trap to the base of the stone outlet (feet) |

| Table C-SSM-11-1 Design Criteria for Temporary Sediment Trap | |
|---|---|
| Trap Capacity | Drawdown or Dry Storage:<br>Half of the storage volume (67 cubic yards/acre) provides extended settling time during less frequent, larger storm events.<br>Measure the dry storage volume from the base of the stone outlet to the crest of the stone outlet (overflow mechanism).<br>Calculate the dry storage volume as follows:<br>$V_2 = \frac{A_1 + A_2}{2} D_2$<br>where,<br>V2 = dry storage volume (cubic feet)<br>A1 = surface area of the flooded area at the base of the stone outlet (square feet)<br>A2 = surface area of the flooded area at the crest of the stone outlet (overflow mechanism) (square feet)<br>D2 = depth measured from the base of the stone outlet to the crest of the stone outlet (feet)<br>Remove sediment from the basin when the wet storage volume is reduced by half.<br>Note: Convert cubic feet to cubic yards as follows:<br>number of cubic feet x 0.037 = number of cubic yards |
| Length to Width Ratio | Provide a storage area with a minimum 2:1 length-to-width ratio measured from point of maximum runoff introduction to outlet. |
| Excavation | Ensure the side slopes of excavated areas are no steeper than 1H:1V. Design the trap such that the maximum depth of excavation within the wet storage area is 4 feet to facilitate cleanout and for site safety considerations. |
| Outlet: Design temporary sediment trap outlet configurations in accordance with one or more of the configurations described below. | |

| Table C-SSM-11-1 Design Criteria for Temporary Sediment Trap | |
|---|---|
| . 1. *Stone Outlet* | In this configuration, the outlet of the sediment trap consists of a stone section of the embankment set to the top of the wet storage volume.<br><br>Use a combination of coarse aggregate and riprap to provide for filtering/detention as well as outlet stability. Use Virginia Department of Transportation (VDOT) #3, #357, or #5 Coarse Aggregate (smaller stone sizes will enhance filter efficiency) for the smaller stone and "Class I" for the riprap. Place filter cloth that meets the physical requirements noted in Riprap (BMP C-ECM-13) at the stone-soil interface to act as a "separator."<br><br>Design the outlet so that the minimum outlet length is 6 feet times the number of acres comprising the total area draining to the trap. The stone outlet crest is at least 1 foot below the top of the embankment to ensure that the flow will travel over the stone and not the embankment. Configure the outlet as noted on Figure C-SCM-11-3. The ends of the stone outlet must extend 1 foot up to the elevation of the embankment to prevent erosion at the stone/soil interface during discharge. |
| 2. *Pipe Outlet* | In this configuration, the outlet for the trap is through a perforated riser and a pipe through the embankment. Use an outlet pipe and riser made of steel, corrugated metal, or other suitable material. Design the top of the embankment to be at least 1.5 feet above the crest of the riser. Dewatering of the sediment trap may be accomplished using a surface skimmer. If the riser alone is used for dewatering, perforate the top two thirds of the riser with 1-inch nominal diameter holes or slits spaced 6 inches vertically and horizontally placed in the concave portion of the corrugated pipe. Do not place holes or slits within 6 inches of the top of the horizontal barrel. Ensure all pipe connections are watertight. Wrap the riser with 0.5- to 0.25-inch hardware cloth wire, then wrap with filter cloth with a sieve size between #40 and #80 and secure with strapping or connecting band at the top and bottom of the cloth.<br><br>Ensure the cloth covers an area at least 6 inches above the highest hole and 6 inches below the lowest hole. Do not cover the top of the riser pipe with filter cloth. The riser will have a base with sufficient weight to prevent flotation of the riser (see Temporary Sediment Basin, BMP C-SCM-12).Select the riser and barrel diameters from Table C-SCM-11-3.Configure the outlet as noted on Figure C-SSM-11-3. Ensure that riser perforations remain free from clogging and debris. |

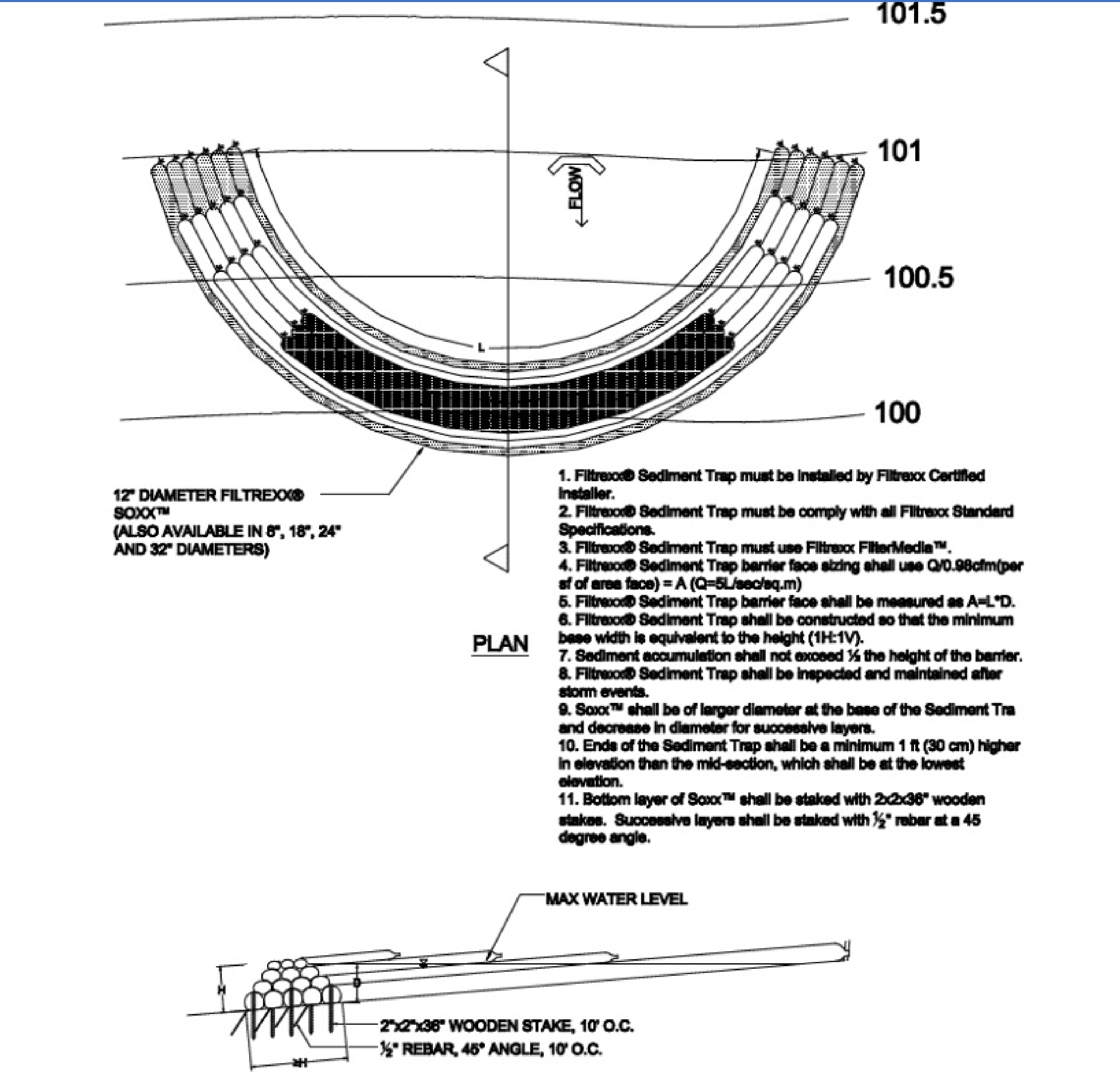
| Table C-SSM-11-1 Design Criteria for Temporary Sediment Trap | |
|---|---|
| 3. *Compost Filter Sock Outlet* | Use larger-diameter compost filter socks (18-inch, 24-inch, 32-inch) at the base of the sediment trap system with increasingly smaller-diameter compost filter socks (8-inch, 12-inch, 18-inch) placed on top to form a berm. Construct the compost filter sock berm to have a minimum effective height of 3 feet with a base width equivalent to the height. Additional height and runoff-sediment storage volume can be attained by excavating immediately upslope from the sediment trap. Ensure that excavation does not undermine the compost filter sock berm and integrity of the sediment trap system.<br><br>Stake the bottom larger-diameter compost filter socks forming the base of the sediment trap berm into the ground using 2-inch by 2-inch by 36-inch-long hardwood stakes placed 10 feet on center. Stake the top layer of smaller-diameter compost filter socks to the bottom layer of socks where the socks overlap using two 2-inch by 2-inch by 48-inch-long (minimum) hardwood stakes wrapped together with 16-gauge wire placed 10 feet on center, starting 5 feet from the bottom stakes. Ensure the angled stakes are placed a minimum of 18 inches into the ground and extend a minimum of 12 inches above the top layer of socks. |
| 4. *Compost Filter Sock Trap* | The compost filter sock embankment must be located to provide, in combination with excavation, a minimum of 134 cubic yards of storage at the design depth. Place compost filter sock sediment traps on low-grade or level contours to maximize runoff- sediment volume containment. The compost filter socks used to form the embankment will be continuous with no gaps or joints. Ensure the flow of water is perpendicular to the sediment trap at impact. Place sediment traps on undisturbed soil to reduce the potential for undermining. Do not place sediment traps on fill soil or slopes. Place compost material behind the bottom layer of compost filter sock to reduce undermining potential.<br><br>To prevent water flowing around the ends of sediment traps, construct the ends of the compost filter sock sediment trap pointing upslope with the ends a minimum of 1 foot higher in elevation than the lowest point (mid-section) of the sediment trap. Install the mid-section of the sediment trap to be the point of lowest elevation.<br><br>Configure the outlet as noted on Figure C-SSM-11-3. |
| *Embankment Cross-Section* | Design the sediment trap embankment so that the maximum height is 5 feet as measured from the base of the stone outlet. Design the minimum top widths and outlet heights for various embankment heights according to Table C-SCM-11-2.<br><br>Design the embankment sideslopes to be 2H:1V or flatter. |
| *Removal* | Remove sediment traps after the contributing drainage area is stabilized. Ensure that plans identify how the site of the sediment trap is to be graded and stabilized after removal. |

| Table C-SCM-11-2 Minimum Top Width Required for Sediment Trap Embankments According to Height of Embankment | | |
|---|---|---|
| Embankment Height (ft) | Outlet Crest Height (ft) | Minimum Embankment Top Width (ft) |
| 1.5 | 0.5 | 2.0 |
| 2.0 | 1.0 | 2.0 |
| 2.5 | 1.5 | 2.5 |
| 3.0 | 2.0 | 2.5 |
| 3.5 | 2.5 | 3.0 |
| 4.0 | 3.0 | 3.0 |
| 4.5 | 3.5 | 4.0 |
| 5.0 | 4.0 | 4.5 |

| Table C-SCM-11-3 Minimum Riser and Barrel Pipe Outlet Sizes | | |
|---|---|---|
| Maximum Drainage Area | Riser Diameter (in.) | Barrel Diameter (in.)[1] |
| 1 | 15 | 12 |
| 2 | 18 | 15 |
| 3 | 21 | 18 |

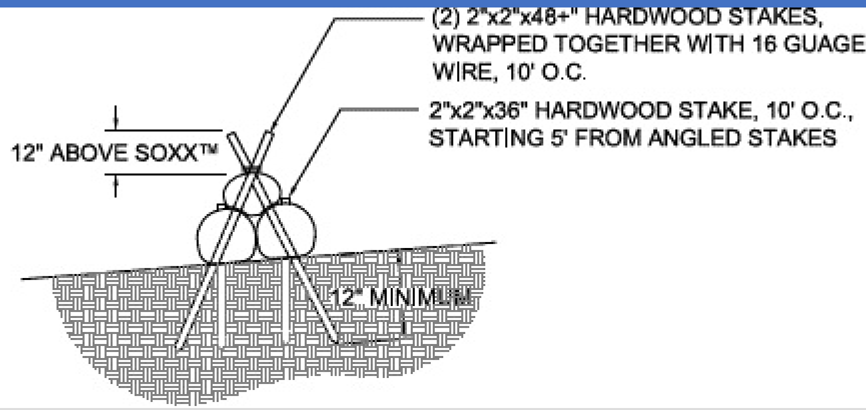
1. Barrel diameter may be same as riser diameter.

**Figure C-SCM-11-1 Compost Filter Sock Sediment Trap**



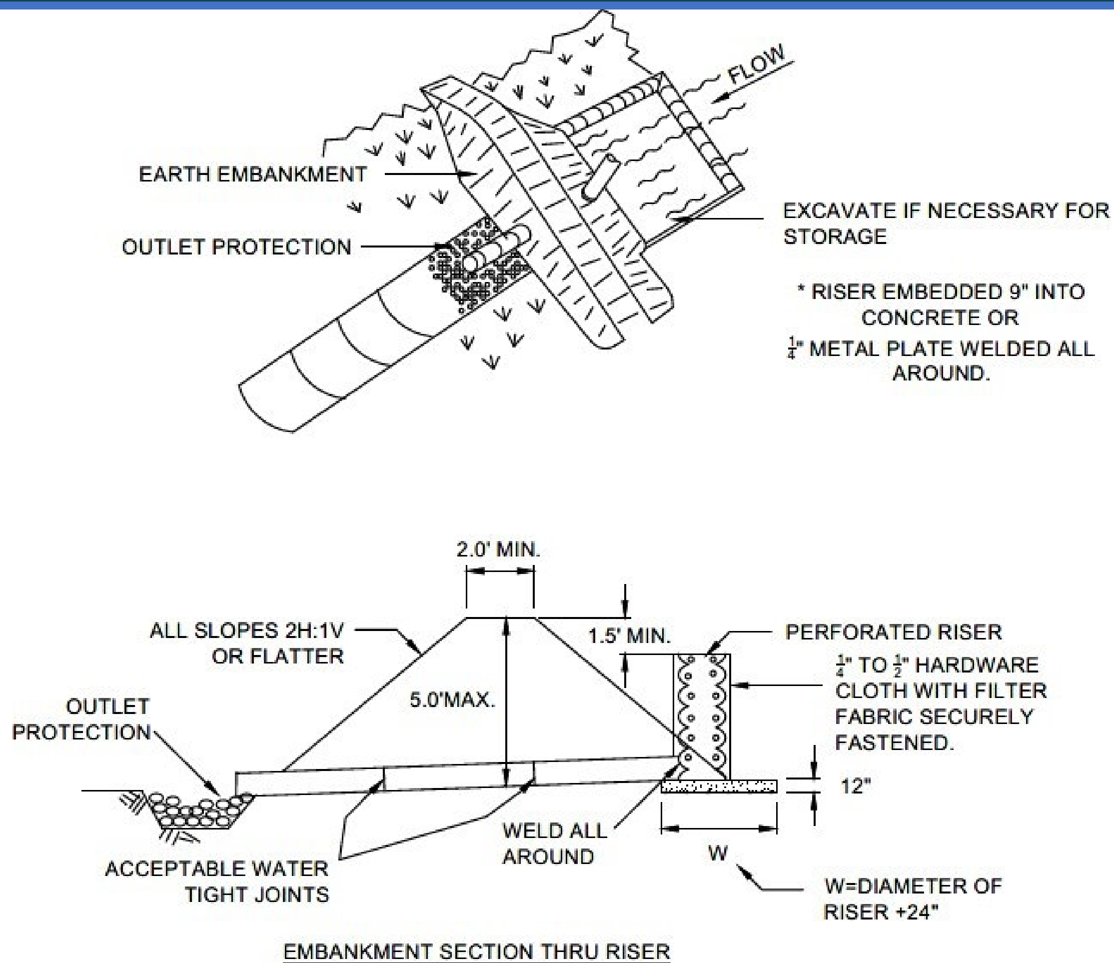

*Source: Filtrexx®*

**Figure C-SCM-11-2 Sediment Trap Staking Detail**




*Source: Filtrexx® Design Specification 1.9 Sediment Trap – Compost Filter Sock*

**Figure C-SCM-11-3 Temporary Sediment Trap Embankment Detail**




*Source: New York State Standards and Specifications for Erosion and Sediment Control*

## 6.0 Construction Specifications

1. Clear, grub, and strip any vegetation and root mat from the area under the embankment.

2. Ensure that fill material for the embankment is free of roots or other woody vegetation, organic material, large stones, and other objectionable material. Construct the embankment in 6-inch layers compacted by traversing with construction equipment.
3. Seed the earthen embankment with Temporary Seeding (BMP C-SCM-09) or Permanent Seeding (BMP C-SCM-10) immediately after installation.
4. Carry out construction operations to minimize erosion and water pollution.
5. Remove the structure and stabilize its area when the upslope drainage area has been stabilized.
6. Ensure that all cut and fill slopes are constructed with 2H:1V side slopes or flatter.

## 7.0 Operations and Maintenance Considerations

Remove sediment and restore the trap to its original dimensions when the sediment has accumulated to one half the design volume of the wet storage. Deposit sediment removed from the trap in a suitable area so that the placed material will not erode and cause sedimentation.

Regularly check filter stone to ensure that filtration performance is maintained. Remove and clean or replace stone choked with sediment. Replace stone that has been displaced within the embankment or outlet.

Regularly check the structure to ensure that the embankment and outlet are structurally sound and have not been damaged by erosion or construction equipment. Restore damaged embankments and/or outlets to design conditions. Check the height of the stone outlet to ensure that its center is at least 1 foot below the top of the embankment.

Repair or replace any damaged compost filter socks used in the compost filter sock sediment trap.

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# C-SCM-12 Temporary Sediment Basin

## 1.0 Definition

A temporary sediment basin is a temporary barrier or dam with a controlled stormwater release structure formed by constructing an embankment of compacted soil across a drainageway.

– CAD C-SCM-12-1 Minimum Storage Volume and Sediment Storage

– CAD C-SCM-12-2 Sediment Basin Schematic Elevations

– CAD C-SCM-12-3 Riser Pipe Base Conditions

– CAD C-SCM-12-4 Anti-Seep Collar

– CAD C-SCM-12-5 Emergency Spillway

– CAD C-SCM-12-6 Example Plan Views of Baffle Locations in Sediment Basins

– CAD C-SCM-12-7 Principal Spillway Design

– CAD C-SCM-12-9 Excavated Earth Spillway

– CAD C-SCM-12-10 Anti-Vortex Device Design

– CAD C-SCM-12-13 Details of Corrugated Metal Anti Seep Collar

– CAD C-SCM-12-14 Riser Pip Base Conditions for Embankements Less than 10' High

– CAD C-SCM-12-15 Recommended Dewatering System for Sediment Basins

## 2.0 Purpose and Applicability of Best Management Practice

A temporary sediment basin is used to detain sediment-laden runoff from disturbed areas in "wet" and "dry" storage long enough for much of the sediment to settle out.

The maximum drainage area that a sediment basin should contain is 100 acres. There must be sufficient space and appropriate topography for the construction of a temporary impoundment. These structures are limited to a useful life of 18 months unless the basins are designed as permanent impoundments. It is recommended that these measures, by virtue of their potential to impound large volumes of water, be designed by a qualified professional.

Temporary sediment basins can be combined with Straw Wattles (BMP C-ECM-01) to capture sediment in a drainageway that leads to a sinkhole outside of the limits of disturbance (LOD).

## 3.0 Planning and Considerations

### 3.1 Effectiveness

Sediment basins constructed per this specification are, at best, 60% effective at trapping sediment that flows into them during large storm events (those which cause flow from the outfall pipe) or during periods of minimal vegetative cover at a construction site. Therefore, use sediment basins in conjunction with erosion control practices, such as Temporary Seeding (BMP C-SSM-09), Mulching (BMP C-SSM-11), Temporary Diversion Dike (BMP C-ECM-04) to reduce the amount of sediment flowing into the basin.

To contain most of the sediment that flows to the structure, design and construct the basin to have a permanent pool or wet storage area and a dry storage area that dewaters over time. Sediment trapping efficiency is primarily a function of sediment particle size and the ratio of basin surface area to inflow rate. Therefore, design the basin to have a large surface area for its volume.

Construct sediment basins, along with other perimeter controls intended to trap sediment, as a first step in any land-disturbing activity and make functional before upslope land disturbance (Minimum Standard MS-4).

The use of a floating skimmer may be used to increase the trapping efficiency of the BMP.

### 3.2 Location

To improve effectiveness, locate the basin to intercept the largest possible amount of runoff from the disturbed area. The best locations are generally low areas and natural drainageways below disturbed areas. Drainage into the basin can be improved using diversion dikes and ditches. Do not locate the basin in a live stream, instead, locate the basin to trap sediment-laden runoff before it enters a stream. Do not locate the basin where its failure would result in the loss of life, interruption of the use or service of public utilities or roads, or major impacts to wetlands and/or streams.

Always consider access for cleanout and disposal of trapped sediment. Locations where a pond can be formed by constructing a low dam across a natural swale are generally preferred to sites that require excavation. Where practical, divert sediment-free runoff away from the basin.

In karst topography, impounded water causes soil saturation and loss of cohesion, and introduces stress from the weight of the water. See Appendix E for additional considerations in karst areas. Differences in hydraulic head and steep hydraulic gradients can result in sinkhole development. To ensure that these facilities are kept small and shallow, it is recommended that drainage areas be kept to 5 acres or less, and that sediment traps be used to the maximum extent practicable so that the total depth is kept below 5 feet. Where a sediment basin cannot be avoided, keep the depth to the minimum (4 feet to the top of the settling volume). At the discretion of the designer, it may be necessary to install an impermeable liner based on geotechnical testing, known occurrences of sinkhole development, and whether the basin will be converted to a permanent stormwater management facility. Emphasize the importance of ensuring the integrity of all pipes in the maintenance instructions. Pipe leakage or sagging can become the focus of soil loss into subsurface voids, leading to subsidence and the development of sinkholes. If sinkholes develop, promptly and properly repair the sinkholes.

It is important for the basin designer to consider the effect that the basin discharge will have on downstream properties and natural resources. During the construction phase of a project, the area draining to a basin location may be greatly increased from the pre-construction condition by way of the use of diversions or temporary or permanent storm sewers. Additionally, the coefficient of runoff from a typically denuded and compacted construction site will be greatly increased even if the drainage area of the basin is unchanged. On very large construction sites, multiple sediment basins may discharge to a single receiving channel, conveying higher volumes of flow for a given storm and for a longer duration. As a result, the channel or other conveyance downstream from a temporary sediment basin should be analyzed for the construction condition to ensure that the discharge it will receive is not beyond its limits of capacity or stability.

**3.3 Multiple Use**

Sediment basins may remain in place after construction and final site stabilization to serve as permanent stormwater management structures. Because the most practical location for a sediment basin is often the most practical location for a stormwater management basin, it is often desirable to use these structures for permanent stormwater management purposes. It should be noted, however, that in most cases, a typical structure's outfall system will vary during the construction and post-construction periods. Care must be taken to avoid constructing an outfall system that will achieve the desired post-construction quantity or quality control but will not provide the necessary medium for the containment and settling of sediment-laden construction runoff. Notably, the design for permanent ponds is beyond the scope of these standards and specifications.

When a sediment basin is designed to be converted to a permanent stormwater basin, specific direction must be provided for the process of making that conversion. The timing of the conversion must be coordinated with the sequence of site construction and the stage of stabilization of the basin drainage area to ensure optimal performance in both the temporary and permanent configuration.

## 4.0 Stormwater Performance Summary

**MS-4: FIRST-STEP MEASURES** – Sediment basins and traps, perimeter dikes, sediment barriers, and other measures intended to trap sediment shall be constructed as a first step in any land-disturbing activity and shall be made functional before upslope land disturbance takes place.

**MS-6: TRAPS AND BASINS** – Sediment traps and basins shall be designed and constructed based on the total drainage area they serve.

**MS-19: STORMWATER** – Protect properties and waterways downstream of a land-disturbing activity from erosion and sediment deposition due to increases in peak stormwater runoff.

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: HIGH**

## 5.0 Design Criteria

Refer to Appendix A of this specification for design procedures for temporary sediment basins.

| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Drainage Area | Below disturbed areas where the total contributing drainage area is up to 100 acres.<br><br>A hydraulic routing model, or other approved alternative design procedure, must be prepared when the drainage area to any one temporary sediment basin exceeds 25 acres.<br><br>The design procedures in this standard and specification do not generate hydrographs, use storage volumes or provide a routing of the design storms; for a large drainage area, this may result in an excessively large-diameter riser or an oversized basin. Notably, design considerations that are more accurate and project- specific than those in this specification are acceptable and encouraged with any size basin. |
| Basin Capacity | Design the basin with a storage capacity of at least 134 cubic yards/acre of **total contributing drainage area**. Half of the design volume (or 67 cubic yards) will be in the form of a permanent pool, and the remaining half as drawdown volume.<br><br>"Dry" Storage (drawdown volume) = 67 cubic yards/acre (min.)<br><br>Measure the volume of the drawdown area from the elevation of the permanent pool to the crest of the principal spillway (riser pipe).<br><br>"Wet" Storage (permanent pool) = 67 cubic yards/acre (min.)<br><br>Measure the volume of the permanent pool from the low point of the basin to the elevation corresponding to half the total storage volume.<br><br>Sediment Cleanout Level = 34 cubic yards/acre (min.) bottom of the "Wet" Storage zone<br><br>Remove sediment from the basin when the volume of the permanent pool has been reduced by half. Do not design the sediment cleanout level to be higher than 1 foot below the bottom of the dewatering device. Calculate the elevation of the sediment cleanout level, and clearly mark on the plans and riser (because this part of the riser normally will be under water, a mark should appear above the permanent pool at a measured distance above the cleanout elevation).<br><br>While attempting to attain the desired storage capacities, keep embankment heights to a minimum. This precaution takes on added significance when the basin will only serve as a temporary measure or will need substantial retrofitting before functioning as a permanent measure. When site topography permits, consider the use of excavation to obtain the required capacity and to possibly reduce the height of the embankment. This excavation can be performed to create a wet storage forebay area or increase the storage capacity over the entire length of the basin.<br><br>***The designer may opt to use a hydraulic routing model in place of the traditional long-hand calculations to determine sediment basin capacity.*** |

| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Length of Use | Do not use for longer than 18 months unless the device is designated as a permanent impoundment. |
| Basin Shape | To improve sediment trapping efficiency of the basin, design the effective flow length to be twice the effective flow width.<br>This basin shape may be attained by properly selecting the site of the basin, by excavation, or using baffles or berms to develop an effective flow length from entry point to dewatering device/outfall structure. |
| Embankment Cross-Section | For embankments of less than 10 feet:<br>• Minimum top width of 6 feet<br>• Maximum side slopes of 2H:1V or flatter For embankments 10 to 14 feet in height:<br>• Minimum top width of 8 feet<br>• Maximum side slopes of 2.5H:1V or flatter<br>For 15-foot embankments (maximum allowed under these specifications):<br>• Minimum top width of 10 feet<br>• Maximum of 2.5H:1V side slopes |
| Spillway Design | Design the outlets for the basin to consist of a combination of principal and emergency spillways that will pass the peak runoff expected from the contributing drainage area for a 25-year storm. Runoff coefficients or curve numbers used in runoff computations should correspond to the soil cover conditions expected throughout the basin's lifetime.<br>If a separate emergency spillway is not feasible due to site conditions and basin geometry, design the principal spillway to pass the entire peak runoff expected from the 25-year storm. However, attempt to provide a separate emergency spillway (refer to Emergency Spillway).<br>Base runoff computations on the soil cover conditions that are expected to prevail during the life of the basin.<br>The spillways designed by the procedures contained in the standard and specification will not necessarily result in any reduction in the peak rate of runoff. If a reduction in peak runoff is desired, generate the appropriate hydrographs/storm routings to choose the basin and outlet sizes. |

| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Principal Spillway | Design the principal spillway to consist of:<br>• Vertical pipe or box of corrugated metal or reinforced concrete;<br>• Minimum diameter of 15 inches; and<br>• Joined by a watertight connection to a horizontal pipe (barrel) extending through the embankment to outlet beyond the downstream toe of the fill.<br>If the principal spillway is used in conjunction with a separate emergency spillway, design the principal spillway to pass at least the peak flow expected from of 2-year storm.<br>If no emergency spillway is used, design the principal spillway to pass the entire peak flow expected from a 25-year storm. |
| Design Elevations | Set the crest of the principal spillway to be at the elevation corresponding to the storage volume required (67 cy/ac wet storage + 67 cy/ac dry storage = 134 cy/ac).<br>If the principal spillway is used in conjunction with an emergency spillway, set the crest elevation to be a minimum of 1 foot below the crest of the emergency spillway. In addition, provide a minimum freeboard of 1 foot between the design high water (25-year storm) and the top of the embankment (see Figure C-SCM-12-2).<br>If no emergency spillway is used, set the crest of the principal spillway to be a minimum of 3 feet below the top of the embankment and provide a minimum freeboard of 2 feet between the design high water and the top of the embankment. |
| Anti-Vortex Device and Trash Rack | Attach an anti-vortex device and trash rack to the top of the principal spillway to improve the flow characteristics of water into the spillway and prevent floating debris from blocking the principal spillway. Use a concentric type of anti-vortex device as shown on Figure C-SCM-12-10. |

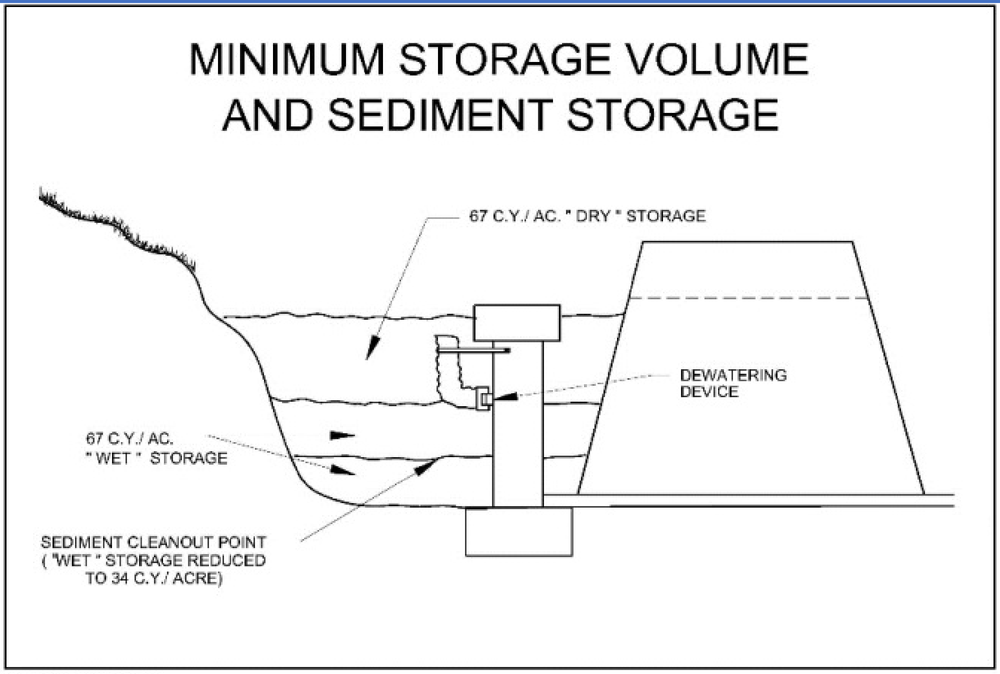
| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Dewatering | Make provisions to dewater the basin down to the permanent pool elevation. Sediment basins must not dewater in less than 24 hours, nor take longer than 120 hours.<br><br>Design the dewatering of the dry storage to remove the "cleaner" water without removing the potentially sediment-laden water found in the wet storage area or any appreciable quantities of floating debris. An economical and efficient device for performing the drawdown is a section of perforated vertical tubing connected to the principal spillway at two locations. By virtue of the potential for the dewatering device or orifice to become clogged, no credit is given for drawdown by the device in the calculation of the principal or emergency spillway locations.<br><br>Dewatering from the surface provides greater trapping efficiency. One common method is use of a skimmer. A floating skimmer can be attached to the base of the riser. The orifice in the skimmer will control the rate of dewatering. The skimmer should be sized to dewater the basin in 2 to 5 days. The skimmer withdraws temporarily detained water from the top part of the water column to avoid sediment that may be suspended lower in the water column. The skimmer is used to draw down water levels in sedimentation ponds to maintain storage capacity in a way that ensures the cleanest water is discharged in a controlled manner.<br><br>The quality of the water discharged can be improved using a floating inlet device or "skimmer" attached to a flexible hose attached to the dewatering outlet. The skimmer floats on top of the dry storage pool, discharging the cleanest, least sediment laden water from the surface of the pool. |
| Barrel | Design the barrel of the principal spillway, which extends through the embankment, to carry the flow provided by the riser of the principal spillway with the water level at the crest of the emergency spillway. The connection between the riser and the barrel must be watertight. Protect the outlet of the barrel to prevent erosion or scour of the downstream area (see Discharge). |
| Structural Integrity | Analyze the structural integrity of a temporary sediment basin using the 25-year storm event. |

| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Principal Spillway Base | Firmly anchor the base of the principal spillway to prevent its floating. For spillway risers taller than 10 feet, determine the anchoring requirements using a minimum factor of safety of 1.25 (downward forces = 1.25 x upward forces).<br>For spillway risers 10 feet tall or less, anchor in one of the two following ways:<br>1. Use a concrete base 18 inches thick, twice the width of riser diameter, and the riser embedded 6 inches into the concrete. See Figure C-SCM-12-3 for design details.<br>2. Use a square steel plate, a minimum of 0.25 inch thick and having a width equal to twice the diameter of the riser. Cover the plate with 2.5 feet of stone, gravel, or compacted soil to prevent flotation. See Figure C-SCM-12-3 for design details.<br>Note: If the steel base is used, give special attention to compaction so that 95% compaction is achieved over the plate. Also, take added precautions to ensure that material over the plate is not removed accidently during removal of sediment from the basin. |
| Anti-Seep Collars | Use anti-seep collars on the barrel of the principal spillway within the normal saturation zone of the embankment to increase the seepage length by at least 10% under either of the following two conditions:<br>1. The settled height of the embankment exceeds 10 feet.<br>2. The embankment has a low silt-clay content (Unified Soil Classes SM or GM), and the barrel is greater than 10 inches in diameter.<br>Install the anti-seep collars within the saturated zone.<br>Design the maximum spacing between collars to be 14 times the projection of the collars above the barrel. Do not locate collars closer than 2 feet from a pipe joint.<br>Space collars sufficiently to allow passage of hauling and compacting equipment. Ensure that 95% compaction is achieved around the collars. Ensure watertight connections between the collars and the barrel. See Figure C-SCM-12-4 for details. |

| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Alternatives to Anti-Seep Collars | Anti-seep collars are designed to control seepage and piping along the barrel by increasing the flow length along the barrel. Due to the constraints that collars impose on embankment fill placement and compaction, collars may sometimes be ineffective or result in an increase in seepage and piping.<br><br>Measures alternative to the use of anti-seep collars have been developed and incorporated into embankment designs. These include a structure known as a "filter diaphragm," or a layer of sand and fine gravel that runs through the dam embankment perpendicular to the barrel. The filter diaphragm is 4 to 5 inches wide, approximately 1 foot tall and is located where the barrel elevation intersects with the upper bounds of the seepage zone. The measure controls the transport of embankment fines, which is the major concern with piping and seepage. The diaphragm channels any undesirable flow through the fine-graded material, which traps embankment material. The flow is then conveyed out of the embankment through a perforated toe drain.<br><br>The critical design element of the filter diaphragm is the grain-size distribution of the filter material determined by the grain-size distribution of the embankment fill material. Base the use and design of these measures on site-specific geotechnical information, and have the installation supervised by a qualified professional. |

| Table C-SCM-12-1 Design Criteria Parameters | |
|---|---|
| **Parameter** | **Details** |
| Discharge | Release concentrated stormwater flow from a temporary sediment basin into an adequate stormwater conveyance system.<br>1. Adequacy of all stormwater conveyance systems should be verified in the following manner:<br>a. Demonstrate that the total drainage area at the point of discharge within the stormwater conveyance system is at least 100 times greater than the drainage area served by the temporary sediment basin in question, **OR**<br>b. Analyze the manmade stormwater conveyance systems using the 2-year storm event to demonstrate that stormwater flow will be contained within the system and will not cause erosion of the system, **OR**<br>c. Analyze the manmade stormwater conveyance systems using the 2-year storm event to demonstrate that stormwater flow will be contained within the system and will not cause erosion of the system, **OR**<br>d. Analyze the restored stormwater conveyance systems to demonstrate that stormwater flow, in combination with other stormwater runoff, is consistent with the design parameters of the restored stormwater conveyance system, **OR**<br>e. Analyze the restored stormwater conveyance systems to demonstrate that stormwater flow, in combination with other stormwater runoff, is consistent with the design parameters of the restored stormwater conveyance system, **OR**<br>f. Analyze the natural stormwater conveyance systems using the 2-year storm event to demonstrate that stormwater flow will be contained within the system and will not cause erosion of the system.<br>2. If an existing manmade stormwater conveyance system is not adequate:<br>a. Improve the manmade stormwater conveyance system to contain the 2-year storm event within the system and does not cause erosion of the system, **OR**<br>b. Develop a temporary sediment basin design that will not cause the pre- development peak runoff rate from a 2-year storm event to increase, **OR**<br>c. Provide a combination of manmade stormwater conveyance system improvement, stormwater detention, or other measures.<br>3. If an existing restored stormwater conveyance system is not adequate, develop a temporary sediment basin design to ensure that stormwater flow, in combination with other stormwater runoff, is consistent with the design parameters of the restored stormwater conveyance system.<br>4. If an existing natural stormwater conveyance system is not adequate:<br>a. Improve the natural stormwater conveyance system to contain the 2-year storm event within the system and does not cause erosion of the system, **OR**<br>b. Develop a temporary sediment basin design that will not cause the pre- development peak runoff rate from a 2-year, 24-hour storm event to increase, **OR**<br>c. Provide a combination of natural stormwater conveyance system improvement, stormwater detention, or other measures. |

## Figure C-SCM-12-1 Minimum Storage Volume

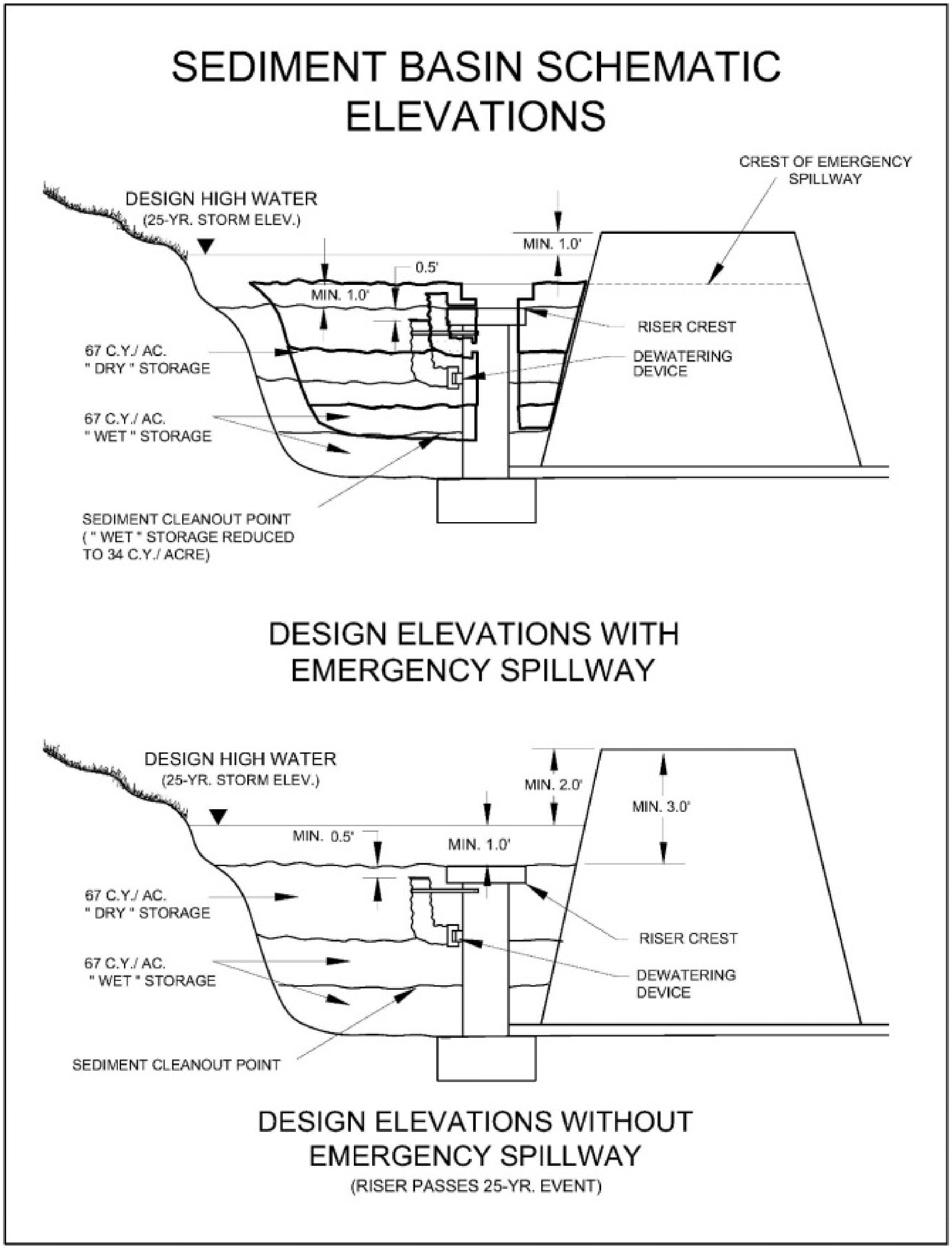



SOURCE: VA. DSWC.

| Table C-SCM-12-2 Emergency Spillway Design | |
|---|---|
| **Emergency Spillway** | |
| Design & Construction | The emergency spillway acts as a safety release for a sediment basin, or any impoundment-type structure, by conveying the larger, less frequent storms through the basin without damage to the embankment. The emergency spillway also acts as its name implies – in case of an emergency such as excessive sedimentation or damage to the riser that prevents flow through the principal spillway. Design the emergency spillway to consist of an open channel (earthen and vegetated) constructed adjacent to the embankment over undisturbed material (not fill). Where conditions will not allow the construction of an emergency spillway on undisturbed material, a spillway may be constructed of a non-erodible material such as riprap.<br>Design the spillway to have a control section at least 20 feet long. The control section is a level portion of the spillway channel at the highest elevation in the channel. See Figure C-SCM-12-5 for details.<br><br>Evaluate site and downstream conditions to determine the feasibility and justification for the incorporation of an emergency spillway. In some cases, the site topography does not allow construction of a spillway to in undisturbed material, and the temporary nature of the facility may not warrant the cost of disturbing more acreage to construct and armor a spillway. In such cases, size the principal spillway to convey all the design storms. If the facility is designed as a permanent facility with downstream restrictions, the added expense of constructing and armoring an emergency spillway may be justified. |
| Capacity | Design the emergency spillway to carry the portion of the peak rate of runoff expected from a 25-year storm that is not carried by the principal spillway. |
| Design Elevations | Design the 25-year storm elevation through the emergency spillway to be at least 1 foot below the top of the embankment. Design the crest of the emergency spillway channel to be at least 1 foot above the crest of the principal spillway. |
| Location | Locate the emergency spillway channel so that it will not be constructed over fill material. Locate the channel to avoid sharp turns or bends. Design the channel to return the flow of water to a defined channel downstream from the embankment. |
| Maximum Velocities | The maximum allowable velocity in the emergency spillway channel will depend on the type of lining used. For vegetated linings, allowable velocities are listed in Table C-ECM-09-2 in Stormwater Conveyance Channel (BMP C-ECM-09).<br><br>For non-erodible linings, such as concrete or riprap, design velocities may be increased. However, design the emergency spillway channel to return the flow to the receiving channel at a non-eroding velocity. |

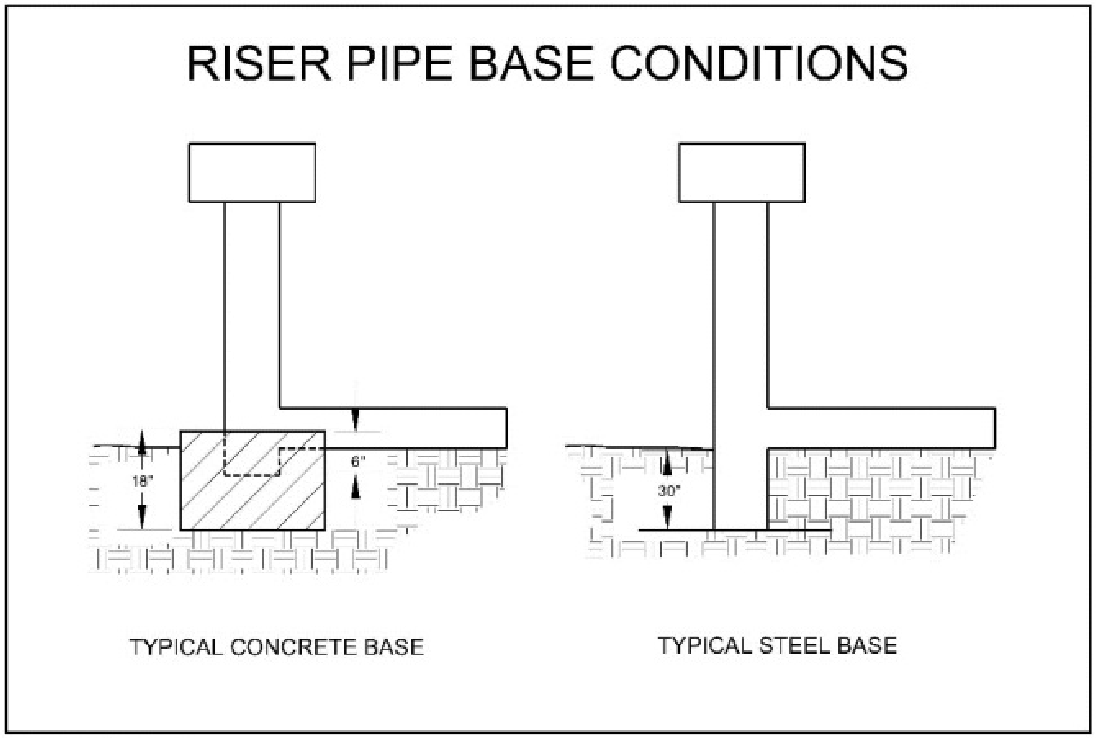
| Table C-SCM-12-2 Emergency Spillway Design | |
|---|---|
| Emergency Spillway | |
| Stabilization | Install temporary or permanent seeding to the spillway channel section of the sediment basin immediately after installation, see Temporary Seeding (BMP C-SSM-09) or Permanent Seeding (BMP C-SSM-10). If excavation is required in the basin, design the side slopes to be no steeper than 1.5H:1V. |
| Disposal | Remove sediment from the basin when the sediment level is no higher than 1 foot below the bottom of the dewatering orifice, or one half of the permanent pool volume, whichever is lower.<br><br>On plans for the sediment basin, indicate the methods for disposing of sediment removed from the basin. Possible options are the use of the material in fill areas on site or removal to an approved off-site location.<br><br>On the sediment basin plans, indicate the final disposition of the sediment basin after stabilization of the upstream drainage area including methods for the removal of excess water lying over the sediment, stabilization of the basin site, and the disposal of any excess material. Where the sediment basin has been designed as a permanent stormwater management basin, on the plans, address the steps necessary for the conversion from sediment basin to a permanent detention or retention facility. |
| Safety | Sediment basins can be appealing to children and can be dangerous. Install fence around or otherwise make inaccessible sediment basins to persons or animals unless this is deemed unnecessary by the certified plan reviewer due to the remoteness of the site or other circumstances.<br><br>Install strategically placed signs around the impoundment reading "DANGER- QUICKSAND". In any case, adhere to local ordinances and regulations regarding health and safety, see Safety Fence (BMP C-PCM-01). |

**Figure C-SCM-12-2 Sediment Basin Design Elevation**



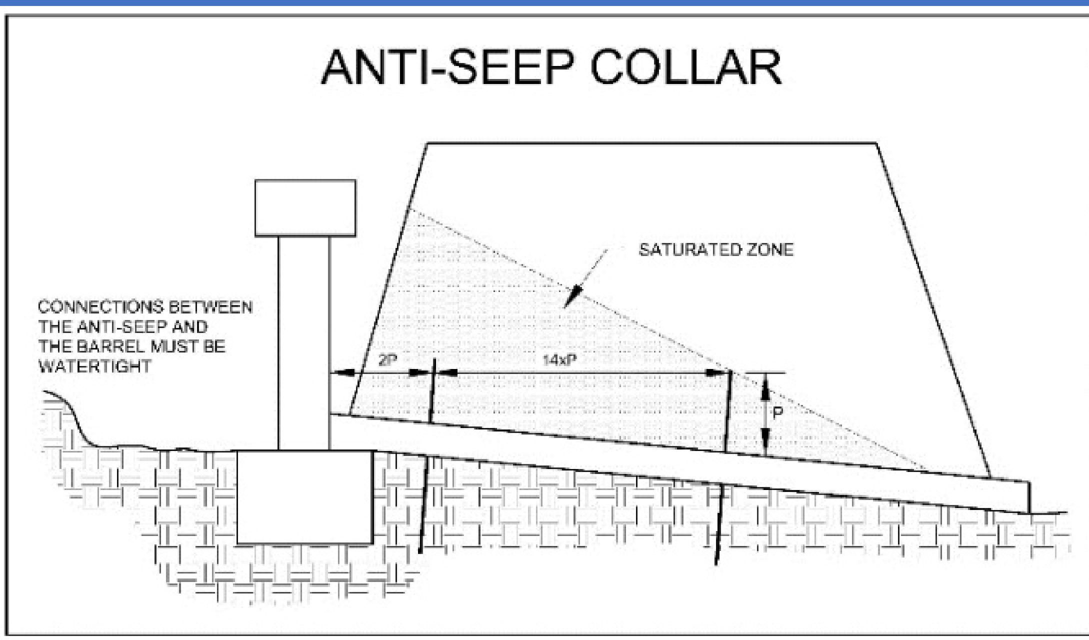

SOURCE: VA. DSWC

**Figure C-SCM-12-3 Riser Pipe Base Conditions**



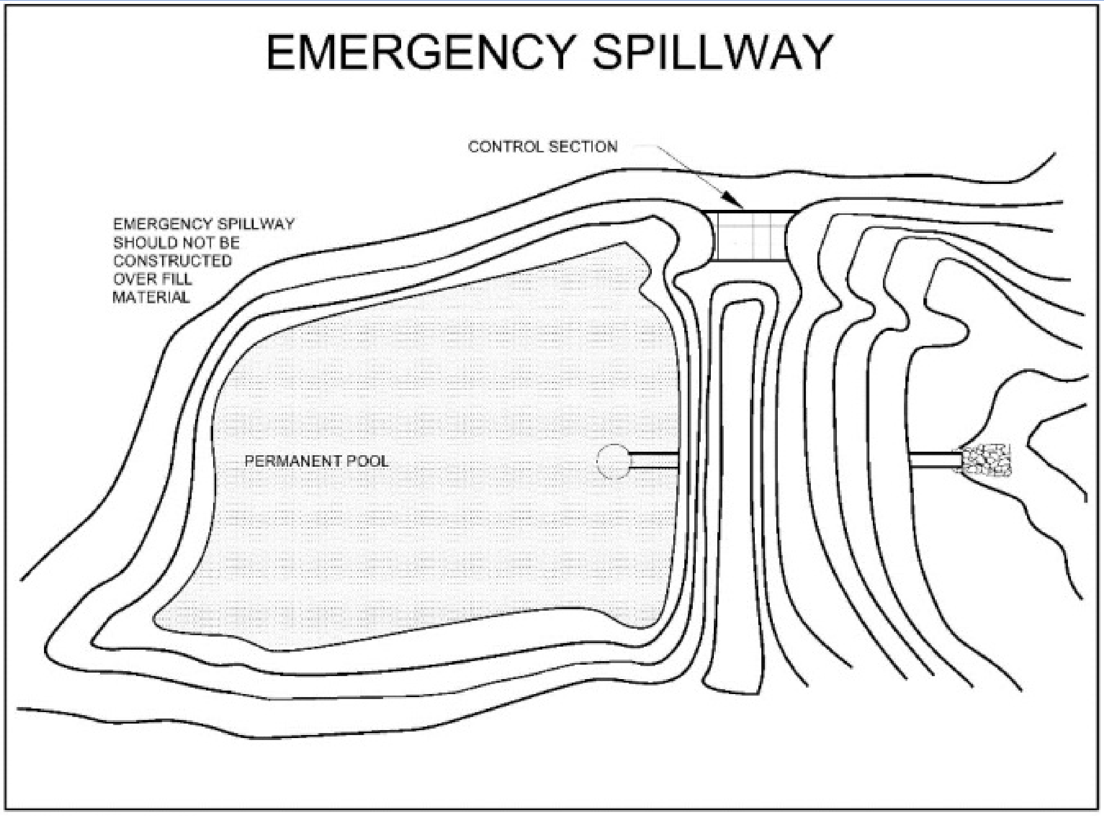

SOURCE: VA. DSWC

**Figure C-SCM-12-4 Anti-Seep Collar Design**



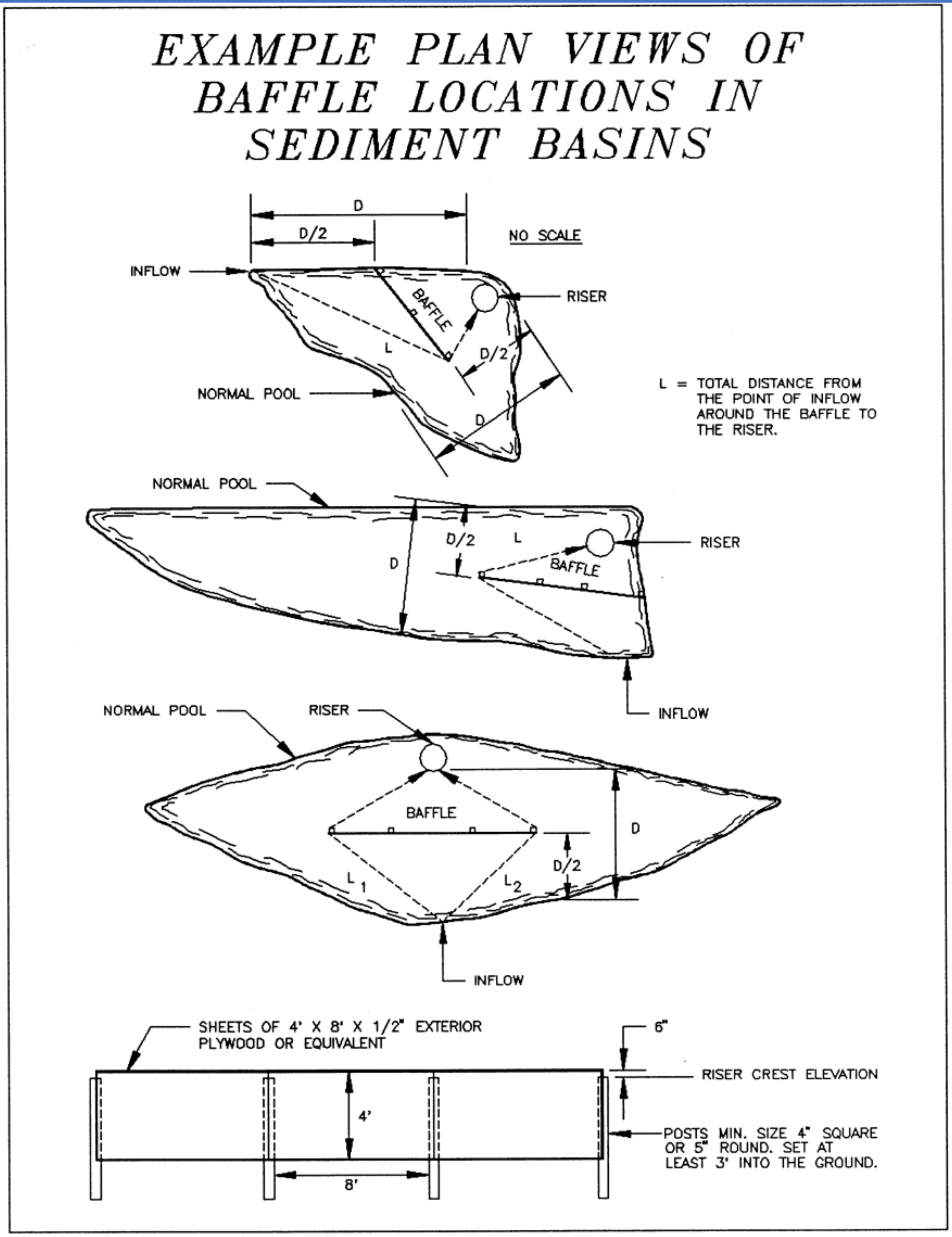

SOURCE: VA. DSWC

### *Figure C-SCM-12-5 Emergency Spillway Design*




SOURCE: VA. DSWC

Figure C-SCM-12-6 Baffle Board Inclusion Considerations and Design




Source: USDA-SCS

Plate 3.14-6

## 6.0 Construction Specifications

| Table C-SCM-12-3 Construction Specifications and Criteria | |
|---|---|
| **Component** | **Details** |
| Site Preparation | Clear, grub, and strip the areas under the embankment or any structural works related to the basin of topsoil to remove trees, vegetation, roots, or other objectionable material.<br>To facilitate cleanout and restoration, clear the area of most frequent inundation (measured from the top of the principal spillway) of all brush and trees. |
| Cutoff Trench | For earth-fill embankments, excavate a cutoff trench along the centerline of the dam. Extend the trench at least 1 foot into a stable, impervious layer of soil and establish a minimum depth of 2 feet.<br>Extend the cutoff trench up both abutments to the riser crest elevation. Construct the cutoff trench with a minimum bottom width of 4 feet, but wide enough to permit operation of compaction equipment. Construct the trench with side slopes no steeper than 1H:1V.<br>Use the same compaction requirements as those for the embankment. Drain the trench during the backfilling/compacting operations. |
| Embankment | Take the fill material from approved borrow areas. Ensure the material is clean mineral soil, free of roots, woody vegetation, stumps, sod, oversized stones, rocks, or other perishable or objectionable material. Ensure the material selected has enough strength for the dam to remain stable and be tight enough, when properly compacted, to prevent excessive percolation of water through the dam.<br>Fill containing particles ranging from small gravel or coarse sand to fine sand and clay in desired proportions is appropriate. Ensure any embankment material contains approximately 20% clay particles by weight. Using the Unified Soil Classification System, SC (clayey sand), GC (clayey gravel), and CL (low liquid limit clay) are among the preferred types of embankment soils.<br>Scarify areas on which fill is to be placed before placement of fill. Ensure the fill material contains the proper amount of moisture to ensure achievement of 95% compaction.<br>Place fill material in 6-inch continuous layers over the entire length of the fill.<br>Achieve compaction by routing the hauling equipment over the fill so that the entire surface of the fill is traversed by at least one wheel or tread track of the equipment, or by using a compactor. Take special care when compacting around the anti-seep collars (compact by hand, if necessary) to avoid damage and achieve desired compaction.<br>Construct the embankment to an elevation 10% higher than the design height to allow for settlement if compaction is accomplished with hauling equipment. If compactors are used for compaction, reduce the overbuild to not less than 5%. |

| Table C-SCM-12-3 Construction Specifications and Criteria | |
|---|---|
| **Component** | **Details** |
| Principal Spillway | Securely attach the riser of the principal spillway to the barrel by a watertight connection. Place the barrel and riser on a firmly compacted soil foundation.<br>Firmly anchor the base of the riser according to design criteria to prevent its floating.<br>Do not use pervious materials (such as sand, gravel, or crushed stone) as backfill around the barrel or anti-seep collars. Take special care when compacting around the anti-seep collars (compact by hand, if necessary).<br>Place fill material around the pipe in 4-inch layers and compact until 95% compaction is achieved. Hand-compact a minimum of 2 feet of fill over the barrel before crossing it with construction equipment. |
| Emergency Spillway | Do not construct vegetated emergency spillways over fill material.<br>Design elevations, widths, and entrance and exit channel slopes are critical to the successful operation of the spillway and should be closely followed during construction. |
| Inlets | Discharge water into the basin in a manner that prevents erosion. Use diversions with outlet protection to divert sediment-laden water to the upper end of the pool area to improve basin efficiency.<br>To prevent eroding the slope of the basin wall, use a slope drain or a stabilized, lined channel to convey concentrated stormwater flows to the wet storage pool. |
| Vegetative Stabilization | Stabilize the embankment and emergency spillway of the sediment basin with temporary or permanent vegetation immediately after installation of the basin (see Temporary Seeding (C-SSM-09) or Permanent Seeding (C-SSM-10). Vegetative stabilization of the sediment basin and the areas around it will improve the water quality in the basin and reduce the need for maintenance.<br>Stabilize outside slopes with soil stabilization blankets and matting, refer to Soil Stabilization Blankets and Matting (C-SSM-05).<br>Do not plant trees on any basin embankment because the root systems may compromise the integrity of the berm over time. Trees may be planted in the non- embankment (pool) areas of permanent basins. |
| Erosion and Sediment Control | Construct the sediment basin in accordance with all the appropriate construction best management practices outlined within, so that the basin itself does not cause a degradation of downstream water quality and habitat. |
| Safety | Meet all state and local requirements concerning fencing and signs warning the public of the hazards of soft, saturated sediment and flood waters, refer to Safety Fence (C-PCM-01). |

| Table C-SCM-12-3 Construction Specifications and Criteria | |
|---|---|
| **Component** | **Details** |
| Final Disposal | When temporary structures have served their intended purpose, and the contributing drainage area has been properly stabilized, level or otherwise dispose of the embankment and resulting sediment deposits in accordance with the approved erosion and sediment control plan.<br><br>The proposed use of a sediment basin site will often dictate final disposition of the basin and any sediment contained therein. If the site is scheduled for future construction, then remove the basin material and trapped sediments, safely dispose of the removed material, and backfill with a structural fill.<br><br>When the basin area is to remain open space, pump dry, grade, and backfill the basin. |

### 6.1 Temporary to Permanent Basin Conversion

Design permanent basins used temporarily as sediment basins to meet the requirements of the permanent basin (e.g., side slopes, permanent outlet structures, benches, forebays, access ramps, and preservation/remediation of subsoils for infiltration rates). Construct sediment basins that will be converted to post-construction stormwater BMPs that utilize infiltration in the design in accordance with the appropriate specification.

***Note that the risk of infiltration failure may increase significantly for infiltration BMPs used as sediment basins during construction. Soil compaction by construction vehicles in these areas may also reduce the intended infiltration capacity in the area.***

## 7.0 Operations and Maintenance Considerations

Inspect the basin embankment regularly to ensure that it is structurally sound and has not been damaged by erosion or construction equipment.

Inspect the emergency spillway regularly to ensure that its lining is well established and erosion-resistant. After every runoff producing rainfall, inspect the principal spillway and dewatering orifice for clogging and remove accumulated debris to maintain free flow from the basin. Inspect the vegetative stabilization, soil stabilization matting, slope drains and baffles if present, and maintain or repair immediately.

Inspect the basin after each runoff-producing rainfall for sediment cleanout. When the sediment reaches the cleanout level, remove and properly dispose of the sediment.

Inspect the basin for sinkhole formation, and if found, repair promptly.

## 8.0 References

North Carolina Department of Environmental Quality. 2017. *Stormwater Design Manual*.

North Carolina Sedimentation Control Commission, et al. 2013. *Erosion and Sediment Control Planning and Design Manual*.

Pennsylvania Department of Environmental Protection. 2012. *Erosion and Sediment Pollution Control Program Manual*. Final ed.

Washington State Department of Transportation Engineering and Regional Operations, Development Division, Design Office. 2019. *Temporary Erosion and Sediment Control Manual*.

## 9.0 Appendix A Design Procedure for Temporary Sediment Basins

The following design procedure provides a step-by-step method for designing a temporary sediment basin. The data sheet included in the end of this Appendix should be used in the erosion and sediment control plan to document design values calculated.

Note, if the drainage basin is on karst, review the design considerations listed in Section 3.0 Planning and Considerations.

I. **Basin Volume**

A. Determine the required basin volume. Design the storage capacity of the basin to be at least 134 cubic yards per acre of total contributing drainage area, half of which is in the form of a permanent pool or wet storage, and the remaining half as a "drawdown" area or dry storage.

1. For a natural basin, the wet storage volume may be approximated as follows:

$$V_1 = 0.4 \times A_1 \times D_1$$

where,

$V_1$ = the wet storage volume (cubic feet)

$A_1$ = the surface area of the flooded area at the invert of the dewatering outlet (square feet)

$D_1$ = the maximum depth (feet), measured from the low point in the basin to the invert of the dewatering outlet

2. For a natural basin, the dry storage volume may be approximated as follows:

$$V_2 = \frac{A_1 \times A_2}{2} \times D_2$$

where,

$V_2$ = the dry storage volume (cubic feet)

$A_2$ = the surface area of the flooded area at the crest of the principal spillway (square feet)

$D_2$ = the depth (feet), measured from the invert of the dewatering outlet to the crest of the principal spillway

Note 1: The volumes may be computed from more precise contour information or other suitable data.

Note 2: Convert between cubic feet and cubic yards using the following equation:
number of cubic feet x 0.037 number of cubic yards.

B. If the volume of the basin is inadequate, or embankment height becomes excessive, excavate to obtain the required volume.

II. **Basin Shape**

A. The shape of the basin must align with a length-to-width ratio of at least 2 to 1 according to the following equation:

$$\text{Length-to-width Ratio} = \frac{L}{W_e}$$

where,

$W_e$ = A/L = the effective width

A = the surface area of the normal pool

L = the length of the flow path from the inflow to the outflow. If there is more than one inflow point, any inflow that carries more than 30% of the peak rate of inflow must meet these criteria.

B. The correct basin shape can be obtained by proper site selection, excavation, or the use of baffles. Baffles increase the flow length by deflecting the flow. The baffles should be placed halfway between the inflow point and the outflow. Figure C-SCM-12-6 shows the detail for baffle construction and three situations for which baffles might be used.

III. **Determine whether the basin will have a separate emergency spillway.**

IV. **Determine the elevation of the crest of the principal spillway for the required volume (dewatering orifice at 67 cubic yards per acre and crest of principal spillway 134 cubic yards per acre).**

V. **Estimate the elevation of the design high water and the required height of the dam.**

A. If an emergency spillway is included:

1. Design the crest of the principal spillway to be at least 1 foot below the crest of the emergency spillway.
2. Design the elevation of the peak flow through the emergency spillway (which will be the design high water for the 25-year storm) to be at least 1 foot below the top of embankment.

B. If an emergency spillway is not included:

1. Design the crest of the principal spillway to be at least 3 feet below the top of the embankment.
2. Design the elevation of the design high water for the 25-year storm to be 2 feet below the top of the embankment.

VI. **Determine the peak rate of runoff expected from the drainage area of the basin for a 25-year storm. Derive the "C" factor or "CN" value used in the runoff calculations from analysis of the contributing drainage area at the peak of land disturbance (condition that will create greatest peak runoff).**

VII. **Principal Spillway Design**

A. If an emergency spillway is included, design the principal spillway to at least pass the peak rate of runoff from the basin drainage area for a 2-year storm.

1. $Q_p$ = the 2-year peak rate of runoff

B. If an emergency spillway is not included, design the principal spillway to pass the peak rate of runoff from the basin drainage area for a 25-year storm.

1. $Q_p$ = the 25-year peak rate of runoff

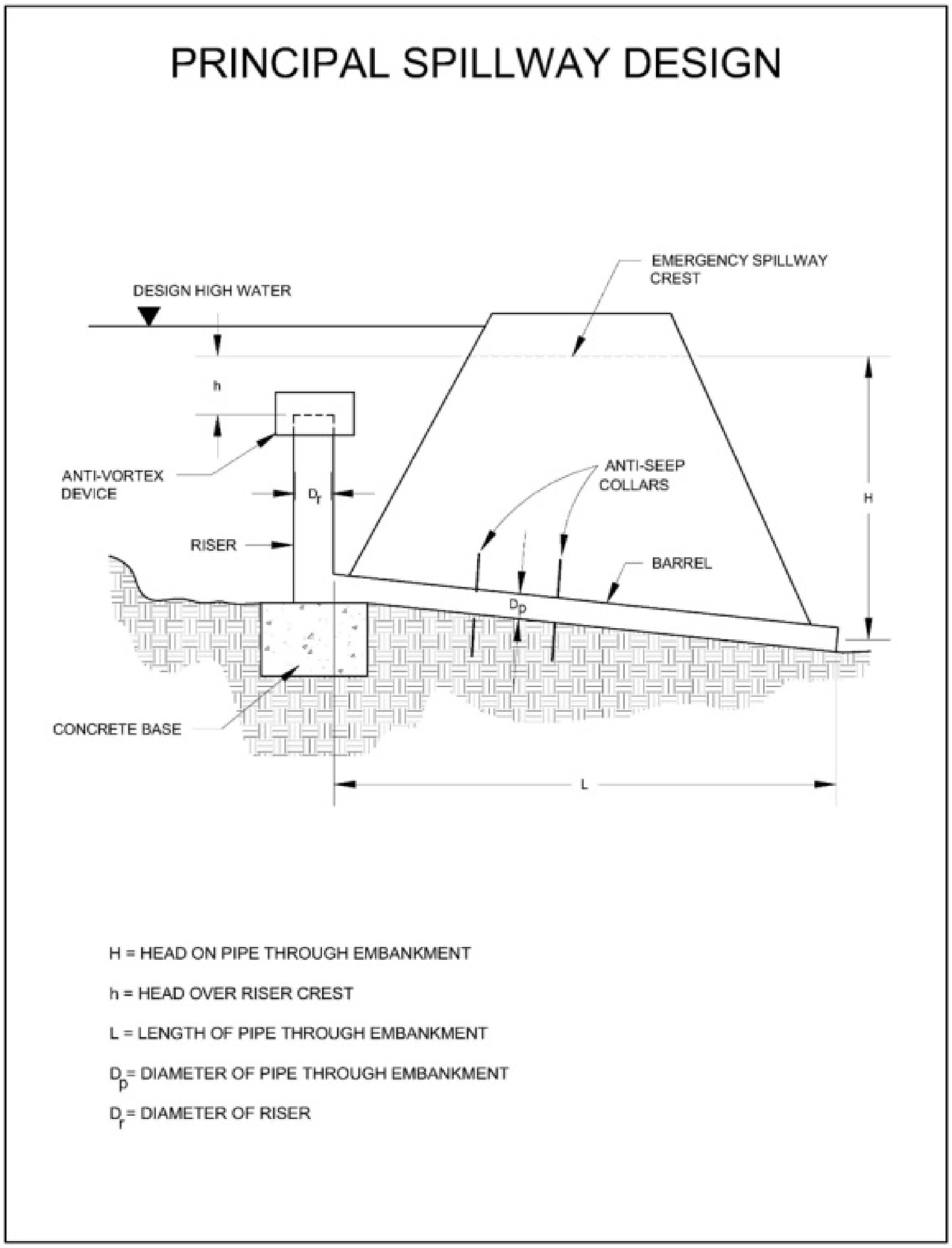
C. Refer to Figure C-SCM-12-7, where h is the difference between the elevation of the crest of the principal spillway and the elevation of the crest of the emergency spillway.

D. Enter Figure C-SCM-12-7 with $Q_p$. Choose the smallest riser that will pass the required flow with the available head (h).

E. Refer to Figure C-SCM-12-7, where H is the difference in elevation of the centerline of the outlet of the barrel and the crest of the emergency spillway. L is the length of the barrel through the embankment.

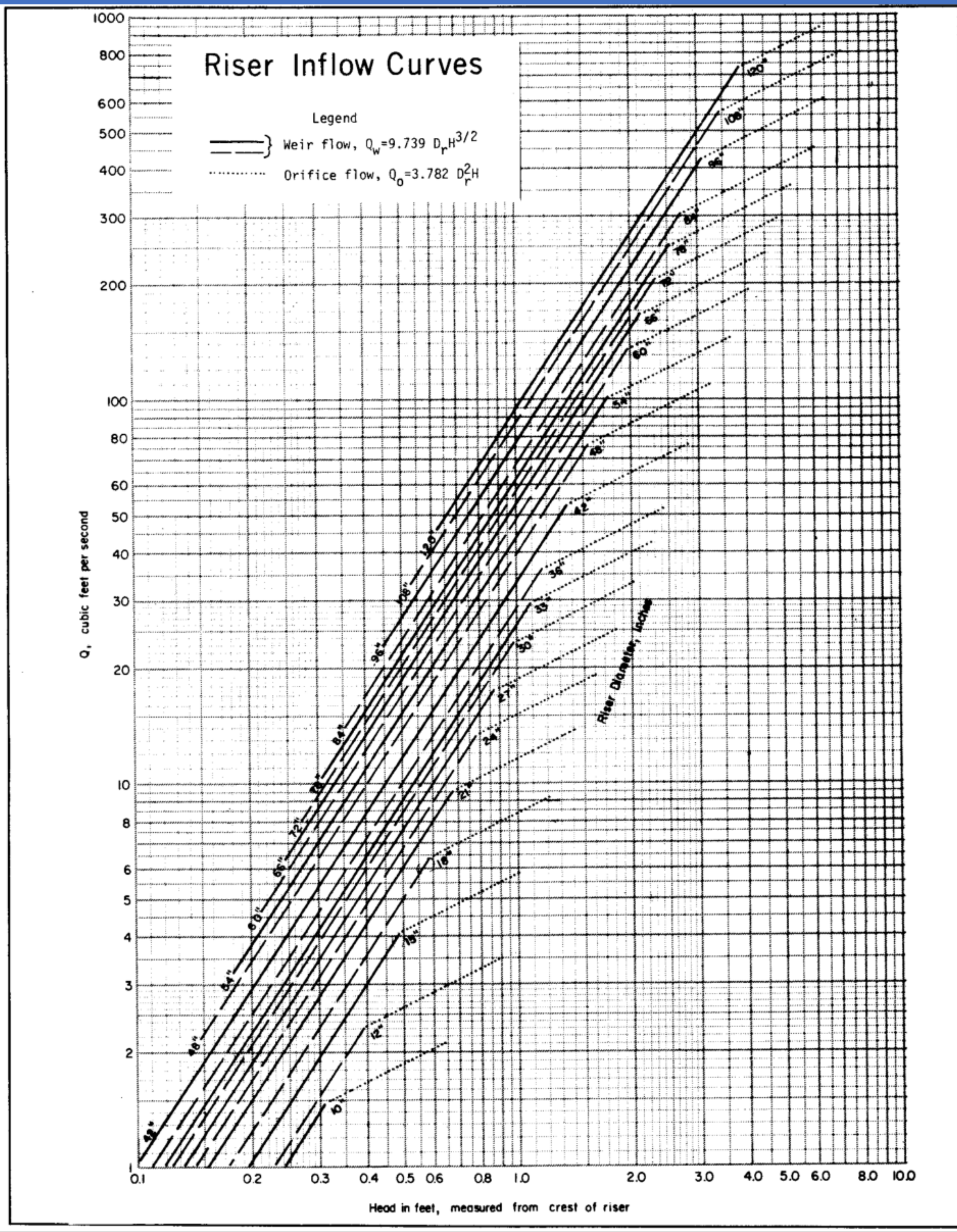
F. Enter H in Table C-SCM-12-7. Choose the smallest size barrel that will pass the flow provided by the riser. If L is other than 70 feet, make the necessary correction.

## Figure C-SCM-12-7 Principal Spillway Design




SOURCE: VA. DSWC

## Figure C-SCM-12-8 Riser Inflow Curves




Source: USDA-SCS

| Table C-SCM-12-4 Pipe Flow Chart, n = 0.025 | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H, in feet | 6" | 8" | 10" | 12" | 15" | 18" | 21" | 24" | 30" | 36" | 42" | 48" | 54" | 60" | 66" | 72" | 78" | 84" | 90" | 96" | 102" |
| 1 | 0.33 | 0.7 | 1.25 | 1.98 | 3.48 | 5.47 | 7.99 | 11 | 18.8 | 28.8 | 41.1 | 55.7 | 72.6 | 91.8 | 113 | 137 | 163 | 191 | 222 | 255 | 290 |
| 2 | 0.47 | 0.99 | 1.76 | 2.8 | 4.92 | 7.74 | 11.3 | 15.6 | 26.6 | 40.8 | 58.2 | 78.8 | 103 | 130 | 160 | 194 | 231 | 271 | 314 | 360 | 410 |
| 3 | 0.58 | 1.22 | 2.16 | 3.43 | 6.02 | 9.48 | 13.8 | 19.1 | 32.6 | 49.9 | 71.2 | 96.5 | 126 | 159 | 196 | 237 | 282 | 331 | 384 | 441 | 502 |
| 4 | 0.67 | 1.4 | 2.49 | 3.97 | 6.96 | 10.9 | 16 | 22.1 | 37.6 | 57.7 | 82.3 | 111 | 145 | 184 | 226 | 274 | 326 | 383 | 444 | 510 | 580 |
| 5 | 0.74 | 1.57 | 2.79 | 4.43 | 7.78 | 12.2 | 17.9 | 24.7 | 42.1 | 64.5 | 92 | 125 | 162 | 205 | 253 | 306 | 365 | 428 | 496 | 570 | 648 |
| 6 | 0.82 | 1.72 | 3.05 | 4.86 | 8.52 | 13.4 | 19.6 | 27 | 46.1 | 70.6 | 101 | 136 | 178 | 225 | 277 | 336 | 399 | 469 | 544 | 624 | 710 |
| 7 | 0.88 | 1.86 | 3.3 | 5.25 | 9.2 | 14.5 | 21.1 | 29.2 | 49.8 | 76.3 | 109 | 147 | 192 | 243 | 300 | 362 | 431 | 506 | 587 | 674 | 767 |
| 8 | 0.94 | 1.99 | 3.53 | 5.61 | 9.84 | 15.5 | 22.6 | 31.2 | 53.2 | 81.5 | 116 | 158 | 205 | 260 | 320 | 388 | 461 | 541 | 628 | 721 | 820 |
| 9 | 1.00 | 2.11 | 3.74 | 5.95 | 10.4 | 16.4 | 24 | 33.1 | 56.4 | 86.5 | 123 | 167 | 218 | 275 | 340 | 411 | 489 | 574 | 666 | 764 | 870 |
| 10 | 1.05 | 2.22 | 3.94 | 6.27 | 11 | 17.3 | 25.3 | 34.9 | 59.5 | 91.2 | 130 | 176 | 230 | 290 | 358 | 433 | 516 | 605 | 702 | 806 | 917 |
| 11 | 1.10 | 2.33 | 4.13 | 6.58 | 11.5 | 18.2 | 26.5 | 36.6 | 62.4 | 95.6 | 136 | 185 | 241 | 304 | 376 | 454 | 541 | 635 | 736 | 845 | 962 |
| 12 | 1.15 | 2.43 | 4.32 | 6.87 | 12.1 | 19 | 27.7 | 38.2 | 65.2 | 99.9 | 142 | 193 | 252 | 318 | 392 | 475 | 565 | 663 | 769 | 883 | 1004 |
| 13 | 1.20 | 2.53 | 4.49 | 7.15 | 12.6 | 19.7 | 28.8 | 39.8 | 67.8 | 104 | 148 | 201 | 262 | 331 | 408 | 494 | 588 | 690 | 800 | 919 | 1045 |
| 14 | 1.25 | 2.63 | 4.66 | 7.42 | 13 | 20.5 | 29.9 | 41.3 | 70.4 | 108 | 154 | 208 | 272 | 343 | 424 | 513 | 610 | 716 | 830 | 953 | 1085 |
| 15 | 1.29 | 2.72 | 4.83 | 7.68 | 13.5 | 21.2 | 30.9 | 42.8 | 72.8 | 112 | 159 | 216 | 281 | 355 | 439 | 531 | 631 | 741 | 860 | 987 | 1123 |
| 16 | 1.33 | 2.81 | 4.99 | 7.93 | 13.9 | 21.9 | 32 | 44.2 | 75.2 | 115 | 165 | 223 | 290 | 367 | 453 | 548 | 652 | 765 | 888 | 1019 | 1160 |
| 17 | 1.37 | 2.9 | 5.14 | 8.18 | 14.3 | 22.6 | 32.9 | 45.5 | 77.5 | 119 | 170 | 230 | 229 | 378 | 467 | 565 | 672 | 789 | 915 | 1051 | 1195 |
| 18 | 1.41 | 2.98 | 5.29 | 8.41 | 14.8 | 23.2 | 33.9 | 46.8 | 79.8 | 120 | 174 | 236 | 308 | 389 | 480 | 581 | 692 | 812 | 942 | 1081 | 1230 |
| 19 | 1.45 | 3.06 | 5.43 | 8.64 | 15.2 | 23.9 | 34.8 | 48.1 | 82 | 126 | 179 | 243 | 316 | 400 | 494 | 597 | 711 | 834 | 967 | 1111 | 1264 |
| 20 | 1.49 | 3.14 | 5.57 | 8.87 | 15.6 | 24.5 | 35.7 | 49.4 | 84.1 | 129 | 184 | 249 | 325 | 410 | 506 | 613 | 729 | 856 | 993 | 1139 | 1297 |
| 21 | 1.53 | 3.22 | 5.71 | 9.09 | 15.9 | 25.1 | 36.6 | 50.6 | 86.2 | 132 | 188 | 255 | 333 | 421 | 519 | 628 | 747 | 877 | 1017 | 1168 | 1329 |
| 22 | 1.56 | 3.29 | 5.85 | 9.3 | 16.3 | 25.7 | 37.5 | 51.8 | 88.2 | 135 | 193 | 261 | 341 | 430 | 531 | 643 | 765 | 898 | 1041 | 1195 | 1360 |
| 23 | 1.60 | 3.37 | 5.98 | 9.51 | 16.7 | 26.2 | 38.3 | 53 | 90.2 | 138 | 197 | 267 | 348 | 440 | 543 | 657 | 782 | 918 | 1064 | 1222 | 1390 |
| 24 | 1.63 | 3.44 | 6.11 | 9.72 | 17 | 26.8 | 39.1 | 54.1 | 92.1 | 141 | 201 | 273 | 356 | 450 | 555 | 671 | 799 | 937 | 1087 | 1248 | 1420 |
| 25 | 1.66 | 3.51 | 6.23 | 9.92 | 17.4 | 27.4 | 39.9 | 55.2 | 94 | 144 | 206 | 279 | 363 | 459 | 566 | 685 | 815 | 957 | 1110 | 1274 | 1450 |
| 26 | 1.7 | 3.58 | 6.36 | 10.1 | 17.7 | 27.9 | 40.7 | 56.3 | 95.9 | 147 | 210 | 284 | 370 | 468 | 577 | 699 | 831 | 976 | 1132 | 1299 | 1478 |
| 27 | 1.73 | 3.65 | 6.48 | 10.3 | 18.1 | 28.4 | 41.5 | 57.4 | 97.7 | 150 | 214 | 290 | 377 | 477 | 588 | 712 | 847 | 994 | 1153 | 1324 | 1507 |
| 28 | 1.76 | 3.72 | 6.6 | 10.5 | 18.4 | 29 | 42.3 | 58.4 | 99.5 | 153 | 218 | 295 | 384 | 486 | 599 | 725 | 863 | 1013 | 1174 | 1348 | 1534 |
| 29 | 1.79 | 3.78 | 6.71 | 10.7 | 18.7 | 29.5 | 43 | 59.5 | 101 | 155 | 221 | 300 | 391 | 494 | 610 | 738 | 878 | 1030 | 1195 | 1372 | 1561 |
| 30 | 1.82 | 3.85 | 6.83 | 10.9 | 19.1 | 30 | 43.7 | 60.5 | 103 | 158 | 225 | 305 | 398 | 503 | 620 | 750 | 893 | 1048 | 1216 | 1396 | 1588 |
| L, in feet | Correction Factors for Other Pipe Lengths | | | | | | | | | | | | | | | | | | | | |
| 20 | 1.69 | 1.63 | 1.58 | 1.53 | 1.47 | 1.42 | 1.37 | 1.34 | 1.28 | 1.24 | 1.2 | 1.18 | 1.16 | 1.14 | 1.13 | 1.11 | 1.1 | 1.1 | 1.09 | 1.08 | 1.08 |
| 30 | 1.44 | 1.41 | 1.39 | 1.36 | 1.32 | 1.29 | 1.27 | 1.24 | 1.21 | 1.18 | 1.15 | 1.13 | 1.12 | 1.11 | 1.1 | 1.09 | 1.08 | 1.07 | 1.07 | 1.06 | 1.06 |
| 40 | 1.28 | 1.27 | 1.25 | 1.23 | 1.21 | 1.2 | 1.18 | 1.17 | 1.14 | 1.12 | 1.11 | 1.1 | 1.09 | 1.08 | 1.07 | 1.06 | 1.06 | 1.05 | 1.05 | 1.05 | 1.04 |
| 50 | 1.16 | 1.16 | 1.15 | 1.14 | 1.13 | 1.12 | 1.11 | 1.1 | 1.09 | 1.08 | 1.07 | 1.06 | 1.06 | 1.05 | 1.05 | 1.04 | 1.04 | 1.04 | 1.03 | 1.03 | 1.03 |
| 60 | 1.07 | 1.07 | 1.07 | 1.06 | 1.06 | 1.05 | 1.05 | 1.05 | 1.04 | 1.04 | 1.03 | 1.03 | 1.03 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 |
| 70 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 80 | 0.94 | 0.94 | 0.95 | 0.95 | 0.95 | 0.95 | 0.96 | 0.96 | 0.96 | 0.97 | 0.97 | 0.97 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 | 0.99 | 0.99 |
| 90 | 0.89 | 0.89 | 0.9 | 0.9 | 0.91 | 0.91 | 0.92 | 0.92 | 0.93 | 0.94 | 0.94 | 0.95 | 0.95 | 0.96 | 0.96 | 0.96 | 0.97 | 0.97 | 0.97 | 0.97 | 0.94 |
| 100 | 0.85 | 0.85 | 0.86 | 0.86 | 0.87 | 0.88 | 0.89 | 0.89 | 0.9 | 0.91 | 0.92 | 0.93 | 0.93 | 0.94 | 0.94 | 0.95 | 0.95 | 0.95 | 0.96 | 0.96 | 0.94 |
| 120 | 0.78 | 0.79 | 0.79 | 0.9 | 0.81 | 0.82 | 0.83 | 0.83 | 0.85 | 0.86 | 0.87 | 0.89 | 0.89 | 0.9 | 0.91 | 0.89 | 0.92 | 0.93 | 0.93 | 0.94 | 0.92 |
| 140 | 0.72 | 0.73 | 0.74 | 0.75 | 0.76 | 0.77 | 0.78 | 0.79 | 0.81 | 0.82 | 0.84 | 0.85 | 0.86 | 0.87 | 0.88 | 0.86 | 0.89 | 0.9 | 0.91 | 0.91 | 0.9 |
| 160 | 0.68 | 0.69 | 0.69 | 0.7 | 0.71 | 0.73 | 0.74 | 0.75 | 0.77 | 0.79 | 0.8 | 0.82 | 0.83 | 0.84 | 0.85 | 0.92 | 0.87 | 0.88 | 0.89 | 0.89 | |

**Notes:**

For corrugated metal pipe inlet Km = Kc + Kb = 1.0 and 70 feet of corrugated metal pipe conduit (full flow assumed)

Correction factors for pipe lengths other than 70 feet diameter of pipe in inches

Source: USDA-SCS

| Table C-SCM-12-5 Pipe Flow Chart, n = 0.013 | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H, in feet | 12" | 15" | 18" | 21" | 24" | 30" | 36" | 42" | 48" | 54" | 60" | 66" | 72" | 78" | 84" | 90" | 96" | 102" |
| 1 | 3.22 | 5.44 | 8.29 | 11.8 | 15.9 | 26.0 | 38.6 | 53.8 | 71.4 | 91.5 | 114 | 139 | 167 | 197 | 229 | 264 | 302 | 342 |
| 2 | 4.55 | 7.69 | 11.7 | 16.7 | 22.5 | 36.8 | 54.6 | 76 | 101 | 129 | 161 | 197 | 236 | 278 | 324 | 374 | 427 | 483 |
| 3 | 5.57 | 9.42 | 14.4 | 20.4 | 27.5 | 45.0 | 66.9 | 931 | 124 | 159 | 198 | 241 | 289 | 341 | 397 | 458 | 523 | 592 |
| 4 | 6.43 | 10.9 | 16.6 | 23.5 | 31.8 | 52.0 | 77.3 | 108 | 143 | 183 | 228 | 278 | 334 | 394 | 459 | 529 | 604 | 683 |
| 5 | 7.19 | 12.2 | 18.5 | 26.3 | 35.5 | 58.1 | 86.4 | 120 | 160 | 205 | 255 | 311 | 373 | 440 | 513 | 591 | 675 | 764 |
| 6 | 7.88 | 13.3 | 20.3 | 28.8 | 38.9 | 63.7 | 94.6 | 132 | 175 | 224 | 280 | 341 | 409 | 482 | 562 | 647 | 739 | 837 |
| 7 | 8.51 | 14.4 | 21.9 | 31.1 | 42.0 | 68.8 | 102 | 142 | 189 | 242 | 302 | 368 | 441 | 521 | 607 | 699 | 798 | 904 |
| 8 | 9.10 | 15.4 | 23.5 | 33.3 | 44.9 | 73.5 | 109 | 152 | 202 | 259 | 323 | 394 | 472 | 557 | 685 | 748 | 854 | 966 |
| 9 | 9.65 | 16.3 | 24.9 | 35.3 | 47.7 | 78.0 | 116 | 161 | 214 | 275 | 342 | 418 | 500 | 590 | 688 | 793 | 905 | 1025 |
| 10 | 10.20 | 17.2 | 26.2 | 37.2 | 50.2 | 82.2 | 122 | 170 | 226 | 289 | 361 | 440 | 527 | 622 | 725 | 836 | 954 | 1080 |
| 11 | 10.70 | 18.0 | 27.5 | 39.0 | 52.7 | 86.2 | 128 | 178 | 237 | 304 | 379 | 462 | 553 | 653 | 761 | 877 | 1001 | 1133 |
| 12 | 11.10 | 18.9 | 28.7 | 40.8 | 55.0 | 90.1 | 134 | 186 | 247 | 317 | 395 | 482 | 578 | 682 | 794 | 916 | 1045 | 1184 |
| 13 | 11.60 | 19.6 | 29.9 | 42.4 | 57.3 | 93.7 | 139 | 194 | 257 | 330 | 411 | 502 | 601 | 710 | 827 | 953 | 1088 | 1232 |
| 14 | 12.00 | 20.4 | 31.0 | 44.1 | 59.4 | 97.3 | 145 | 201 | 267 | 342 | 427 | 521 | 624 | 736 | 858 | 989 | 1129 | 1278 |
| 15 | 12.50 | 21.1 | 32.1 | 45.6 | 61.5 | 101 | 150 | 208 | 277 | 354 | 442 | 539 | 646 | 762 | 888 | 1024 | 1169 | 1323 |
| 16 | 12.90 | 21.8 | 33.2 | 47.1 | 63.5 | 104 | 155 | 215 | 286 | 366 | 457 | 557 | 667 | 787 | 917 | 1057 | 1207 | 1367 |
| 17 | 13.30 | 22.4 | 34.2 | 48.5 | 65.5 | 107 | 159 | 222 | 294 | 377 | 471 | 574 | 688 | 812 | 946 | 1090 | 1244 | 1409 |
| 18 | 13.70 | 23.1 | 35.2 | 49.9 | 67.4 | 110 | 164 | 228 | 303 | 388 | 484 | 591 | 708 | 835 | 973 | 1121 | 1280 | 1450 |
| 19 | 14.00 | 23.7 | 36.1 | 51.3 | 69.2 | 113 | 168 | 234 | 311 | 399 | 497 | 607 | 727 | 858 | 1000 | 1152 | 1315 | 1489 |
| 20 | 14.40 | 24.3 | 37.1 | 52.6 | 71.0 | 116 | 173 | 240 | 319 | 409 | 510 | 623 | 746 | 880 | 1026 | 1182 | 1350 | 1528 |
| 21 | 14.70 | 24.9 | 38.0 | 53.9 | 72.8 | 119 | 177 | 246 | 327 | 419 | 523 | 638 | 764 | 902 | 1051 | 1211 | 1383 | 1566 |
| 22 | 15.10 | 25.5 | 38.9 | 55.2 | 74.5 | 122 | 181 | 252 | 335 | 429 | 535 | 653 | 782 | 923 | 1076 | 1240 | 1415 | 1603 |
| 23 | 15.40 | 26.1 | 39.8 | 56.5 | 76.2 | 125 | 186 | 258 | 342 | 439 | 547 | 668 | 800 | 944 | 1100 | 1268 | 1447 | 1639 |
| 24 | 15.80 | 26.7 | 40.6 | 57.7 | 77.8 | 127 | 189 | 263 | 350 | 448 | 559 | 682 | 817 | 964 | 1123 | 1295 | 1478 | 1674 |
| 25 | 16.10 | 27.2 | 41.5 | 58.9 | 79.4 | 130 | 193 | 269 | 357 | 458 | 571 | 696 | 834 | 984 | 1147 | 1322 | 1509 | 1708 |
| 26 | 16.40 | 27.7 | 42.3 | 60.0 | 81.0 | 133 | 197 | 274 | 364 | 467 | 582 | 710 | 850 | 1004 | 1169 | 1348 | 1539 | 1742 |
| 27 | 16.70 | 28.3 | 43.1 | 61.2 | 82.5 | 135 | 201 | 279 | 371 | 476 | 593 | 723 | 867 | 1023 | 1192 | 1373 | 1568 | 1775 |
| 28 | 17.00 | 28.8 | 43.9 | 62.3 | 84.1 | 138 | 204 | 285 | 378 | 484 | 604 | 737 | 883 | 1041 | 1214 | 1399 | 1597 | 1808 |
| 29 | 17.30 | 29.3 | 44.7 | 63.4 | 85.5 | 140 | 208 | 290 | 384 | 493 | 615 | 750 | 898 | 1060 | 1235 | 1423 | 1625 | 1840 |
| 30 | 17.60 | 29.8 | 45.4 | 64.5 | 87.0 | 142 | 212 | 294 | 391 | 501 | 625 | 763 | 913 | 1078 | 1256 | 1448 | 1653 | 1871 |
| **L, in feet** | **Correction Factors for Other Pipe Lengths** | | | | | | | | | | | | | | | | | |
| 20 | 1.30 | 1.24 | 1.21 | 1.18 | 1.15 | 1.12 | 1.10 | 1.08 | 1.07 | 1.06 | 1.05 | 1.05 | 1.04 | 1.04 | 1.03 | 1.03 | 1.03 | 1.03 |
| 30 | 1.22 | 1.18 | 1.15 | 1.13 | 1.12 | 1.09 | 1.08 | 1.06 | 1.05 | 1.05 | 1.04 | 1.04 | 1.03 | 1.03 | 1.03 | 1.02 | 1.02 | 1.02 |
| 40 | 1.15 | 1.13 | 1.11 | 1.10 | 1.08 | 1.07 | 1.05 | 1.05 | 1.04 | 1.03 | 1.03 | 1.03 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 |
| 50 | 1.09 | 1.08 | 1.07 | 1.06 | 1.05 | 1.04 | 1.03 | 1.03 | 1.03 | 1.02 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| 60 | 1.04 | 1.04 | 1.03 | 1.03 | 1.03 | 1.02 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| 70 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 80 | 0.96 | 0.97 | 0.97 | 0.97 | 0.98 | 0.98 | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |
| 90 | 0.93 | 0.94 | 0.94 | 0.95 | 0.95 | 0.96 | 0.97 | 0.97 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 | 0.99 | 0.99 | 0.99 | 0.99 |
| 100 | 0.90 | 0.91 | 0.92 | 0.93 | 0.93 | 0.95 | 0.95 | 0.96 | 0.97 | 0.97 | 0.97 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 |
| 120 | 0.84 | 0.86 | 0.87 | 0.89 | 0.90 | 0.91 | 0.93 | 0.94 | 0.94 | 0.95 | 0.96 | 0.96 | 0.96 | 0.97 | 0.97 | 0.97 | 0.97 | 0.98 |
| 140 | 0.80 | 0.82 | 0.83 | 0.85 | 0.86 | 0.88 | 0.90 | 0.91 | 0.92 | 0.93 | 0.94 | 0.94 | 0.95 | 0.95 | 0.96 | 0.96 | 0.96 | 0.97 |
| 160 | 0.76 | 0.78 | 0.80 | 0.82 | 0.83 | 0.86 | 0.88 | 0.89 | 0.90 | 0.91 | 0.92 | 0.93 | 0.94 | 0.94 | 0.95 | 0.95 | 0.95 | 0.96 |

**Notes:**

For reinforced concrete pipe inlet Km = Kc + Kb = 0.65 and 70 feet of corrugated metal pipe conduit (full flow assumed)

Correction factors for pipe lengths other than 70 feet diameter of pipe in inches

Source: USDA-SCS

## Table C-SCM-12-6 Design Data for Earth Spillways

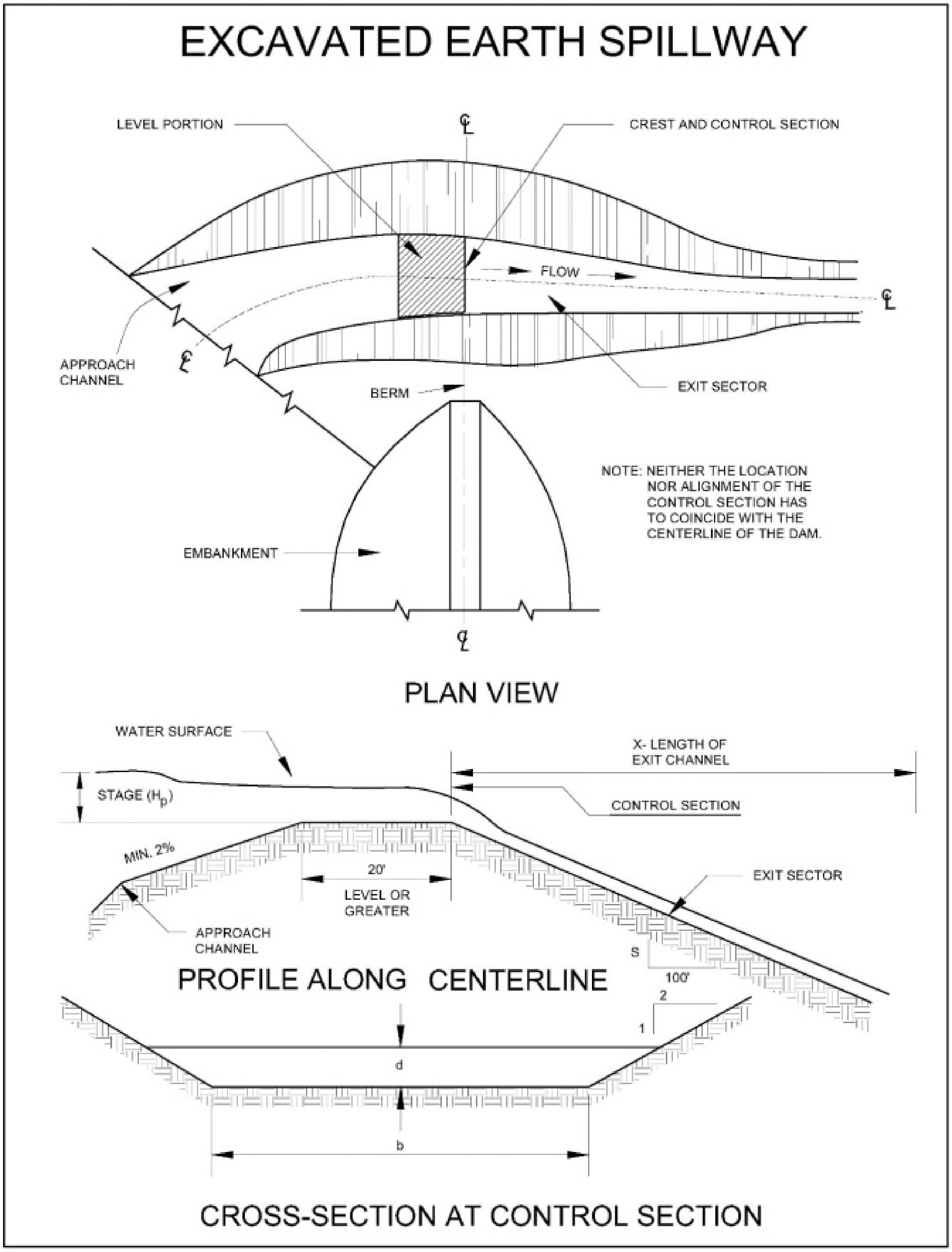
| Stage (Hp) in Feet | Spillway Variables | Bottom Width (b) in Feet | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
| 0.5 | Q | 6 | 7 | 8 | 10 | 11 | 13 | 14 | 15 | 17 | 18 | 20 | 21 | 22 | 24 | 25 | 27 | 28 |
| | V | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| | S | 3.9 | 3.9 | 3.9 | 3.9 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 |
| | X | 32 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 |
| 0.6 | Q | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 35 | 37 | 39 |
| | V | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | S | 3.7 | 3.7 | 3.7 | 3.7 | 3.6 | 3.7 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | X | 36 | 36 | 36 | 36 | 36 | 36 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 |
| 0.7 | Q | 11 | 13 | 16 | 18 | 20 | 23 | 25 | 28 | 30 | 33 | 35 | 38 | 41 | 43 | 44 | 46 | 48 |
| | V | 3.2 | 3.2 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| | S | 3.5 | 3.5 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |
| | X | 39 | 40 | 40 | 40 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 |
| 0.8 | Q | 13 | 16 | 19 | 22 | 26 | 29 | 32 | 35 | 38 | 42 | 45 | 46 | 48 | 51 | 54 | 57 | 60 |
| | V | 3.5 | 3.5 | 3.5 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S | 3.3 | 3.3 | 3.3 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| | X | 44 | 44 | 44 | 44 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| 0.9 | Q | 17 | 20 | 24 | 28 | 32 | 35 | 39 | 43 | 47 | 51 | 53 | 57 | 60 | 64 | 68 | 71 | 75 |
| | V | 3.7 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 |
| | S | 3.2 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| | X | 47 | 47 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 49 | 49 | 49 | 49 | 49 | 49 | 49 |
| 1.0 | Q | 20 | 24 | 29 | 33 | 38 | 42 | 47 | 51 | 56 | 61 | 63 | 68 | 72 | 77 | 81 | 86 | 90 |
| | V | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| | S | 3.1 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | X | 51 | 51 | 51 | 51 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| 1.1 | Q | 23 | 28 | 34 | 39 | 44 | 49 | 54 | 60 | 65 | 70 | 74 | 79 | 84 | 89 | 95 | 100 | 105 |
| | V | 4.2 | 4.2 | 4.2 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 |
| | S | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| | X | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| 1.2 | Q | 28 | 33 | 40 | 45 | 51 | 58 | 64 | 69 | 76 | 80 | 86 | 92 | 98 | 104 | 110 | 116 | 122 |
| | V | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| | S | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| | X | 58 | 58 | 59 | 59 | 59 | 59 | 59 | 59 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| 1.3 | Q | 32 | 38 | 46 | 53 | 58 | 65 | 73 | 80 | 86 | 91 | 99 | 106 | 112 | 119 | 125 | 133 | 140 |
| | V | 4.5 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 |
| | S | 2.8 | 2.8 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| | X | 62 | 62 | 62 | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 64 | 64 | 64 | 64 | 64 | 64 |
| 1.4 | Q | 37 | 44 | 51 | 59 | 66 | 74 | 82 | 90 | 96 | 103 | 111 | 119 | 127 | 134 | 142 | 150 | 158 |
| | V | 4.7 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 |

| Table C-SCM-12-6 Design Data for Earth Spillways | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stage (Hp) in Feet | Spillway Variables | Bottom Width (b) in Feet | | | | | | | | | | | | | | | | |
| | | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
| | S | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| | X | 65 | 66 | 66 | 66 | 66 | 67 | 67 | 67 | 67 | 67 | 67 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.9 |
| 1.5 | Q | 41 | 50 | 58 | 66 | 75 | 85 | 92 | 101 | 108 | 116 | 125 | 133 | 142 | 150 | 160 | 169 | 178 |
| | V | 4.8 | 4.9 | 4.9 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.1 | 5.1 | 5.1 |
| | S | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 |
| | X | 69 | 69 | 70 | 70 | 71 | 71 | 71 | 71 | 71 | 71 | 71 | 72 | 72 | 72 | 72 | 72 | 72 |
| 1.6 | Q | 46 | 56 | 65 | 75 | 84 | 94 | 104 | 112 | 122 | 132 | 142 | 149 | 158 | 168 | 178 | 187 | 197 |
| | V | 5.0 | 5.1 | 5.1 | 5.1 | 5.1 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 |
| | S S | 2.6 | 2.6 | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| | X | 72 | 74 | 74 | 75 | 75 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 |
| 1.7 | Q | 52 | 62 | 72 | 83 | 94 | 105 | 115 | 126 | 135 | 145 | 156 | 167 | 175 | 187 | 196 | 206 | 217 |
| | V | 5.2 | 5.2 | 5.2 | 5.3 | 5.3 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 |
| | S | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| | X | 76 | 78 | 79 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| 1.8 | Q | 58 | 69 | 81 | 93 | 104 | 116 | 127 | 138 | 150 | 160 | 171 | 182 | 194 | 204 | 214 | 226 | 233 |
| | V | 5.3 | 5.4 | 5.4 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 |
| | S | 2.5 | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| | X | 80 | 82 | 83 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 |
| 1.9 | Q | 64 | 76 | 88 | 102 | 114 | 127 | 140 | 152 | 164 | 175 | 188 | 201 | 213 | 225 | 235 | 248 | 260 |
| | V | 5.5 | 5.5 | 5.5 | 5.6 | 5.6 | 5.6 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 |
| | S | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| | X | 84 | 85 | 86 | 87 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 |
| 2.0 | Q | 71 | 83 | 97 | 111 | 125 | 138 | 153 | 164 | 178 | 193 | 204 | 218 | 232 | 245 | 256 | 269 | 283 |
| | V | 5.6 | 5.7 | 5.7 | 5.7 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 |
| | S | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| | X | 88 | 90 | 91 | 91 | 91 | 91 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 |
| 2.1 | Q | 77 | 91 | 107 | 122 | 135 | 149 | 162 | 177 | 192 | 207 | 220 | 234 | 250 | 267 | 276 | 291 | 305 |
| | V | 5.7 | 5.8 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| | S | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| | X | 92 | 93 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 96 |
| 2.2 | Q | 84 | 100 | 116 | 131 | 146 | 163 | 177 | 194 | 210 | 224 | 238 | 253 | 269 | 288 | 301 | 314 | 330 |
| | V | 5.9 | 5.9 | 6.0 | 6.0 | 6.0 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.2 | 6.2 | 6.2 | 6.2 |
| | S | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| | X | 96 | 98 | 99 | 99 | 99 | 99 | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2.3 | Q | 90 | 108 | 124 | 140 | 158 | 175 | 193 | 208 | 226 | 243 | 258 | 275 | 292 | 306 | 323 | 341 | 354 |
| | V | 6.0 | 6.1 | 6.1 | 6.1 | 6.2 | 6.2 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 |
| | S | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |

| Table C-SCM-12-6 Design Data for Earth Spillways | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stage (Hp) in Feet | Spillway Variables | Bottom Width (b) in Feet | | | | | | | | | | | | | | | | |
| | | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
| | X | 100 | 102 | 102 | 103 | 103 | 103 | 104 | 104 | 104 | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 |
| 2.4 | Q | 99 | 116 | 136 | 152 | 170 | 189 | 206 | 224 | 241 | 260 | 275 | 294 | 312 | 327 | 346 | 364 | 378 |
| | V | 6.1 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| | S | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| | X | 105 | 105 | 106 | 107 | 107 | 108 | 108 | 108 | 108 | 109 | 109 | 109 | 109 | 109 | 109 | 109 | 109 |

Source: USDA-SCS

**Figure C-SCM-12-9 Excavated Earth Spillway**




SOURCE: USDA-SCS

VIII. **Emergency Spillway Design**

A. Design the emergency spillway to pass the remainder of the 25-year peak rate of runoff not carried by the principal spillway.

B. Compute, $Q_e = Q_{25} - Q_P$

C. Refer to Figure C-SCM-12-9 and Table C-SCM-12-6.

D. Determine approximate permissible values for b (the bottom width); s (the slope of the exit channel); and X (minimum length of the exit channel).

E. Enter Table C-SCM-12-6 and choose an exit channel cross-section that passes the required flow and meets the other constraints of the site.

F. Note:

1. Consider the maximum permissible velocity for vegetated waterways when designing an exit channel.
2. For a given Hp, a decrease in the exit slope from S (as given in the table) decreases spillway discharge, but increasing the exit slope from S does not increase discharge. If an exit slope (Se) steeper than S is used, then design procedures detailed in "Open Channel Flow" in Chapter 5 of the 1993 VESCH should be used to verify the adequacy of the exit channel.
3. Use the data to the right of heavy vertical lines with caution, as the resulting sections will be either poorly proportioned or have excessive velocities.

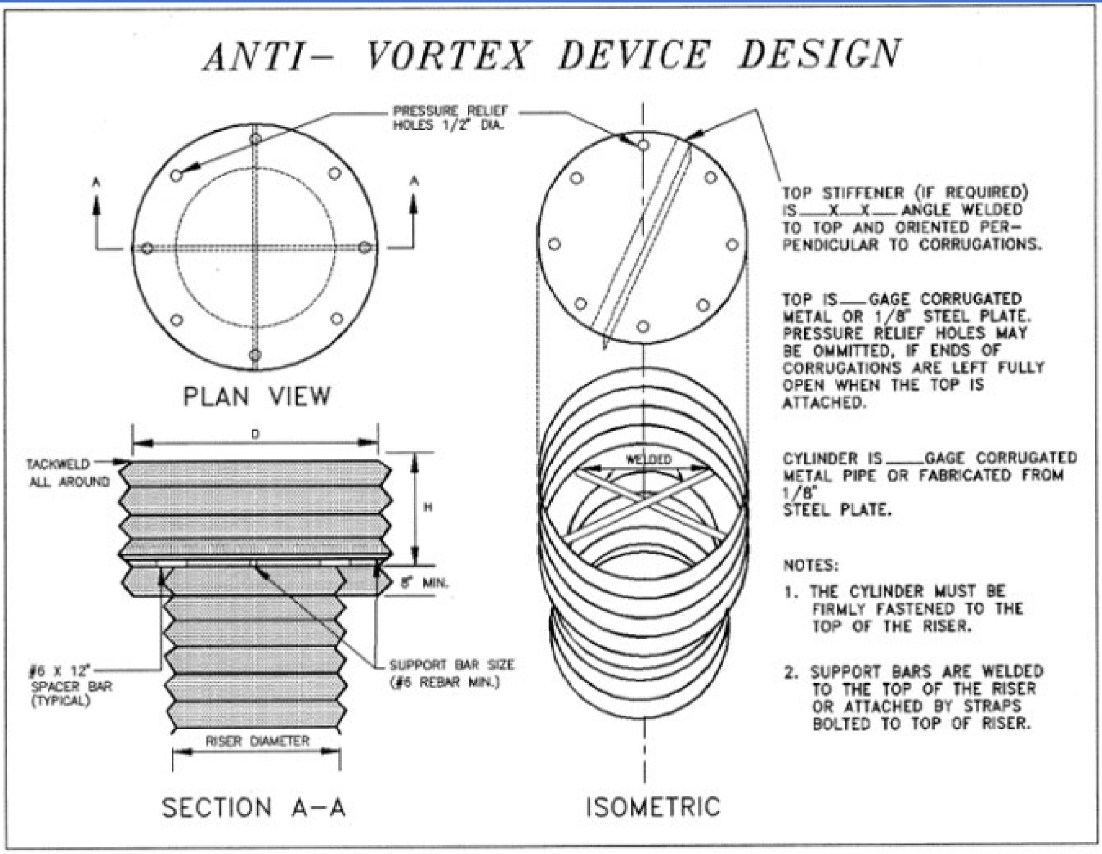
VIII. Re-estimate the elevation of the design high water and the top of the dam based upon the design of the principal spillway and the emergency spillway.

IX. Anti-Vortex Device and Trash Rack

A. This design procedure for the anti-vortex device and trash rack refers only to riser pipes of corrugated metal. There are numerous ways to protect concrete pipe, including hoods, grates, and rebar configurations, which should be a part of project-specific design and will frequently be a part of a permanent structure.

B. Refer to Figure C-SCM-12-10 and Table C-SCM-12-7. Choose cylinder size, support bars, and top requirements from Table C-SCM-12-7 based on the diameter of the riser pipe.

### *Figure C-SCM-12-10 Anti-Vortex Device Design*




*Source: USDA-SCS*

### Table C-SCM-12-7 Anti Vortex Device Design

| Riser Dia. (in.) | Cylinder | | Height (inches) | Minimum Size Support Bar | Minimum Top | |
|---|---|---|---|---|---|---|
| | Diameter (inches) | Thickness (gage) | | | Thickness | Stiffener |
| 12 | 18 | 16 | 6 | #6 Rebar or 1.5 x 1.5 x 0.1875 angle | 16 ga. (F&C) | - |
| 15 | 21 | 16 | 7 | | | - |
| 18 | 27 | 16 | 8 | | | - |
| 21 | 30 | 16 | 11 | | 16 ga.(C), 14 ga.(F) | - |
| 24 | 36 | 16 | 13 | | | - |
| 27 | 42 | 16 | 15 | | | - |
| 36 | 54 | 14 | 17 | #8 Rebar | 14 ga.(C), 12 ga.(F) | - |
| 42 | 60 | 16 | 19 | | | - |
| 48 | 72 | 16 | 21 | 1.25” pipe or 1.25 x 1.25 x 0.25 angle | 14 ga.(C), 10 ga.(F) | - |
| 54 | 78 | 16 | 25 | | | |
| 60 | 90 | 14 | 29 | 1.5” pipe or 1.5 x 1.5 x 0.5 angle | 12 ga.(C), 8 ga.(F) | - |
| 66 | 96 | 14 | 33 | 2” pipe or 2 x 2 x 0.1875 angle | 12 ga.(C), 8 ga.(F) w/stiffener | 2 x 2 x 0.25 angle |

<table>
<tr><th colspan="7">Table C-SCM-12-7 Anti Vortex Device Design</th></tr>
<tr><th rowspan="2">Riser Dia. (in.)</th><th colspan="2">Cylinder</th><th rowspan="2">Height (inches)</th><th rowspan="2">Minimum Size Support Bar</th><th colspan="2">Minimum Top</th></tr>
<tr><th>Diameter (inches)</th><th>Thickness (gage)</th><th>Thickness</th><th>Stiffener</th></tr>
<tr><td>72</td><td>102</td><td>14</td><td>36</td><td></td><td rowspan="3"></td><td rowspan="2">2.5 x 2.5 x 0.25 angle</td></tr>
<tr><td>78</td><td>114</td><td>14</td><td>39</td><td>25” pipe or 2 x 2 x 0.25 angle</td></tr>
<tr><td>84</td><td>120</td><td>12</td><td>42</td><td>2.5” pipe or 2.5 x 2.5 x 0.25 angle</td><td>2.5 x 2.5 x 0.3125 angle</td></tr>
</table>

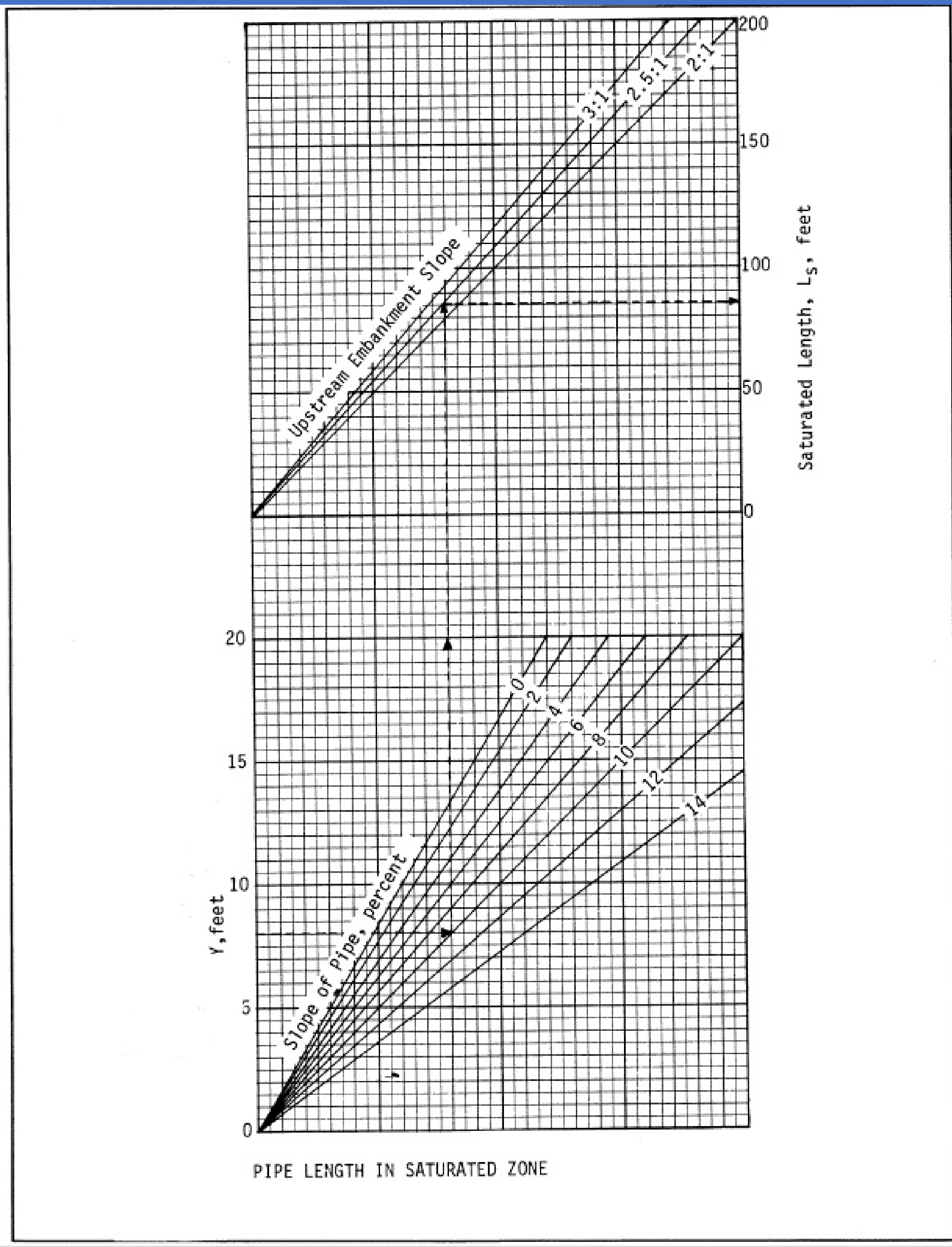
**Notes:**

1. The criterion for sizing the cylinder is that the area between the inside of the cylinder and the outside of the riser is equal to or greater than the area inside the riser. Therefore, this table is invalid for use with concrete pipe risers.
2. Corrugation for 12” to 36” pipe measures 2.7” x 0.5”; for 42” to 84” the corrugation measures 5” x 1” or 8” x 1”.

C = corrugated; F = flat.

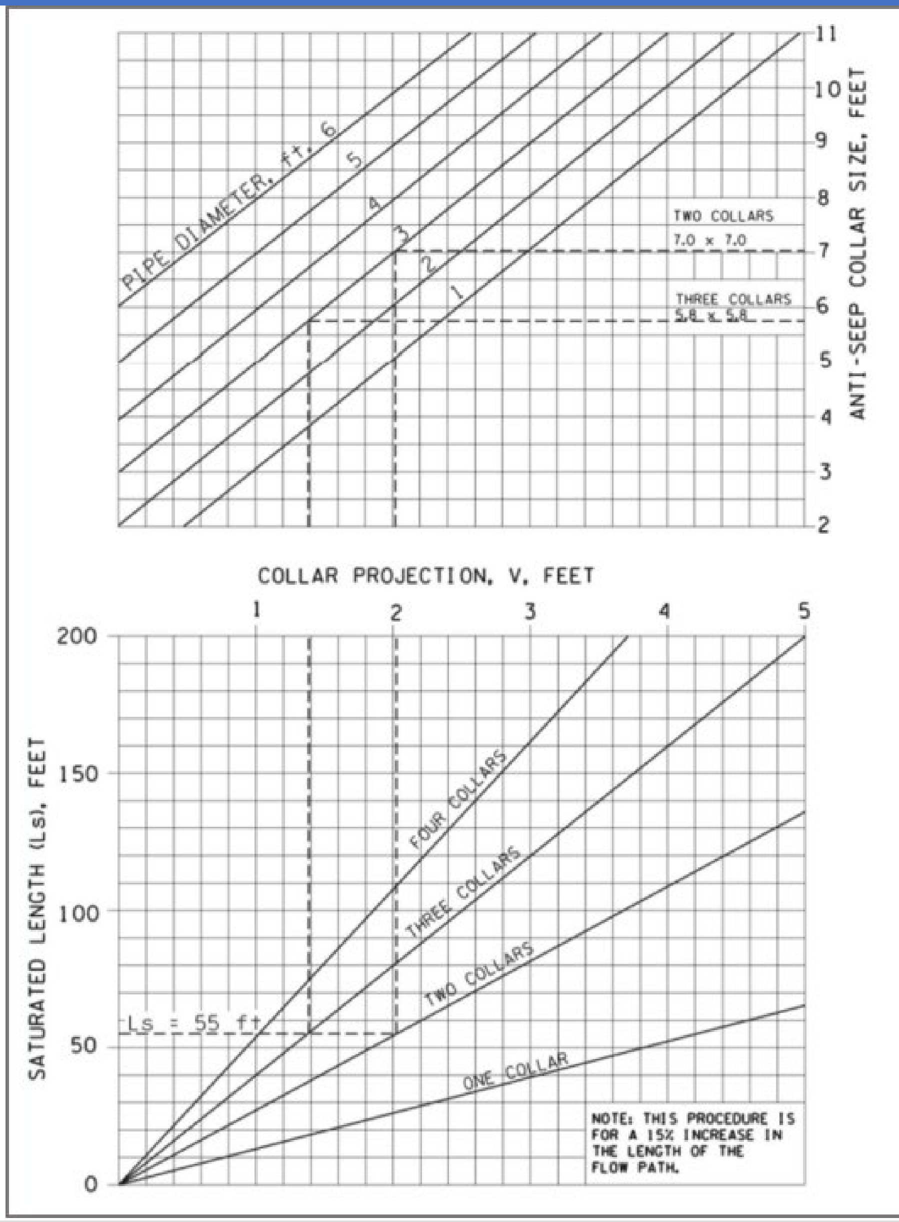
Source: Adapted from USDA-SCS and Carl M. Henshaw Drainage Products Information.

## *Figure C-SCM-12-11 Pipe Length in Saturated Zone*




*Source: USDA-SCS*

**Figure C-SCM-12-12 Anti-Steep Collar Design Chart**




*Source: OHIO DOT (2004)*

XI. Anti-Seep Collars

A. Use anti-seep collars under the conditions specified in the Design Criteria.

B. Use anti-seep collars to increase the seepage length along the barrel by 10%.

C. Determine the length of the barrel within the saturated zone graphically (as in Figure C-SCM-12-11) or by solving the following equation:

$$L_s = Y(Z + 4)\left[1 + \frac{S}{0.25 - S}\right]$$

where:

$L_s$ = length of barrel in the saturated zone, in feet

Y = the depth of water at the principal spillway crest, in feet

Z = slope of the upstream face of embankment in Z feet horizontal to one vertical

S = slope of the barrel in feet per foot

D. Enter Figure C-SCM-12-12 with $L_s$. Move horizontally right until one of the lines is intersected. Move vertically until the correct line for barrel diameter is intersected. Move horizontally right to read P, the size of the anti-seep collar.

E. If more than one collar is used, design the spacing between collars to be 14 times the projection of the collar above the barrel.

F. Do not locate collars closer than 2 feet from a pipe joint.

G. See Figure C-SCM-12-13 for details of the anti-seep collar.

XII. Anchoring the Principal Spillway

A. Firmly anchor the principal spillway to prevent its floating.

B. If the riser is taller than 10 feet, calculate the forces acting on the spillway. Anchor the spillway to provide a safety factor of 1.25 (downward forces = 1.25 x upward forces).

C. If the riser is shorter than 10 feet, choose one of the two methods illustrated on Figure C-SCM-12-14 to anchor the principal spillway.

XIII. Dewatering

A. Refer to Figure C-SCM-12-15 for details and orientation.

B. Calculate the diameter of the dewatering orifice:

Use a modified version of the discharge equation for a vertical orifice and a basic equation for the area of a circular orifice.

Naming the variables:

A = flow area of orifice (square feet)

D = diameter of circular orifice (feet)

H = average driving head (maximum possible head measured from radius of orifice to crest of principal spillway divided by 2) (feet)

Q = volumetric flowrate through orifice needed to achieve approximate 6-hour drawdown (cubic feet per second)

S = total storage available in the dry storage area (cubic feet)

Q = S / 21,600 seconds

Use S for basin and find Q. Then substitute in calculated Q and find A:

$$A = \frac{Q}{(64.32 \quad x \quad h)^{½} \quad (0.6)}$$

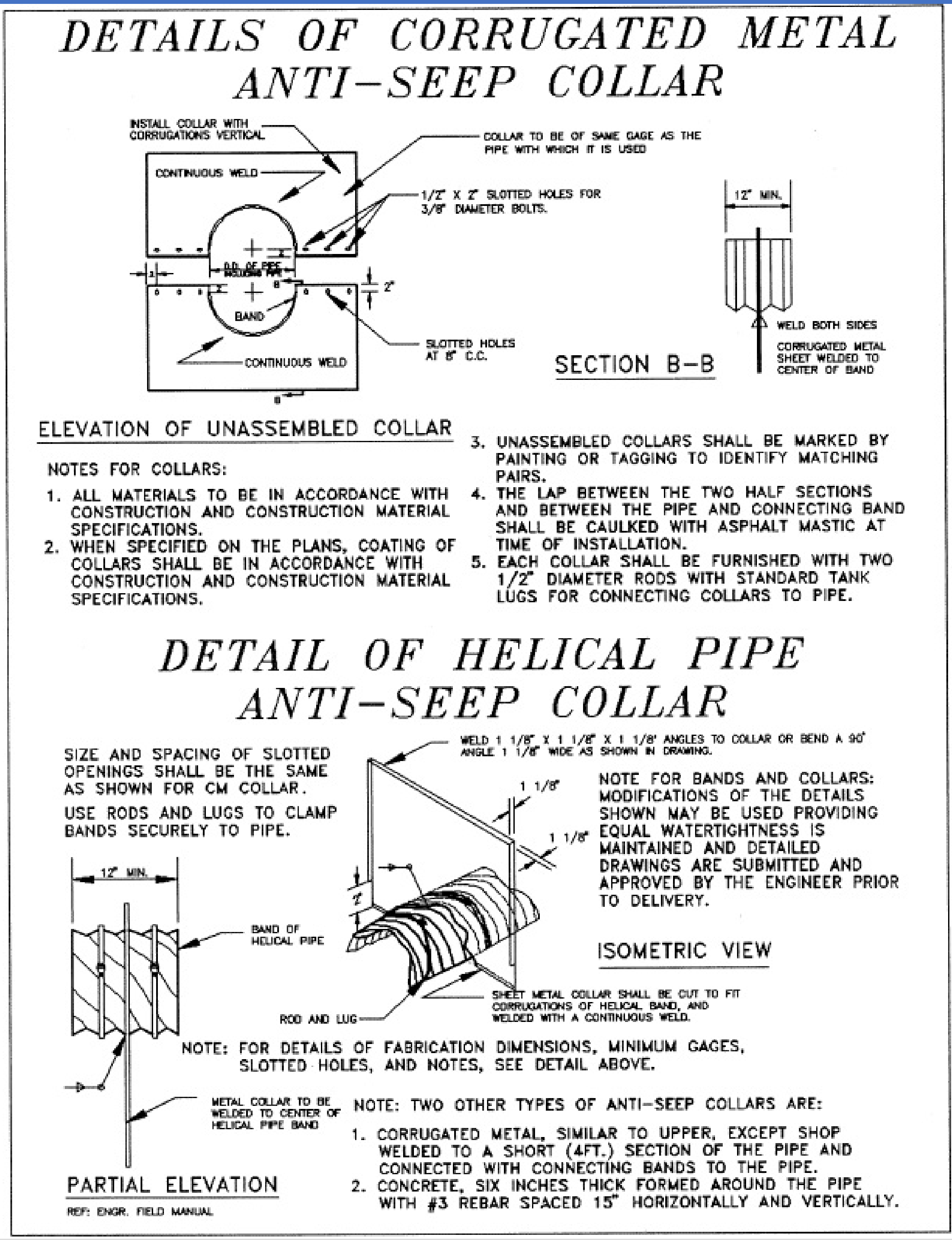
Then, substitute in calculated A and find d:

$$d^* = 2 \quad x \quad \left[\frac{A}{3.14}\right]^{½}$$

*Do not use a diameter of dewatering orifice less than 3 inches to help prevent clogging by soil or debris.

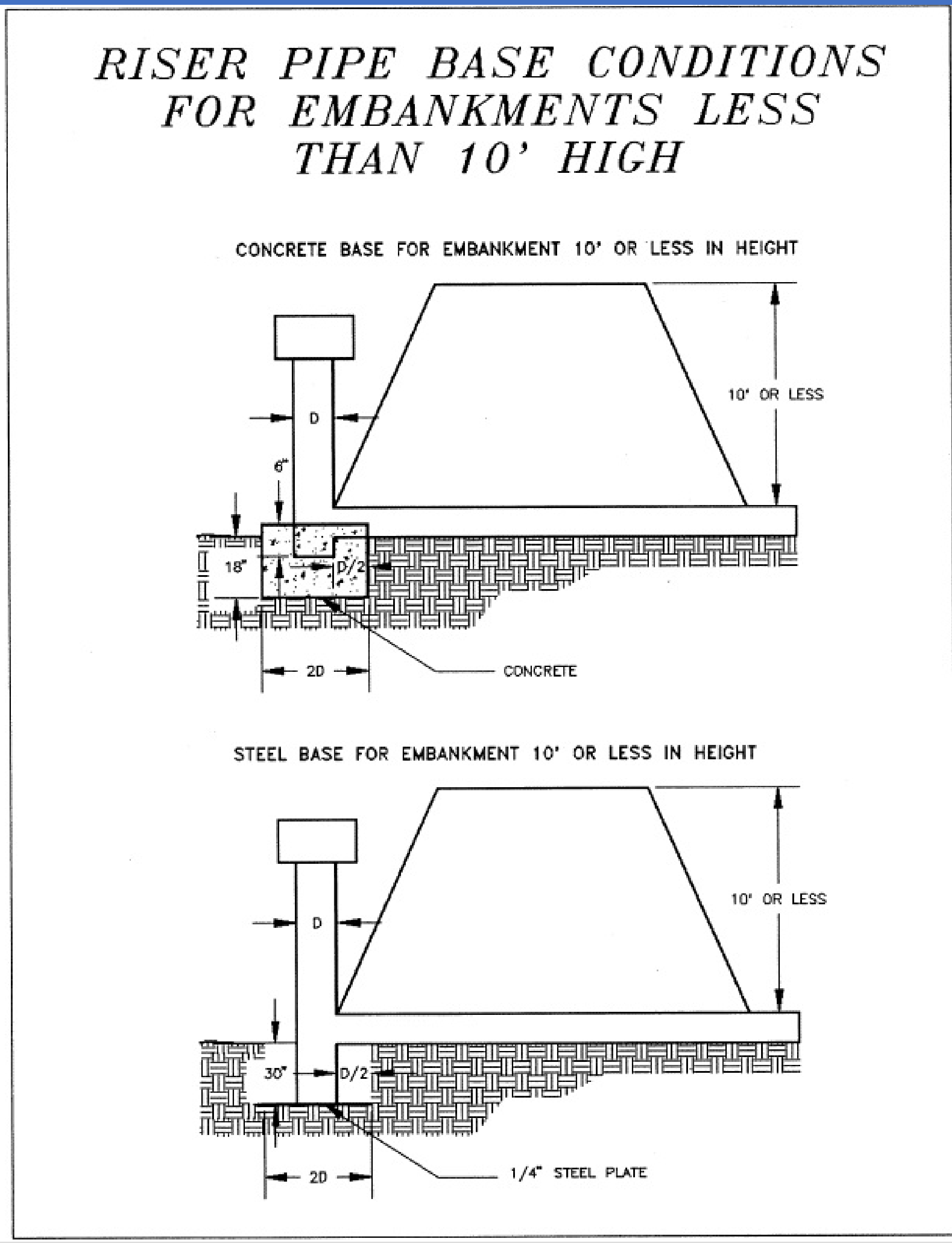
Note: Use perforated flexible tubing at least 2 inches larger in diameter than the calculated orifice to improve flow.

**Figure C-SCM-12-13 Anti-Seep Collar Details**



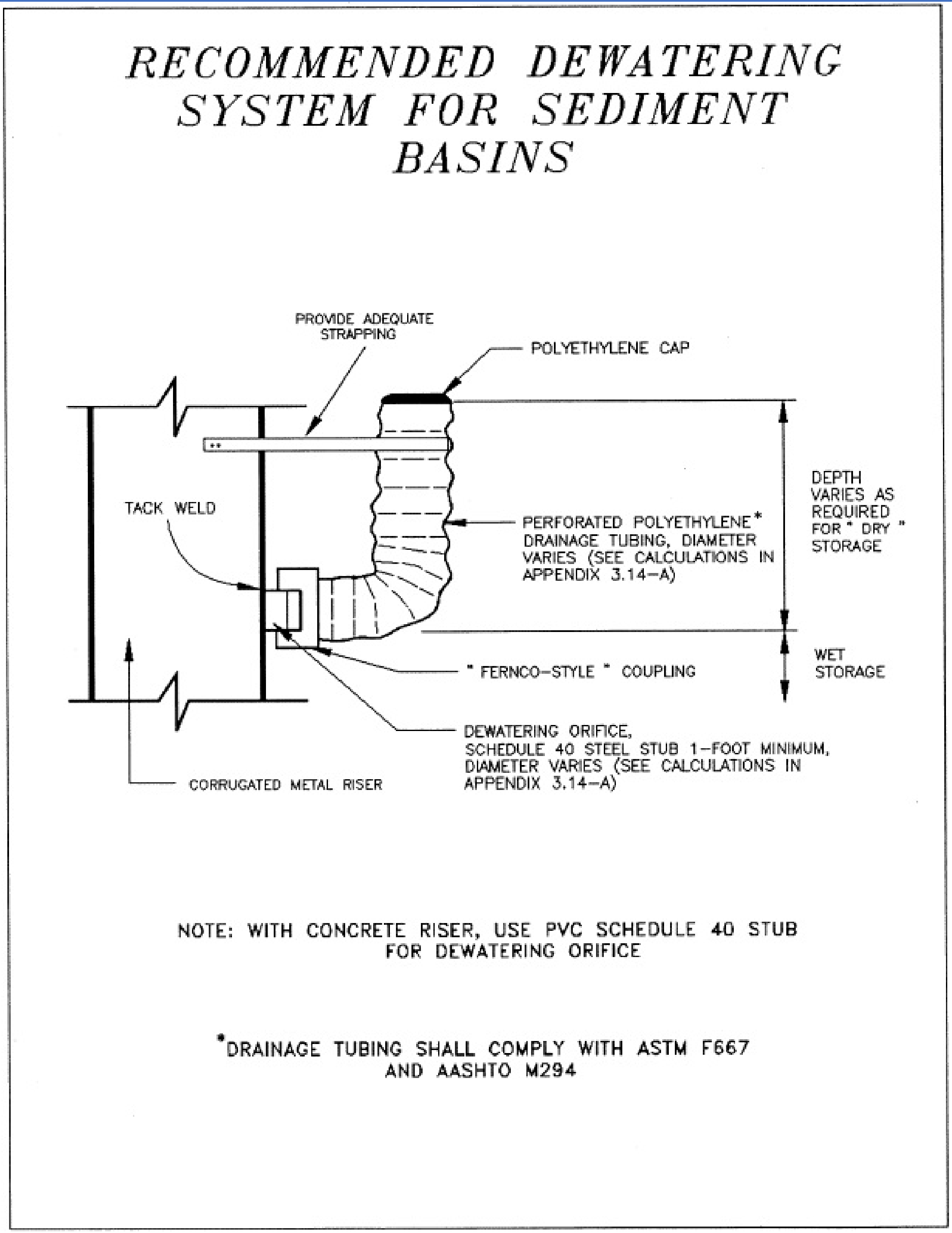

*Source: USDA-SCS*

## Figure C-SCM-12-14 Riser Bank Conditions for Embankments Less Than 10' High




*Source: USDA-SCS*

***Figure C-SCM-12-15 Dewatering System for Sediment Basins***



# Temporary Sediment Basin Design Data Sheet

| | |
|---|---|
| Project: | |
| Basin No.: | |
| Location: | |
| Total Area Draining to Basin: | acres |

| Basin Volume Design | |
|---|---|
| **Wet Storage:** | |
| Minimum Required Volume [1] | cy |
| Available Basin Volume at Elevation [2] | cy |
| Excavation Volume to Obtain Required Volume [3] | cy |
| Available Volume before Cleanout Required [4] | cy |
| Cleanout Level Elevation [2] | ft |
| Distance From Invert of the Dewatering Orifice to Cleanout Level [5] | ft |
| **Dry Storage:** | |
| Minimum Required Volume [1] | cy |
| Available Basin Volume at Crest of Riser Elevation [2,6] | cy |
| Diameter of Dewatering Orifice | in |
| Diameter of Flexible Tubing [7] | in |
| **Preliminary Design Elevations:** | |
| Crest of Riser | ft |
| Top of Dam | ft |
| Design High Water | ft |
| Upstream Toe of Dam | ft |
| **Basin Shape** | |
| Length of Flow to Effective Width Ratio | $L:W_e$ |
| If > 2, baffles are not required | |
| If < 2, baffles are required | |
| **Runoff** | |
| 2-year peak rate of runoff, Q2 | cfs |
| 25-year peak rate of runoff, Q25 | cfs |
| **Principal Spillway Design** | |
| With Emergency Spillway, Required Spillway Capacity Qp = Q2 | cfs |
| Without Emergency Spillway, Required Spillway Capacity Qp = Q25 | cfs |
| With Emergency Spillway, Assumed Available Head (h) (using Q2) [8] | ft |
| Without Emergency Spillway, Assumed Available Head (h) (using Q25) [8] | ft |
| Riser Diameter (Dr) | in |
| Actual Head [9] | ft |
| Barrel Length (l) | ft |
| Head (H) on Barrel Through Embankment [10] | ft |
| Barrel Diameter [11] | in |
| Trash Rack and Anti-Vortex Device Diameter [12] | in |

| Temporary Sediment Basin Design Data Sheet | |
|---|---|
| Trash Rack and Anti-Vortex Device Height [12] | in |
| **Emergency Spillway Design** | |
| Required Spillway Capacity Qe = Q25 – Qp | cfs |
| Bottom Width (b) | ft |
| Slope of the Exit Channel (s) | ft/ft |
| Minimum Length of the Exit Channel (x) [13] | ft |
| **Anti-Seep Collar Design** | |
| Depth of Water at Principal Spillway Crest (Y) | ft |
| Slope of Upstream Face of Embankment (Z) | Z:1 |
| Slope of Principal Spillway Barrel (Sb) | % |
| Length of Barrel in Saturated Zone (Ls) | ft |
| Number of Collars Required | |
| Collar Dimensions [14] | |
| **Final Design Elevations** | |
| Top of Dam | ft |
| Design High Water | ft |
| Emergency Spillway Crest | ft |
| Principal Spillway Crest | ft |
| Dewatering Orifice Invert | ft |
| Cleanout | ft |
| Upstream Toe of Dam or Excavated Bottom of “Wet Storage Area” (If excavation was performed) | ft |

**Notes:**

1. Minimum of 67 cubic yards per acre of total drainage area.
2. Obtain elevations from the storage – elevation curve.
3. Elevation corresponding to required volume = invert of the dewatering orifice.
4. Minimum of 33 cubic yards per acre of total drainage area.
5. Minimum of 10 feet.
6. Minimum of 134 cubic yards per acre of total drainage area.
7. Diameter of dewatering orifice plus 2 inches.
8. h = Crest of Emergency Spillway Elevation minus Crest of Riser Elevation.
9. From Figure C-SCM-12-8. Avoid orifice flow conditions.
10. From Figure C-SCM-12-7.
11. From Table C-SCM-12-4 [Corrugated Metal Pipe] or Table C-SCM-12-5 [Reinforced Concrete Pipe].
12. From Table C-SCM-12-7.
13. From Table C-SCM-12-7.
14. From Figure C-SCM-12-12.

# C-SCM-13 Concrete Washout Pit

## 1.0 Definition

A concrete washout pit is a temporary excavated or above-ground lined constructed pit or a prefabricated or fabricated container in which concrete truck mixers and equipment can be washed after their loads have been discharged to prevent highly alkaline runoff from entering storm drainage systems or leaching into soil.

## 2.0 Purpose and Applicability of Best Management Practice

A concrete washout pit is used for containing wash water from rinsing out concrete trucks, drums, pumps, chutes, equipment, and concrete truck exteriors. Provide washout facilities for every project for which concrete will be poured or otherwise formed on the site.

A concrete washout pit promotes proper disposal of waste concrete and wash water by containing it on site, thereby preventing contamination of waterways, groundwater, and storm drains.

Concrete washout structures are used when concrete equipment is cleaned on-site.

## 3.0 Planning and Considerations

Provide proper signage to alert drivers of the presence of the washout facilities.

Do not place washout facilities near storm drains, open ditches, or surface waters.

Place washout facilities in a convenient location for the trucks, preferably near the location where the concrete is being poured, but distant enough from other vehicular traffic to minimize the potential for accidental damage or spills. Ensure placement follows local setback requirements.

Locate excavated washout structures so that the structures do not intercept surface runoff. If runoff drains toward an excavated structure, provide a diversion around the structure.

If a sinkhole is found on-site, precautions must be taken to ensure that the proposed location of a Concrete Washout Pit is not located within 150 feet of the outer edge of the sinkhole.

Prefabricated containers are an acceptable alternative to fabricated washout structures provided the volume is adequate to contain all wash water and solids while maintaining a minimum 12-inch freeboard.

*Source: Alexis Sidari, PE*

Concrete washout water (or wash water) is a slurry containing toxic metals that are also caustic and corrosive, having a pH near 12. The wash water is retained on-site in the washout facility and allowed to evaporate, leaving only the hardened cementitious solids to be recycled or taken off-site for disposal.

## 4.0 Stormwater Performance Summary

MS-2: Stockpiles, Waste, and Borrow Areas – During construction of the project, soil stockpiles and borrow areas shall be stabilized or protected with sediment trapping measures. The applicant is responsible for the temporary protection and permanent stabilization of all soil stockpiles on site as well as borrow areas and soil intentionally transported from the project site.

**Erosion Control Efficiency: N/A**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

| Table C-SCM-13-1 Concrete Washout Pit Design Criteria | |
|---|---|
| **Parameter** | **Details** |
| Capacity | Size the washout facility to contain solids, wash water, and rainfall and to allow for the evaporation of the wash water and rainfall. Estimate wash water at 7 gallons per chute and 50 gallons per hopper of the concrete pump truck and/or discharging drum. |
| Dimensions | The minimum size of the structure is 10 feet by 10 feet at the bottom. |
| Freeboard | Provide a minimum of 12 inches of freeboard above the liquid and solid waste anticipated between cleanout intervals. |
| Side Slopes | If excavated, the side slopes are a maximum of 1H:1V. |
| Location | Locate the facility a minimum of 100 feet from drainage swales, storm drain inlets, wetlands, streams, and other surface waters. Prevent surface water from entering the structure. Design and location of Concrete Washout Pit to adhere to the standards and setbacks of the local municipalities, if special consideration/location must be used, receive prior approval before the installation of the measure.<br>Sinkhole, cave entrances, or other similar natural earthen cavities should be searched for during initial inspection of site, if found, Concrete Washout Pit should not be within 150- feet of said natural landscape feature. Coordinate location of Concrete Washout Pit with local municipality before installation.<br>Provide appropriate access with a gravel access road sloped down to the structure. Place signs to direct drivers to the facility after their load is discharged. Wherever possible, locate washout facilities on slopes not exceeding a 2% grade |
| Liner | Line all washout facilities to prevent leaching of liquids into the ground. Use plastic sheeting with a minimum thickness of 10 mils with no holes or tears and anchored beyond the top of the pit with an earthen berm, sandbags, stone, or other structural appurtenance.<br>Ensure that pre-fabricated washouts can capture and contain the concrete wash and are sized based on the expected frequency of concrete pours. |
| Removal | After the pit is used to wash down the chutes of multiple ready-mixed trucks, and the wash water has evaporated or has been vacuumed off, the remaining hardened solids can be broken up and removed from the pit. This process may damage the plastic lining and support structure (hay bales, sandbags, or wood planks). If damage occurs, repair and reline the pit with new plastic. When the hardened solids are removed, bind the solids with the plastic lining and send to a landfill or recycling center. If the pit is going to be emptied and repaired frequently, the plastic lining, hay bales, sandbags, and wood planks will generate additional solid waste. |

## 6.0 Construction Specifications

| Table C-SCM-13-2 Construction Specifications | |
|---|---|
| **Component** | **Details** |
| Compost Sock Washout | Where compost sock washouts are used, place a suitable impervious geomembrane at the location of the washout before installing the socks. Stake 24-inch-diameter compost socks with 2-inch by 2-inch by 36-inch-long wood stakes placed 5 feet on center around perimeter of the geomembrane to form a ring with the ends of the sock located at the upslope corner. Overlap the ends of the compost sock by a minimum of 4 feet on the upslope side of the filter ring. Ensure continuous contact of the sock with the geomembrane at all locations. Where necessary, a double row of 24-inch-diameter socks may be stacked and then an 18-inch- diameter sock staked on top to form a triangular cross-section. |
| Hay Bale and Plastic Washout Pit | A washout pit made with hay bales and a plastic lining can be dug into the ground or built above grade. Construct the hay bale washout pit using hay bales placed to a minimum height of 3 feet to form a 10-foot by 10-foot inside area. Stake the bales using two wood or metal stakes per bale. Place the plastic lining over the inside area and the top and sides of the hay bales. Staple the lining to the top of the hay bales using 2-inch-wide by 4-inch-long by 0.125- inch-diameter steel wire staples. Use two staples per hay bale. The washout pit can be constructed using two stacked bales or can be partially excavated to reach the 3-foot depth. |
| Excavated Washout Pit | Excavate the washout area to a minimum depth of 3 feet with a 1H:1V (maximum) side slope to form a 10-foot by 10-foot bottom area. Place the liner over the bottom and side slopes of the excavated area and extend the liner a minimum of 3 feet at the top of the side slopes.<br><br>Place sandbags around the perimeter of the washout pit at the tops of the side slopes to secure the liner in place. Staple the lining to the top of the wood frame using 2-inch-wide by 4-inch-long by 0.125-inch-diameter steel wire staples. |
| Wood Plank and Plastic Washout Pit | Construct the 10-foot by 10-foot washout pit using three 2-inch by 12-inch wood frames stacked to form a 3-foot-high wooden frame above the ground surface. Install two stakes on either side of the wooden frame and fasten to the wooden frame. Install four stakes on each 10-foot side of the wooden frame (16 stakes total). Place the plastic liner over the inside area and top sides of the wood plank frame. Staple the lining to the top of the wood frame using 2- inch wide by 4-inch long by ⅛-inch diameter steel wire staples. |

| Table C-SCM-13-2 Construction Specifications | |
|---|---|
| **Component** | **Details** |
| Vinyl Washout Container | The vinyl washout container is portable, reusable, and easier to install than a hay bale washout pit. The biodegradable filter bag assists in extracting the concrete solids and prolongs the life of the vinyl container. When the bag is lifted, the water is filtered out, and the remaining concrete solids and the bag can be disposed of together in a landfill, or the hardened concrete can be delivered to a recycler. After the solids have been removed several times and the container is full of wash water, the wash water can be allowed to evaporate so that the container can be reused. The wash water can be removed more quickly by placing another filter bag in the container and spreading water gelling granules evenly across the water. In about 5 minutes, the water in the filter bag will turn into a gel that can be removed with the bag. The gel and filter bag can then be disposed of together. |
| Metal Washout Container | The metal roll-off bin is designed to securely contain concrete wash water and solids and is portable and reusable. It also has a ramp that allows concrete pump trucks to wash out their hoppers. Roll-off providers offer recycling services such as picking up the roll-off bins after the wash water has evaporated and the solids have hardened, replacing them with empty washout bins, and delivering the hardened concrete to a recycler rather than a landfill. Some providers will vacuum off the wash water, treat it to remove metals and reduce the pH, and deliver it to a wastewater treatment plant for additional treatment and subsequent discharge to a surface water. Everything is recycled or treated sufficiently to be returned to a natural surface water. |

## 7.0 Operations and Maintenance Considerations

Inspect all concrete washout facilities daily. Deactivate and repair or replace damaged or leaking facilities immediately. Pump excess rainwater that has accumulated over hardened concrete to a stabilized area such as a grass filter strip. Remove accumulated hardened material when 75% of the storage capacity of the structure is filled. Pump any excess wash water into a containment vessel and properly disposed of off-site.

Dispose of the hardened material off site in a construction/demolition landfill. The hardened concrete may be recycled by crushing and reusing the crushed concrete as construction material. The crushed concrete material makes an excellent aggregate for road base and can be used as fill at the construction site in accordance with state and local regulations or delivered to a recycler. Concrete recyclers can be found at municipal solid waste disposal facilities, private recycling plants, or large construction sites.

Replace the plastic liner with each cleaning of the washout facility. Inspect the project site frequently to ensure that concrete is not being discharged in non-designated areas. Before forecasted rainstorms, remove liquids or cover the structure to prevent overflows.


Poorly Maintained Concrete Washout Station


Properly Installed and maintained Concrete Washout Station

## 8.0 References

Maryland Department of the Environment Water Management Administration, Natural Resources Conservation Service, and Maryland Association of Soil Conservation Districts. 2011. *2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.

New York Department of Environmental Conservation. 2016. *New York State Standards and Specifications for Erosion and Sediment Control*.

Pennsylvania Department of Environmental Protection. 2012. *Erosion and Sediment Pollution Control Program Manual*. Final ed.

Town of Bluffton, SC. Www.townofbluffton.sc.gov/447/Sediment-Erosion-Control. Accessed 8 Feb. 2023.

# C-SSM-01 Tree Preservation and Protection

## 1.0 Definition

Tree preservation and protection is the protection of desirable trees from mechanical and other types of injury during land disturbance and construction.

– CAD C-SSM-01-1 Construction Operations Relative to the Location of Protected Trees
– CAD C-SSM-01-2 Fencing and Armoring
– CAD C-SSM-01-3 Tree Well
– CAD C-SSM-01-4 Tree Well Detail
– CAD C-SSM-01-5 Tree Well Without Drain Tiles
– CAD C-SSM-01-6 Tree Wall Detail
– CAD C-SSM-01-7 Trenching VS. Tunneling
– CAD C-SSM-01-8 Tree Care
– CAD C-SSM-01-9 Tree Fertilization

## 2.0 Purpose and Applicability of Best Management Practice

Tree preservation and protection is implemented to ensure the survival of desirable trees and their root zones where the trees will be effective for erosion and sediment control, watershed protection, landscape beautification, dust and pollution control, noise reduction, shade, and other environmental benefits while the land is being converted from forest to urban setting. Tree protection may also be used on previously developed lands where there are existing trees or other plant materials needing protection from damage by construction equipment or soil compaction by vehicular traffic.

Tree preservation and protection should be used where tree-inhabited areas are subject to land-disturbing activities.

## 3.0 Planning and Considerations

Stands of trees and individual trees selected for preservation should be accurately located on the Erosion & Sediment Control Plan and designated as "TREE(S) TO BE SAVED" or equivalent.

New development often takes place on tracts of forested land. In fact, building sites are often selected because of the presence of mature trees. However, unless sufficient care is implemented and planning conducted in the interval between buying the property and completing construction, much of this resource is likely to be destroyed. The property owner is ultimately responsible for protecting as many trees (including their understory and ground cover) as possible. This responsibility is usually exercised by agents, planners, designers, and contractors. Newly planted trees require approximately 20 to 30 years to provide the benefits for which they are so highly valued. Trees perform the following functions on a site:

1. Assist in stabilizing the soil and preventing erosion;
2. Help to decrease stormwater runoff through canopy interception and root zone absorption;
3. Moderate temperature changes and provide shade;
4. Moderate the effects of sun and wind;
5. Provide buffers and screens against noise and undesirable views;
6. Filter pollutants from the air;
7. Help to remove carbon dioxide from the air and release oxygen;
8. Provide a haven for animals and birds, which help to control insect populations;
9. Conserve and increase property values;
10. Provide psychological and aesthetic counterpoints to the man-made urban setting; and
11. Provide definition of outdoor spaces and pathways.

### 3.1 Stresses of Construction

Trees are living organisms that are constantly involved in the process of respiration, food processing, and growth. Construction exposes trees to a variety of stresses resulting in injury ranging from superficial wounds to death.

An understanding of these stresses is helpful in planning for tree protection.

1. **Surface Impacts:** Natural and man-related forces exerted on the tree above the ground can cause significant damage to trees. Table C-SSM-01-1 identifies some of the common surface impacts to which trees are subjected during construction.

| Table C-SSM-01-1 Surface Impacts from Construction | |
|---|---|
| | Surface Impacts from Construction |
| Wind Damage | Removal of some trees from groups will expose those remaining to greater wind velocities. Trees tend to develop anchorage where it is most needed. Isolated trees develop anchorage rather equally all around, with stronger root development on the side of the prevailing winds. The more a tree is protected from the wind, the less secure its anchorage. The result of improper thinning is often wind-thrown trees.<br>Selective removal in favor of a single tall tree may also create a lightning hazard. |
| Excessive Pruning | Unprotected trees are often “topped” or carelessly pruned to prevent interference with utility wires or buildings. If too many branches are cut, the tree may not be able to sustain itself. If the tree is pruned without considering the growth habit, the tree may lose all visual appeal. If the branches are not pruned correctly, decay may set in. |
| Trunk Damage | Tree trunks are often nicked or scarred by trucks and construction equipment. Such superficial wounds provide access to insects and disease. |

2. **Root Zone Impacts:** Disturbing the delicate relationship between soil, roots, and the rest of the tree can damage or kill a tree. The roots of an existing tree are established in an area where they can access essential materials (water, oxygen, and nutrients). The mass of the root system is the correct size to balance the intake of water from the soil with the transpiration of water from the leaves. In general, a tree's root system extends about the same distance from the trunk as its branches.
   a. Raising the grade as little as 6 inches can impact the normal exchange of air and gases. Roots may suffocate due to lack of oxygen or be damaged by toxic gases and chemicals released by soil bacteria.
   b. Raising the grade may also elevate the water table. This can cause drowning of the deeper roots.
   c. Even shallow cuts of 6 to 8 inches will remove most of the topsoil, removing some feeder roots and exposing the rest to drying and freezing.
   d. Deep cuts may sever a large portion of the root system, depriving the tree of water and increasing the chance of wind-throw.
   e. Lowering the grade may lower the water table, inducing drought. This is a problem in large roadway cuts or underdrain installations.
   f. Trenching or excavating through the root zone of a tree can eliminate as much as 40 percent of the root system.
   g. Compaction of the soil within the drip line (even a few feet beyond the drip line) of a tree by equipment operation, materials storage, or paving can block off air and water from roots.
   h. Construction chemicals or refuse disposed of in the soil can change soil chemistry or be toxic to trees. Most damage to trees from construction is due to the invisible root zone stresses.

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization shall be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization shall be applied to areas that are to be left dormant for more than 1 year.

9VAC25-875-560.

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: LOW**

## 5.0 Design Criteria

No formal design is required. However, when planning for the development of a wooded site, where some trees will be preserved, consider the following criteria:

### 5.1 Selecting Trees to be Retained

The proper development of a wooded site requires completion of a plan for tree preservation before clearing and construction begins. Trees should be identified by species and located on a topographical map, either as stands or as individuals, depending on the density and value of the trees. Decide which trees to save based on the considerations identified in Table C-SSM-01-2.

**Table C-SSM-01-2 Design Criteria for Tree Preservation and Protection**

| Design Criteria for Tree Preservation and Protection | |
|---|---|
| Life expectancy and present age | Preference should be afforded to trees with a long life span such as white oak, beech, and maple. Long-lived specimens that are past their prime may succumb to the stresses of construction; therefore, smaller, younger trees of desirable species are preferred because the younger trees are more resilient and will last longer. However, if the cost of preservation is greater than the cost of replacement with a specimen of the same age and size, replacement may be preferred. |
| Health and disease susceptibility | Check for scarring caused by fire or lightning, insect, or disease damage and rotted or broken trunks or limbs. Pest- and pollution-resistant trees are preferred. |
| Structure | Check for structural defects that indicate weakness or reduce the aesthetic value of a tree such as trees growing from old stumps; large trees with overhanging limbs that endanger property; and trees with brittle wood (such as silver maple), misshapen trunks or crowns, and small crowns at the tops of tall trunks. Open grown trees often have better form than those grown in the woods. Trees with strong tap or fibrous root systems are preferred to trees with weak rooting habits. |
| Cleanliness | Some trees (such as elm and black locust) are maintenance-intensive, dropping twigs, bark, fruit, or plant exudates. Trees that seed prolifically or sucker profusely are generally less desirable in urban areas. Thornless varieties are preferred. |
| Aesthetic values | Handsome bark and leaves, neat growth habit, fine fall color, and attractive flowers and fruit are desirable characteristics. Trees that provide interest during several seasons of the year enhance the value of the site. |

| Table C-SSM-01-2 Design Criteria for Tree Preservation and Protection | |
|---|---|
| **Design Criteria for Tree Preservation and Protection** | |
| Comfort | Trees help relieve the heat of summer and buffer strong winds throughout the year. Summer temperatures may be 10 degrees cooler under hardwoods than under conifers. Deciduous trees drop their leaves in winter, allowing the sun to warm buildings and soil. Evergreens are more effective wind buffers. |
| Wildlife | Preference should be given to locally native trees that provide food, cover, and nesting sites for birds and game. |
| Adaptability to the proposed development | 1. Consider the mature height and spread of trees, as these features may interfere with proposed structures and overhead utilities. Roots may interfere with walls; walks; driveways; patios; and other paved surfaces or water lines, septic tanks, and underground drainage.<br>2. Trees must be appropriate to the proposed use of the development; select trees that are pollution-tolerant for high-traffic and industrial areas, screen and buffer trees for noise or objectionable views, and salt-tolerant species for areas exposed to de-icing salts or ocean spray.<br>3. Consider locations of landfills. Gases generated within can travel long distances underground, injuring distant trees. Choose species tolerant of anaerobic soil conditions.<br>4. Determine the effect of proposed grading on the water table. Grading should not take place within the drip line of any tree to be saved. |
| Survival needs of the tree | Chosen trees must have enough room to develop naturally. Trees will be subject to injury from increased exposure to sunlight, heat radiated from buildings and pavement, and wind. It is best to retain groups of trees rather than individuals.<br>Gradually thin trees as they mature and only when necessary. |
| Relationship to other trees | Individual species should be evaluated in relation to other species on the site. A species with low value when growing among hardwoods will increase in value if it is the only species present. Trees standing alone generally have higher landscape value than those in a wooded situation. However, tree groups are much more effective at preventing erosion and excess stormwater runoff. |

| Table C-SSM-01-2 Design Criteria for Tree Preservation and Protection | |
|---|---|
| **Design Criteria for Tree Preservation and Protection** | |
| Ecological Cores | The Virginia Natural Heritage Program (VNHP) in the Department of Conservation and Recreation has developed a network of natural lands for the commonwealth of Virginia. This project, named the Virginia Natural Landscape Assessment (VaNLA), is a landscape-scale geospatial analysis for identifying, prioritizing, and linking natural lands in Virginia. Using land cover data derived from satellite imagery, the VaNLA identifies large patches of natural land with at least one hundred acres of interior cover. This interior cover, known as core area, begins one hundred meters from patch edges.<br><br>Small patches with ten to ninety-nine acres of interior cover are included as habitat fragments that support landscape corridors and that may be important in localities with few large patches of natural land. Core areas and habitat fragments are referred to collectively as “ecological cores.” Although the VaNLA is predominantly an analysis of forests, ecological cores include marshes, dunes, and beaches where these covers are abundant and exceed minimum size requirements. Tree removal should be avoided if any trees on site are determined to be ecological cores. |
| Virginia Native Species | Any Virginia Native Species should be saved to the fullest extent possible and can be identified with the Virginia Native Plant Finder. |

### 5.2 Site Planning for Tree Protection

1. If lot size allows, select trees to be saved before siting the building. No tree should be destroyed or altered until the design of buildings and utility systems is final.
2. Critical areas, such as floodplains, steep slopes, and wetlands, should be left in their natural condition or only partially developed as open space.
3. Locate roadways to cause the least damage to valuable stands. Follow original contours, where feasible, to minimize cuts and fills.
4. Minimize trenching by locating several utilities in the same trench. Excavations for basements and utilities should be kept away from the drip lines of trees.
5. Construction material storage areas, soil stockpiles, and worker parking should be identified on the site plan and located where they will not cause compaction over roots.
6. When retaining existing trees in parking areas, leave enough ground ungraded beyond the drip line of the tree to allow for its survival.
7. Locate erosion and sediment control measures at the limits of clearing (not in wooded areas) to prevent deposition of sediment within the drip lines of trees being preserved. Sediment basins should be constructed in the natural terrain, if possible, rather than where extensive grading and tree removal will be required.

## 6.0 Construction Specifications

1. Groups of trees and individual trees selected for retention should be accurately located on the plan and designated as “TREE(S) TO BE SAVED.” Individual specimens that are not part of a tree group should also be identified by species and diameter on the plan. The boundary of the tree protection zone for both groups and individual trees should be clearly and conspicuously depicted on the grading and E&S plans. Tree protection zones should always be outside of the limits of grading.

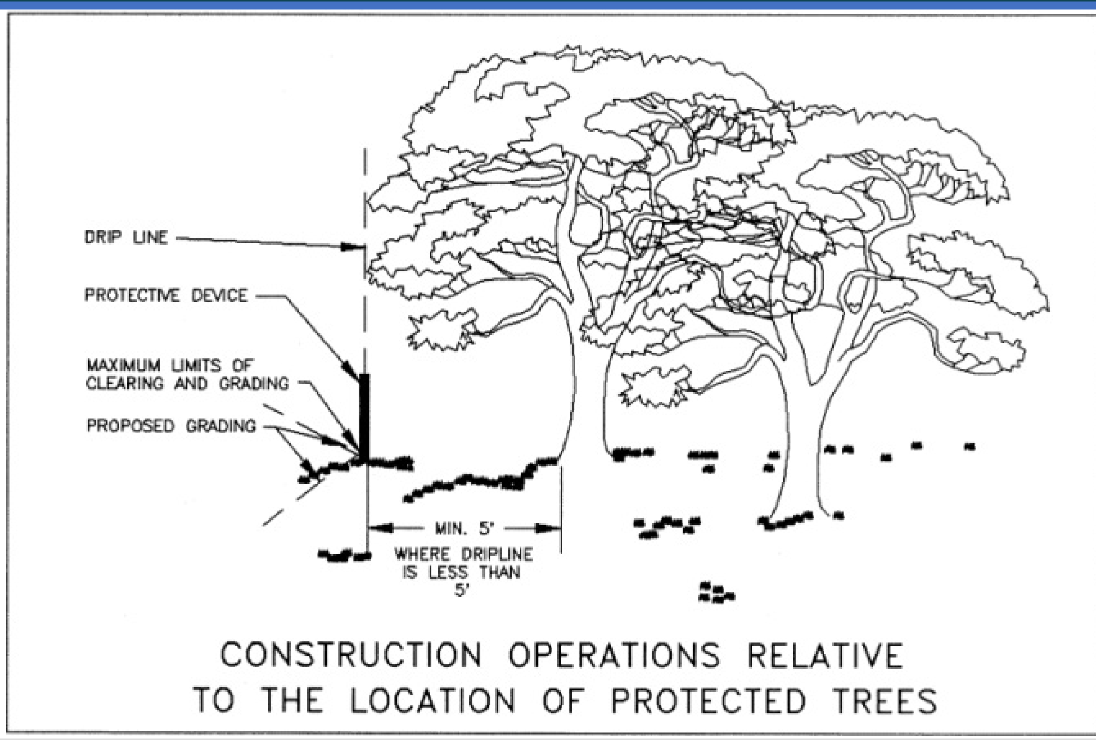
2. At a minimum, the limits of clearing should be located outside the drip line of any tree to be retained and, in no case, closer than 5 feet to the trunk of any tree (see Figure C-SSM-01-1).
3. **Marking:** Before the pre-construction conference, individual trees and stands of trees to be retained within the limits of clearing should be marked at a height visible to equipment operators. According to the Virginia Department of Forestry, a diagonal slash of brightly colored paint approximately 8 to 10 inches long is a common practice where an accidental or purposeful alteration of the proper markings is a concern. In most situations, such as in an area designated for formal landscaping, a surveyor's ribbon or a similar material applied at a reasonable height encircling the tree will suffice.

*Metal Tree Protection Surrounding Steeper Grade Around Tree*

4. **Pre-Construction Conference:** During any pre-construction conference, tree preservation and protection measures should be reviewed with the contractor as they apply to that specific project.
5. **Equipment Operation and Storage:** Heavy equipment, vehicular traffic, or stockpiles of any construction materials (including topsoil) should not be permitted within the drip line of any tree to be retained. Trees being removed should not be felled, pushed, or pulled into trees being retained.

   Equipment operators should not clean any part of their equipment by slamming it against the trunks of trees to be retained.
6. **Fires:** Fires should not be permitted within 100 feet from the drip lines of any trees to be retained. Fires should be limited in size to prevent adverse effects on trees and kept under surveillance.

***Figure C-SSM-01-1 Construction Operations Relative to Protected Tree Location***




*Source: Fairfax County 1976*

7. **Storage and Disposal of Toxic Materials:** No toxic materials should be stored closer than 100 feet to the drip lines of any trees to be retained. Paint, acid, nails, gypsum board, wire, chemicals, fuels, and lubricants should not be disposed of in such a way as to injure vegetation.

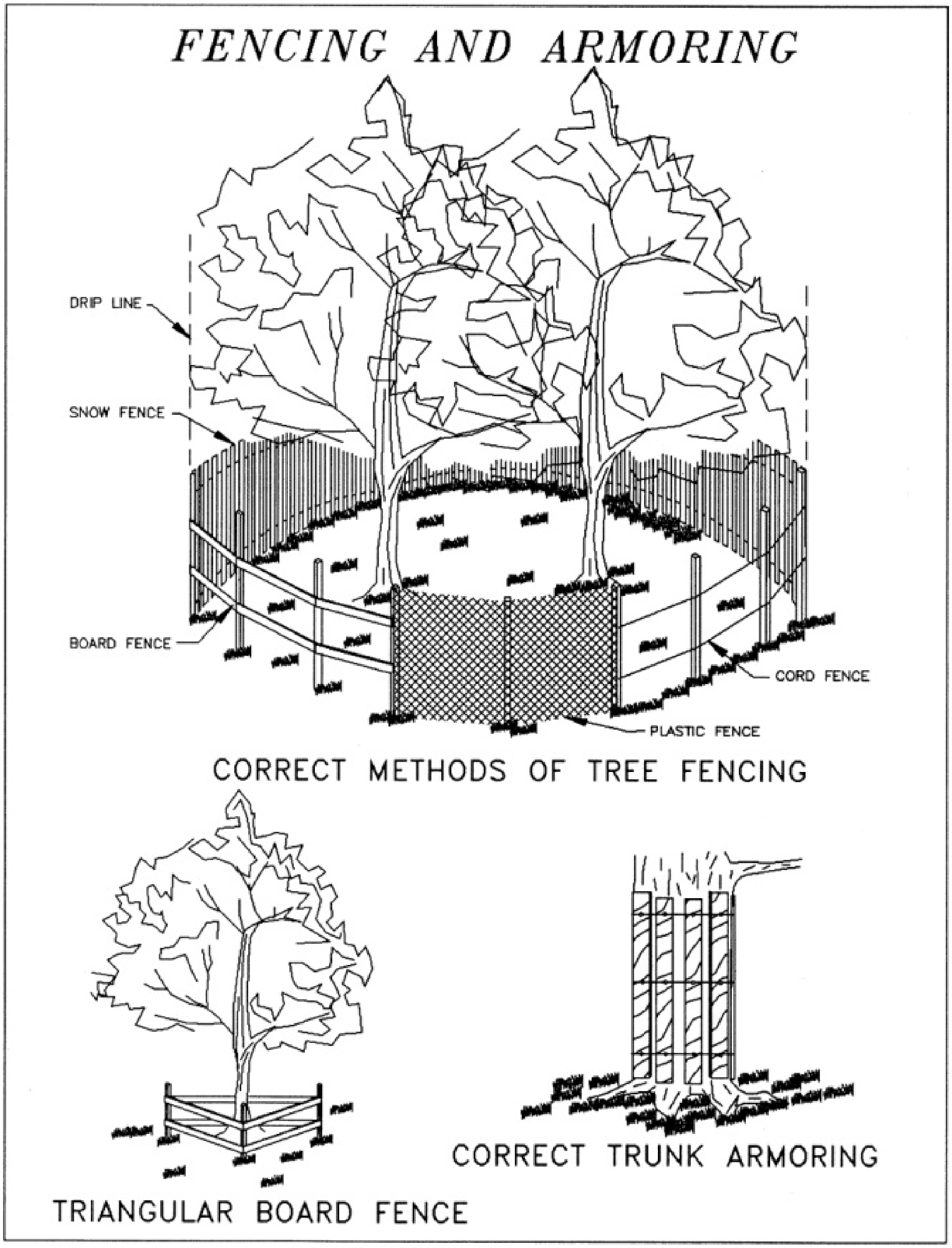
8. **Fencing and Armoring (Figure C-SSM-01-2):** Any device may be used that will effectively protect the roots, trunks, and tops of trees retained on the site. However, trees to be retained within 40 feet of a proposed building or excavation should be protected by fencing. Personnel should be instructed to honor protective devices. The devices described are suggested only and are not intended to exclude the use of other devices that will protect the trees to be retained.

**Table C-SSM-01-3 Fencing and Armoring Specifications**

| Fencing and Armoring Specifications | |
|---|---|
| Snow Fence | Standard 40-inch-high snow fence should be placed at the limits of clearing on standard steel posts set 6 feet apart. |
| Board Fence | Board fencing consisting of 4-inch-square posts set securely in the ground and protruding at least 4 feet above the ground should be placed at the limits of clearing with a minimum of two horizontal boards between posts. If it is not practical to erect a fence at the drip line, construct a triangular fence nearer the trunk. The limits of clearing will still be located at the drip line because the root zone within the drip line will still require protection. |
| Cord Fence | Posts with a minimum size of 2 inches square or 2 inches in diameter set securely in the ground and protruding at least 4 feet above the ground should be placed at the limits of clearing with two rows of cord 0.25 inch or thicker at least 2 feet apart running between posts with strips of colored surveyor's flagging tied securely to the string at intervals no greater than 3 feet. |
| Plastic Fencing | 40-inch-high “international orange” plastic (polyethylene) web fencing secured to 60-inch-high minimum nominal 2-inch by 2-inch oak posts driven to a minimum depth of 18 inches on 6-foot minimum centers should be installed at the limits of clearing. The fence should have the following minimum physical qualities:<br>Tensile yield: Average 2,000 lbs. per 4-foot width (ASTM D638)<br>Ultimate tensile yield: Average 2,900 lbs. per 4-foot width (ASTM D638)<br>Elongation at break (%): Greater than 1,000% (ASTM D638)<br>Chemical resistance: Inert to most chemicals and acids |
| Earth Berms | Temporary earth berms should be constructed according to specifications for a Temporary Diversion Dike (BMP C-ECM-04) with the base of the berm on the tree side located along the limits of clearing. Earth berms may not be used for this purpose if their presence will conflict with drainage patterns. |
| Additional Trees | Additional trees may be left standing as protection between the trunks of the trees to be retained and the limits of clearing. However, for this alternative to be used, the trunks of the trees in the buffer should be no more than 6 feet apart to prevent passage of equipment and material through the buffer. These additional trees should be reexamined before completing construction and either given sufficient treatment to ensure survival or be removed. |

| Table C-SSM-01-3 Fencing and Armoring Specifications | |
|---|---|
| **Fencing and Armoring Specifications** | |
| Trunk Armoring | As a last resort, a tree trunk can be armored with burlap wrapping and 2-inch studs wired vertically no more than 2 inches apart to a height of 5 feet encircling the trunk. If this alternative is used, the root zone within the drip line will still require protection. Nothing should ever be nailed to a tree. |

**Figure C-SSM-01-2 Fencing and Armoring**

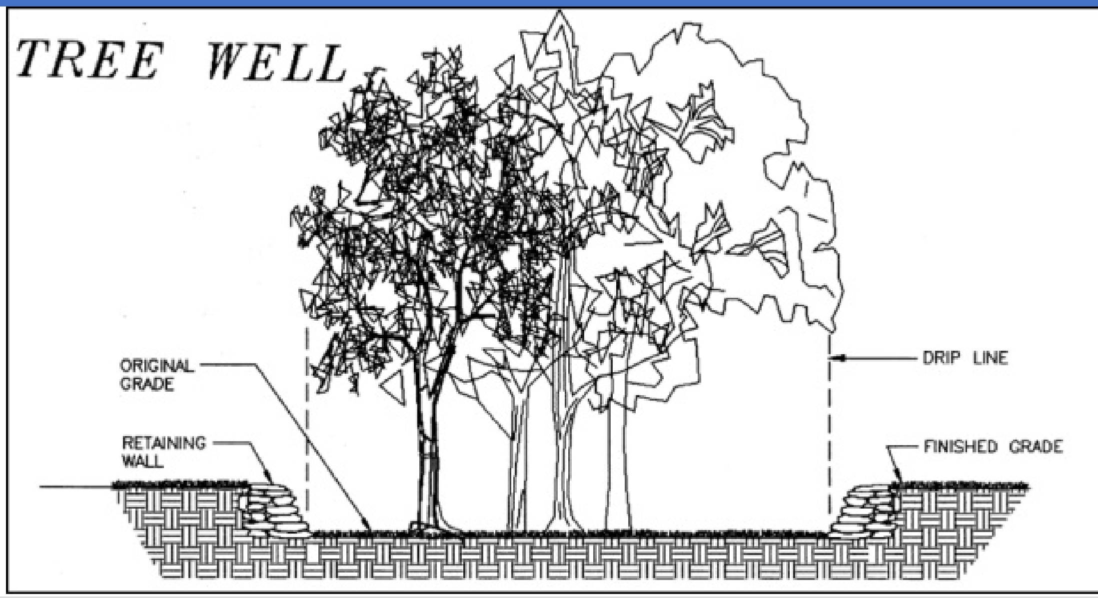



*Source: Va. DSWC*

Fencing and armoring devices should be in place before any excavation or grading begins, should be kept in good repair during construction, and should be the last items removed during the final cleanup after the completion of the project.

Raising the grade: When the ground level must be raised around an existing tree or tree group, the following should be considered and steps taken to adequately care for the affected tree.

**Figure C-SSM-01-3 Tree Well**




Source: Va. DSWC

a. A well may be created around the tree(s) slightly beyond the drip line to retain the natural soil around the feeder roots (Plate 3).

b. In the case of an individual tree, when the alternative described in item a is not practical or desirable, the following method is recommended to ensure survival of the tree (Figure C-SSM-01-4):

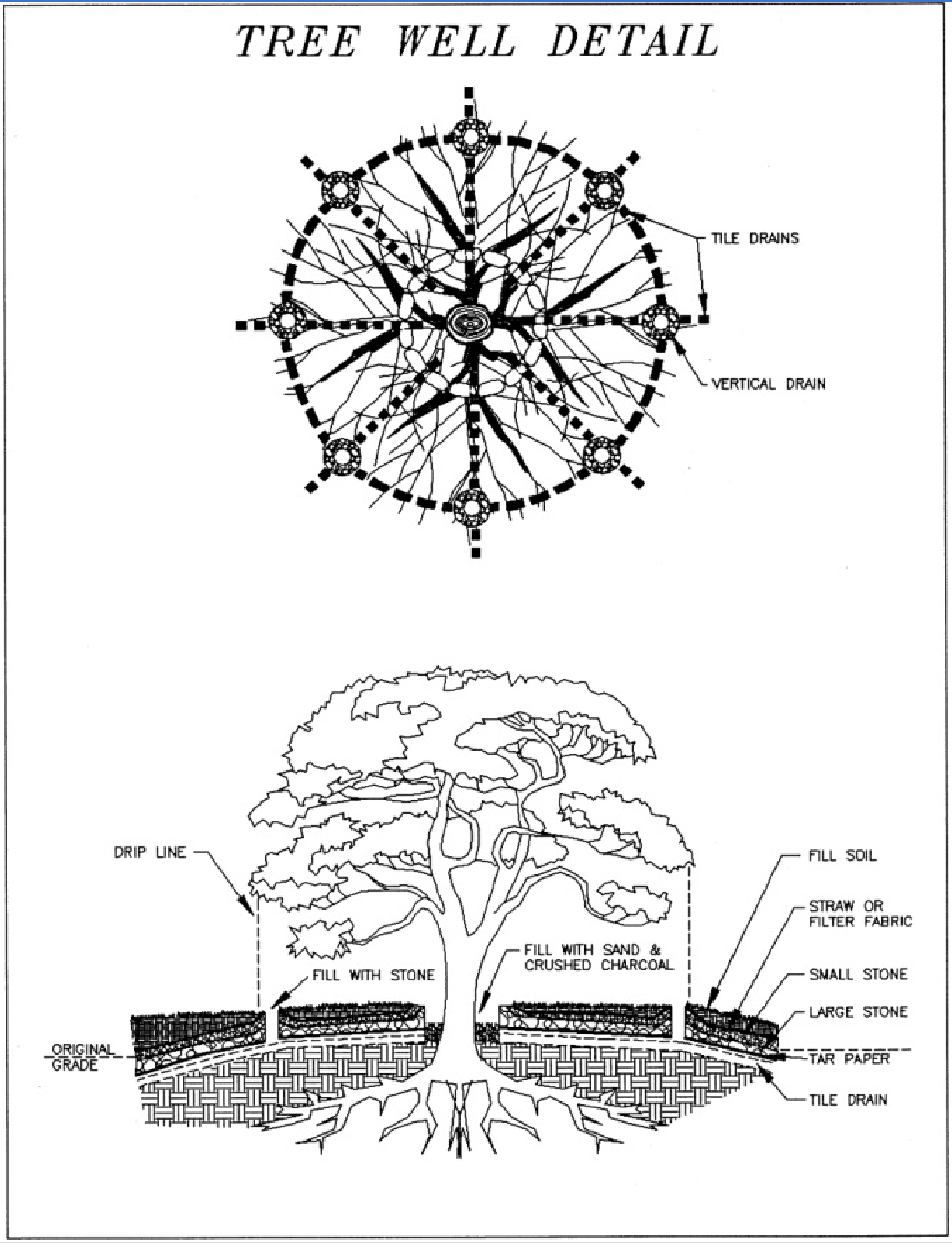
   1) Before making the fill, remove the green vegetation, sod, leaf litter, and other organic matter from beneath the tree or trees to 3 feet beyond the drip line and loosen the surface soil to a depth of approximately 3 inches without damaging the roots.

   2) Apply fertilizer in the root area of the tree to be retained. Fertilizer formulations, application rates, and methods should conform to the guidelines provided in Table C-SSM-01-4.

   3) The dry well should be constructed to allow for tree trunk diameter growth. A space of at least 1 foot between the tree trunk and the well wall is adequate for large, old, slow-growing trees.

      Clearance for younger trees should be at least 2 feet.

## Figure C-SSM-01-4 Tree Well Detail 1




*Source: Pirone 1978.*

<table>
<tr><th colspan="5">Table C-SSM-01-4 Tree Fertilization for Protection from Construction</th></tr>
<tr><th>Tree Type</th><th>Special Conditions</th><th colspan="2">Application Rate & Method</th><th>Formulation</th></tr>
<tr><td rowspan="4">Broad-Leaf Deciduous</td><td rowspan="2">Greater than 6 inches dbh* except American beeches and crabapples</td><td>Normal</td><td>2 to 4 lbs. per inch dbh; broadcast</td><td>Commercial 10-8-6 or 10-6-4</td></tr>
<tr><td>Grade Change</td><td>4 to 5 lbs. per inch dbh; broadcast</td><td>Commercial 10-6-4</td></tr>
<tr><td rowspan="2">Smaller than 6 inches dbh including all American beeches and crabapples</td><td>Normal</td><td>1 to 2 lbs. per inch dbh; broadcast</td><td>Commercial 10-8-6 or 10-6-4</td></tr>
<tr><td>Grade Change</td><td>2 to 3 lbs. per inch dbh; broadcast</td><td>Commercial 10-6-4</td></tr>
<tr><td rowspan="3">Narrow-Leaf Evergreen</td><td>Greater than 6 inches dbh, located in groups</td><td colspan="2">2 to 4 lbs. per 100 sq. ft. of bed area; broadcast</td><td rowspan="2">Commercial 10-6-4</td></tr>
<tr><td>Greater than 6 inches dbh, single specimens in open area</td><td colspan="2">2 lbs. per inch dbh; broadcast</td></tr>
<tr><td>Smaller than 6 inches dbh</td><td colspan="2">5 lbs. per 100 sq. ft. of bed area; incorporated into soil</td><td>Tankage or Cottonseed Meal</td></tr>
<tr><td rowspan="2">Broad-Leaf Evergreen</td><td>Where nitrogen in soil is sufficient</td><td colspan="2">Liberal quantities incorporated into soil and applied as mulch</td><td>Acid Peat Moss or Rotted Oak Leaf Mold</td></tr>
<tr><td>Where additional nitrogen is necessary</td><td colspan="2">Also add 5 lbs. per 100 sq. ft. of bed area incorporated into soil</td><td>Tankage or Cottonseed Meal</td></tr>
<tr><td colspan="5">*dbh = Diameter at breast height (4.5 feet above ground level).</td></tr>
<tr><td colspan="5">Source: Pirone 1978.</td></tr>
</table>

4) The well should be high enough to bring its top just above the level of the proposed fill. The well wall should taper slightly away from the tree trunk at a rate of 1 inch per foot of wall height.

5) The well wall should be constructed of large stones, brick, building tile, concrete blocks, or cinder blocks. Ensure that ample openings are left through the wall of the well to allow for free movement of air and water. Mortar should only be used near the top of the well and only above the porous fill.

6) Drain lines composed of 4-inch, high-quality drain tiles should begin at the lowest point inside the well and extend outward from the tree trunk in a wheel-and-spoke pattern with the trunk as the hub. These radial drain lines should slope away from the well at a rate of 0.125 inch per foot. The circumferential line of tiles should be located beneath the drip line of the tree.

   Vertical tiles or pipes should be placed over the intersections of the two tile systems if a fill of more than 2 feet is planned. These vertical tiles should be held in place with stone fill. Tile joints should be tight. Some radial tiles should extend beyond each intersection and slope sharply downward to ensure good drainage.

7) Tar paper or its approved equivalent should be placed over the tile and/or pipe joints to prevent clogging, and large stone should be placed around and over drain tiles and/or pipes for protection.

8) A layer of 2 to 6 inches of stone should be placed over the entire area under the tree from the well outward at least as far as the drip line. For fills up to 2 feet deep, a layer of stone 8 to 12 inches thick should be adequate. A thicker layer of this stone, not to exceed 30 inches, will be needed for deeper fills.

9) A layer of 0.75-inch to 1-inch stone covered by straw, fiberglass mat, or a manufactured filter fabric should be used to prevent soil from clogging the spaces between stones. Cinders should not be used as fill material.

10) Filling should be completed with porous soil, such as topsoil, until the desired grade is reached. This soil should be suitable to sustain specified vegetation.

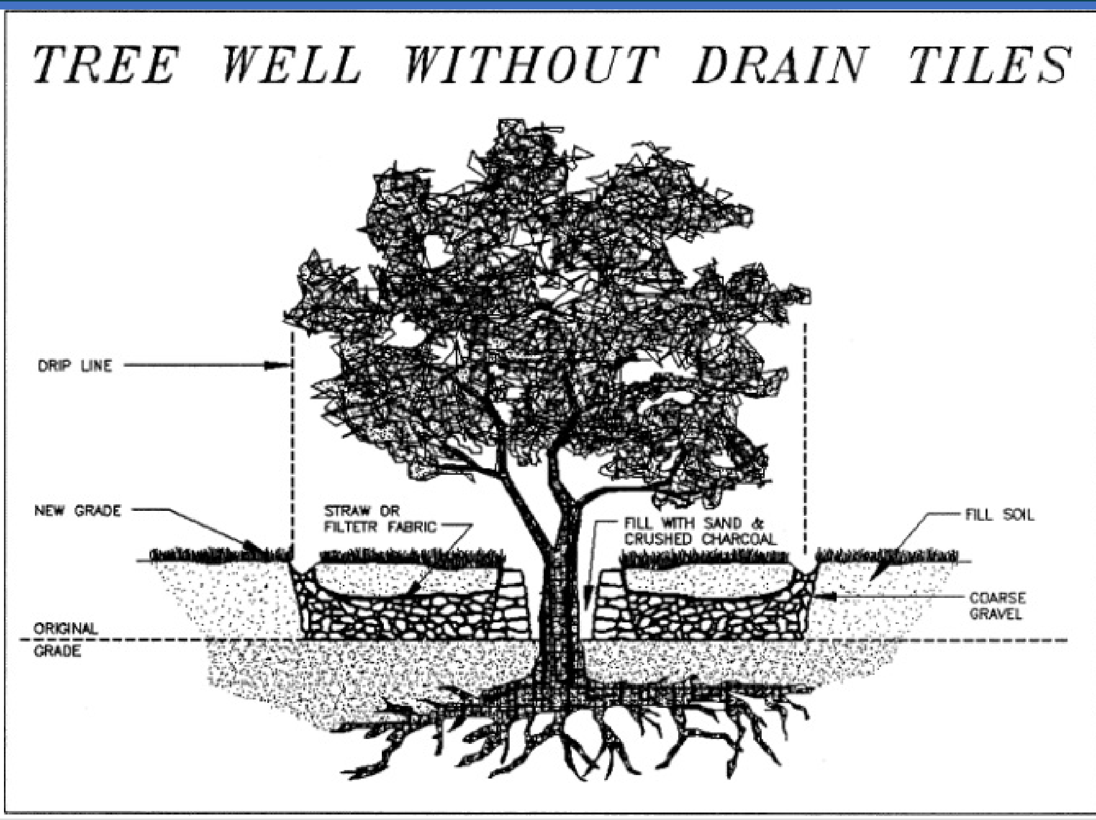
11) To prevent clogging of the drain lines, crushed stone should be placed inside the dry well over the openings of the radial tiles. Vertical tiles should also be filled with crushed rock and may also be covered with a screen.

12) To prevent falls into the dry well and leaves and accumulation of debris, the area between the trunk and the well wall should either be covered by an iron grate or filled with a 50-50 mixture of crushed charcoal and sand (this will also prevent rodent infestation and mosquito breeding).

c. Where water drainage through the soil is adequate, coarse gravel in the fill may be substituted for the tile. This material has sufficient porosity to ensure air drainage. Instead of the vertical tiles or pipes in the system, stones, crushed rock, and gravel may be added so that the upper level of these porous materials slants toward the surface in the vicinity below the drip line (Figure C-SSM-01-5).

d. Raising the grade on only one side of a tree or group of trees may be accomplished by constructing only half of one of these systems.

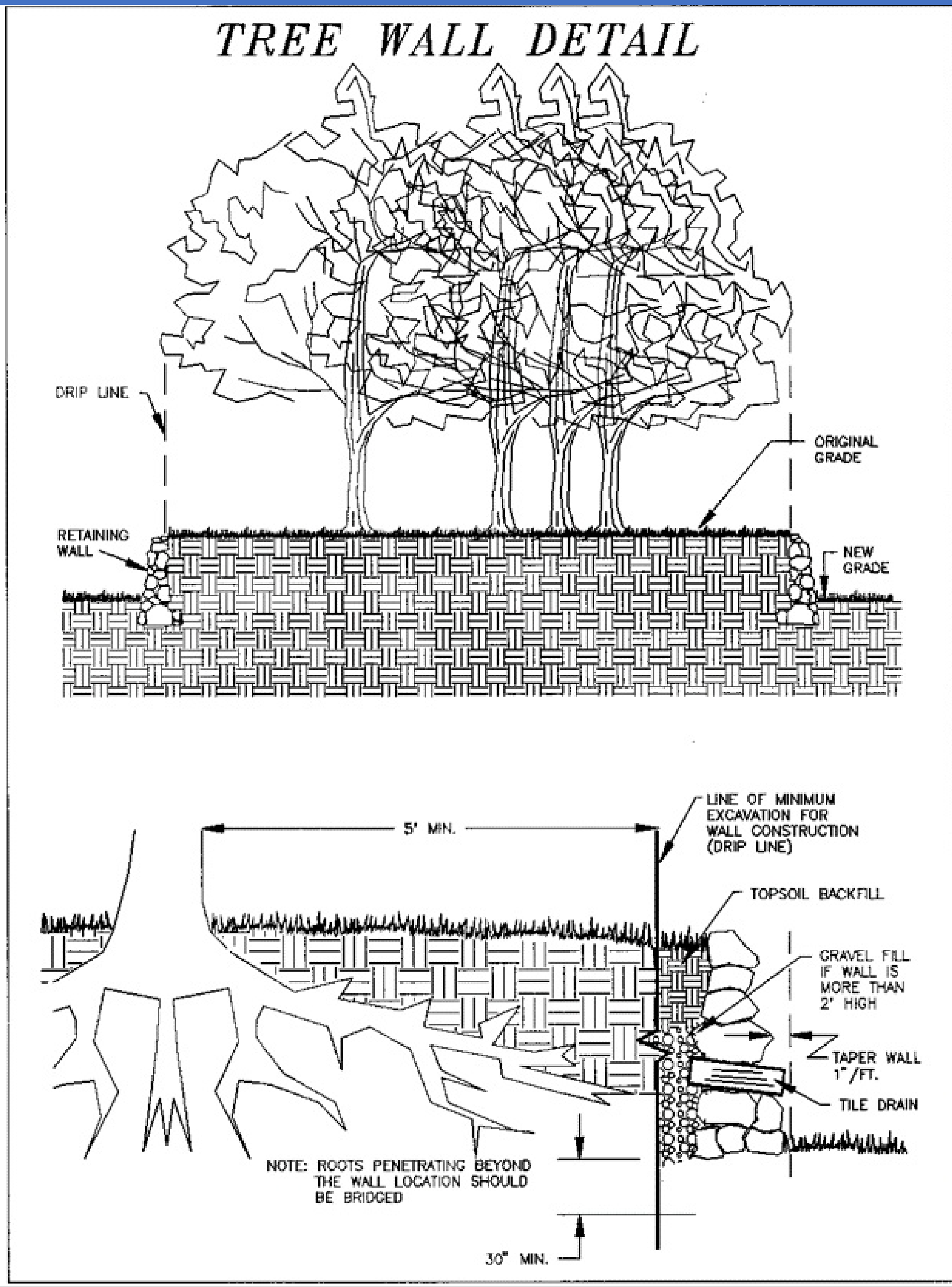
**Figure C-SSM-01-5 Tree Well without Drain Tiles**




*Source: Va. DSWC*

2. **Lowering the grade:** Trees should be protected from harmful grade cuts by the construction of a tree wall (Figure C-SSM-01-6).
    a. Following excavation, all tree roots that are exposed and/or damaged should be trimmed clean; painted with tree paint; and covered with moist peat moss, burlap, or other suitable material to keep them from drying out.
    b. The wall should be constructed of large stones, brick, building tile, or concrete or cinder block in accordance with the detail on Figure C-SSM-01-6.
    c. Backfill with peat moss, other organic material, or with topsoil to retain moisture and aid in root development.
    d. Apply fertilizer and water thoroughly. Fertilizer formulations, application rates, and methods will conform to the guidelines provided in Table C-SSM-01-4.
    e. Prune the tree crown, reducing the leaf surface in proportion to the amount of root loss.
    f. Provide drainage through the wall so water will not accumulate behind the wall.
    g. The grade may be lowered on only one side of a tree or group of trees by constructing only half of this system.

Figure C-SSM-01-6 Tree Well Detail 2




*Source: Zion 1968.*

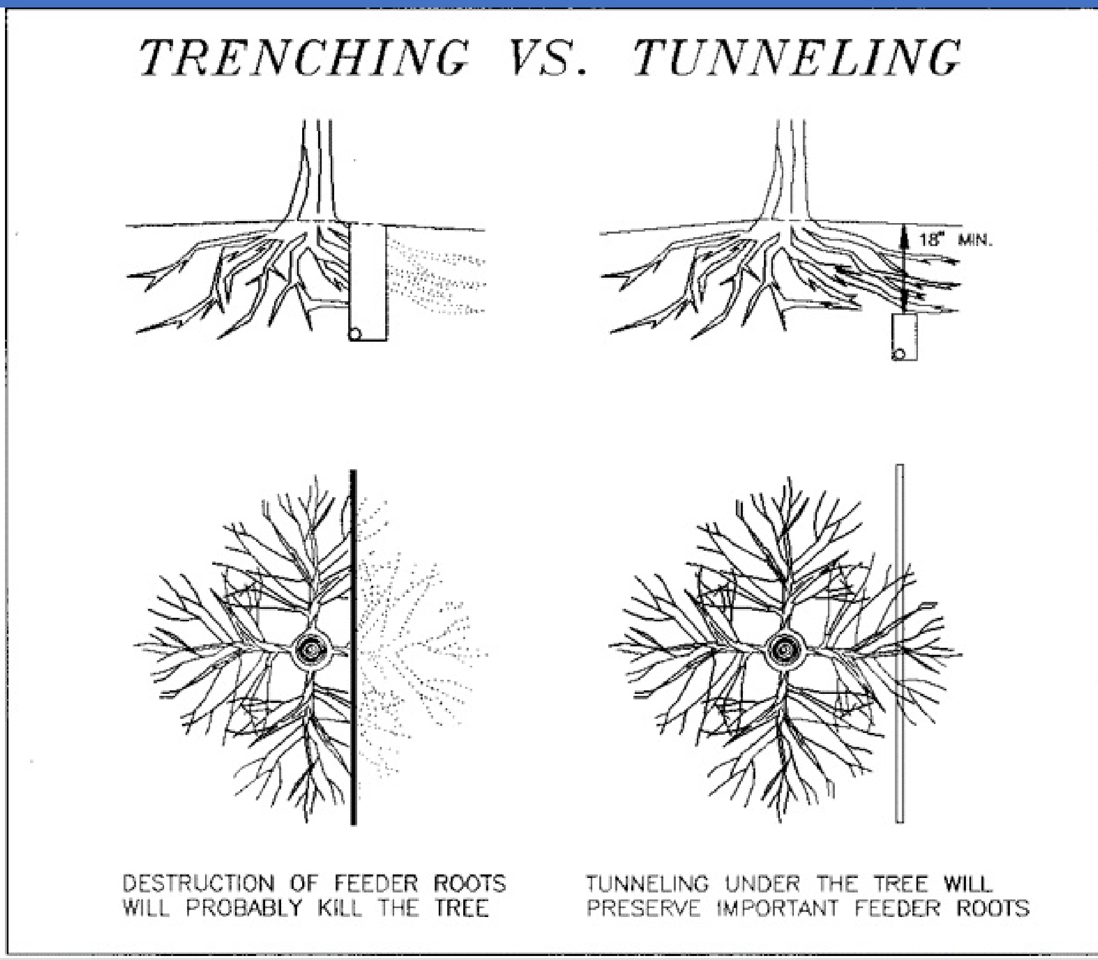
3. **Trenching and Tunnelling:**

   a. Trenching should be conducted as far away from the trunks of trees as possible, preferably outside the reach of branches or crown spreads of trees, to reduce the amount of root area damaged or killed by trenching.

b. Wherever possible, trenches should avoid large roots or root concentrations. This can be accomplished by curving the trench or by tunnelling under large roots and areas of heavy root concentration.

c. Tunnelling is more expensive initially, but it usually causes less soil disturbance and physiological impact on the root system (Figure C-SSM-01-7). The extra cost may offset the potential cost of Tunnelling is almost always preferred over trenching. The tunnel should be 18 inches or deeper below the ground surface and should not be located under the center of the tree (an off-center tunnel has the smallest impact on the roots).

**Figure C-SSM-01-7 Trenching vs. Tunneling**




*Source: Pirone 1979.*

d. Roots should not be left exposed to the air. The roots should be covered with soil as soon as possible or protected and kept moistened with wet burlap or peat moss until the trench or tunnel can be filled.

e. The ends of damaged and cut roots should be cut off smoothly and protected by painting promptly with a tree wound dressing.

f. Trenches and tunnels should be filled as soon as possible. Air spaces in the soil will be avoided by careful filling and tamping.

g. Peat moss or other suitable material should be added to the fill material as an aid to inducing and developing new root growth.

h. The tree should be mulched and fertilized to conserve moisture, stimulate new root growth, and enhance general tree vigor.

i. If a large portion of the root system has been damaged or killed, the crown leaf surface should be proportionately reduced to balance the reduced root system. This may be accomplished by pruning 20 to 30 percent of the crown foliage. If roots are cut during the winter, the tree should be pruned before the next growing season. If roots are cut during the growing season, the tree should be pruned immediately.

4. **Removal and Replacement of Damaged Trees:** Should a tree intended and marked for retention be damaged seriously enough that survival and normal growth are not possible, the tree should be removed. If replacement is desirable and/or required, the replacement tree should be of the same or similar species, 2-inch to 2.5-inch (minimum) caliper balled and burlapped nursery stock. However, today, with the aid of a "tree spade," the same caliper tree may be required as a replacement. Trees being removed should not be felled, pushed, or pulled into any tree being preserved.
5. **Cleanup:** Cleanup after a construction project can be a critical time for tree damage. Trees protected during development are often destroyed by carelessness during the final cleanup and landscaping. Fences and barriers should be removed last, after everything else is cleaned up and carried away. Equipment operators should not clean any part of their equipment by slamming it against the trunk of any tree to be preserved.

## 7.0 Operations and Maintenance Considerations

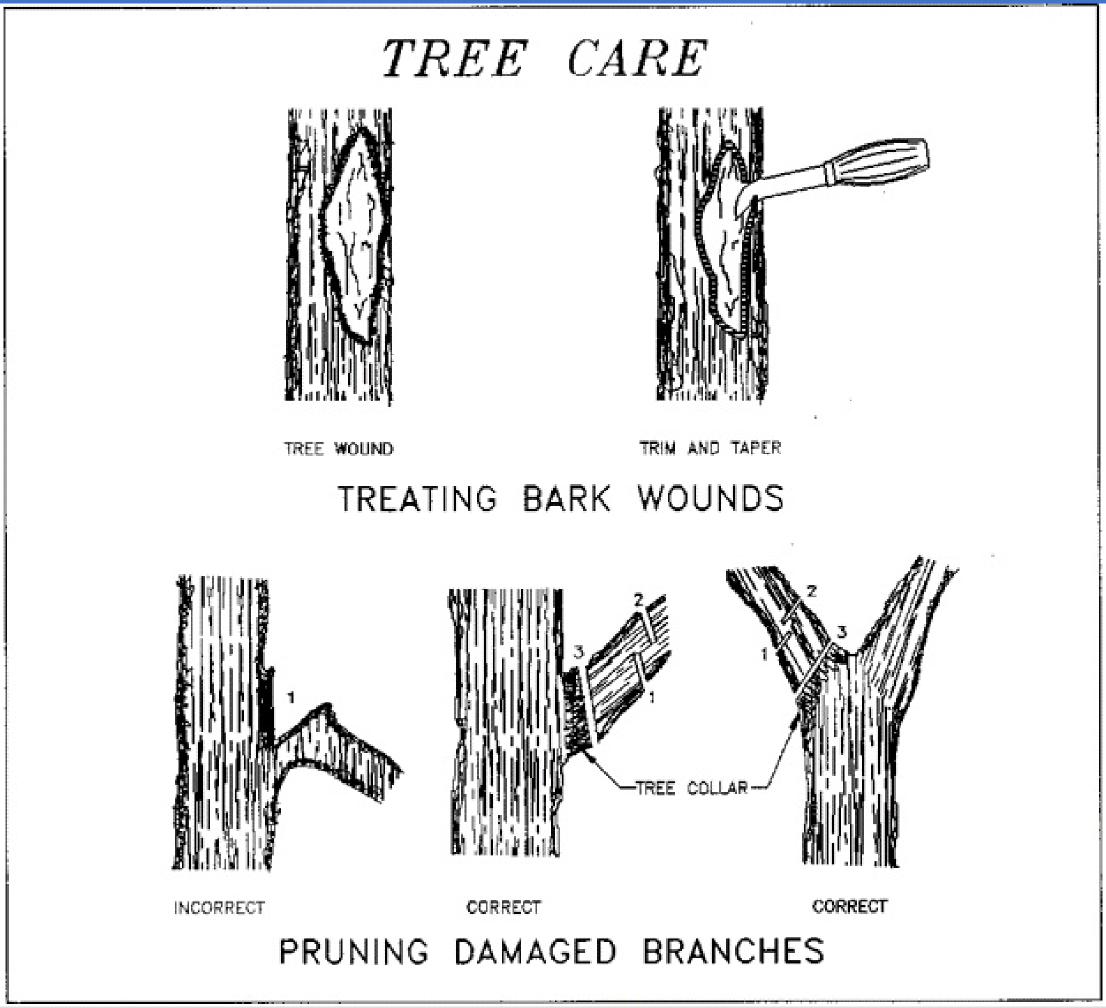
Despite precautions, some protected trees may suffer damage. In such cases, the maintenance guidelines identified in Table C-SSM-01-5 should be implemented:

**Table C-SSM-01-5 Operation and Maintenance**

| Operation and Maintenance Considerations | |
|---|---|
| Soil Aeration | If the soil has become compacted over the root zone of any tree, the ground should be aerated by punching holes with an iron bar. The bar should be driven 1 foot deep and then moved back and forth until the soil is loosened. This procedure should be repeated every 18 inches until all the compacted soil beneath the crown of the tree has been loosened. |
| Repair of Damage | 1. Any damage to the crown, trunk, or root system of any tree retained on the site should be repaired immediately.<br>2. When major root or bark damage occurs, remove some foliage to reduce the demand for water and nutrients.<br>3. Damaged roots should immediately be cut off cleanly inside the exposed or damaged area. Paint cut surfaces with approved tree paint and spread moist peat moss, burlap, or topsoil over the exposed area.<br>4. To treat bark damage, carefully cut away all loosened bark back into the undamaged area, taper the cut at the top and bottom, and provide drainage at the base of the wound (Figure C-SSM-01-8).<br>5. All tree limbs damaged during construction or removed for any other reason should be cut off above the collar at the preceding branch junction (Figure C-SSM-01-8).<br>6. Care for serious injuries should be prescribed by a forester or a tree specialist. |

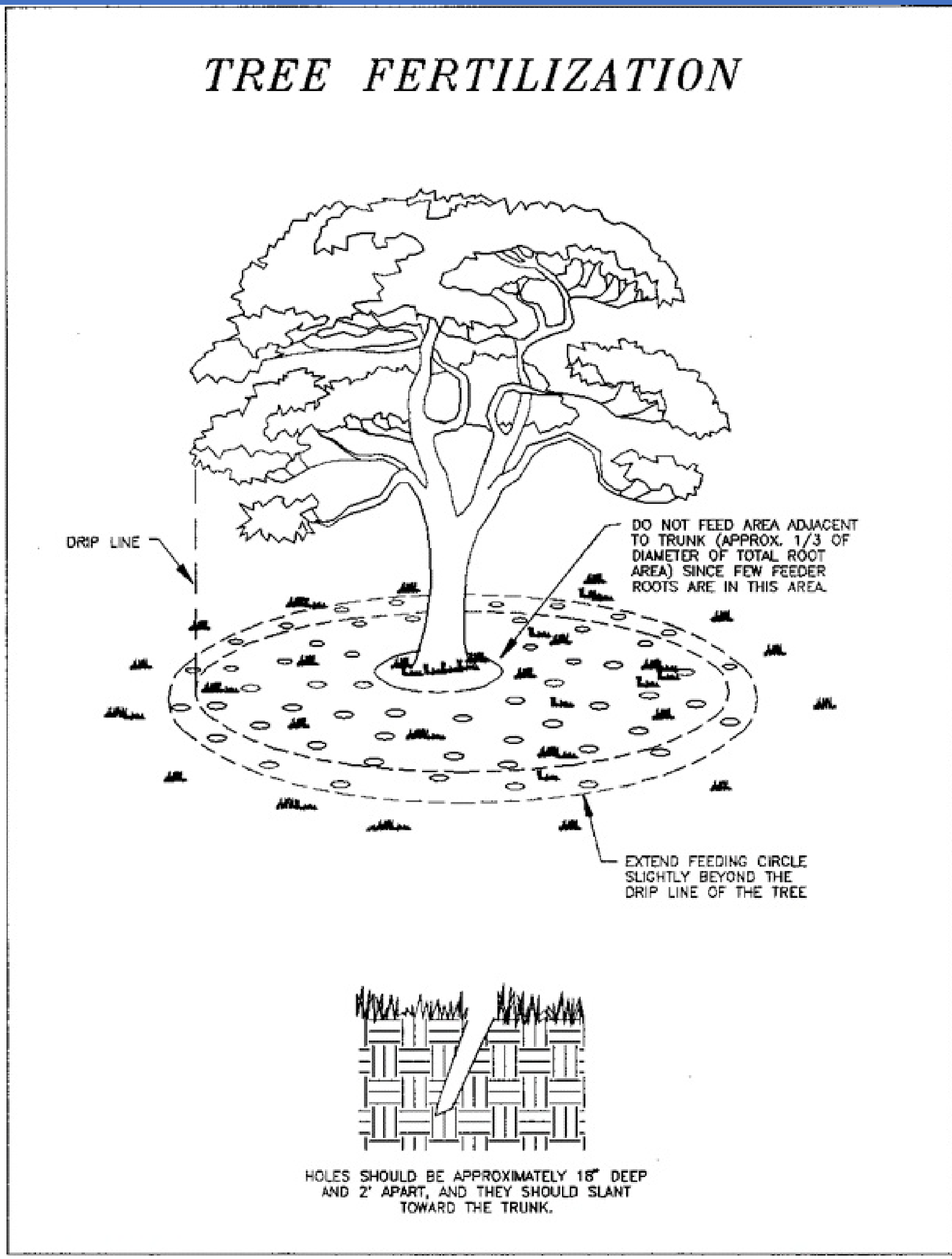
| Table C-SSM-01-5 Operation and Maintenance | |
|---|---|
| **Operation and Maintenance Considerations** | |
| Fertilization | Broadleaf trees that have been stressed or damaged should receive a heavy application of fertilizer to aid their recovery.<br>1. Trees should be fertilized in the late fall (after October 1) or the early spring (from the time frost is out of the ground until May 1). Fall applications are preferred, as the nutrients will be made available over a longer period.<br>2. Fertilizer should be applied to the soil over the feeder roots (see Figure C-SSM-01-9). In no case should it be applied closer than 3 feet from the trunk. The root systems of conifers extend some distance beyond the drip line. Increase the area to be fertilized by one fourth the area of the crown.<br>3. Fertilizer should be applied using approved fertilization methods and equipment.<br>4. Formulations and application rates should conform to the guidelines provided in Table C-SSM-01-4.<br>Maintain a ground cover of organic mulch around trees sufficient to prevent erosion, protect roots, and hold water. |

*Figure C-SSM-01-8 Tree Care*




*Source: Fairfax County 1976.*

Figure C-SSM-01-9 Tree Fertilization




*Source: Pirone 1979.*

## 8.0 References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Fairfax County. 1976. Fairfax County's Public Facilities Manual. Land Development Services. Volume III.

Georgia Soil and Water Conservation Commission.2016. Manual for Erosion and Sediment Control in Georgia. Vegetative & Structural BMPs for Land-Disturbing Activities. 2016.

Pirone, P.P. 1978 Tree Maintenance. Fifth Edition.

Virginia Department of Environmental Quality. 1992. Virginia Erosion and Sediment Control Handbook. Third edition.

Va. DSWC [Add reference]

Zion, R.L. 1968. Trees for Architecture and the Landscape. January.

# C-SSM-02 Topsoiling

## 1.0 Definition

*Source: Wetlands Inc. 2021*

Topsoil is defined as the A and E horizons of the existing mineral soil profile. Well humified litter layer (O horizon) material may also be included but not fresh or partially decomposed litter. Topsoiling as a construction best management practice (BMP) entails preserving and using the surface layer of undisturbed soil, often enriched in organic matter, to obtain a more desirable planting and growth medium and enhance final site stabilization.

## 2.0 Purpose and Applicability of Best Management Practice

Topsoiling provides a suitable growth medium for final site-stabilizing vegetation.

Topsoiling applies where:

1. The preservation or importation of topsoil is determined to be the most effective method of providing a suitable growth medium.
2. High-quality turf is desirable to withstand intense use or meet aesthetic requirements.
3. Permanent vegetation will be established.
4. Slopes are 2H:1V or flatter unless other measures are taken to prevent erosion and sloughing.

Topsoiling is necessary when the subsoil or existing soil presents the following problems:

1. The texture, rockiness, pH, or nutrient balance of the available soil cannot be modified by reasonable means to provide an adequate growth medium (which would contain a high volume of air-void space [approximately 20 percent by volume]), moderate water-holding capacity with a high percent of the contained water readily available for plant uptake, stability against compaction and decomposition that would alter the air-water balance, low concentrations of soluble salts, freedom from pests and toxins, and uniformity.
2. The soil material is too shallow (less than 20 inches depth of solum) to provide an adequate root zone and to supply necessary moisture and nutrients for plant growth.
3. The existing soil contains pollutants that are potentially toxic to plant growth.

## 3.0 Planning and Considerations

Topsoil is the surface layer of the soil profile, generally characterized as being darker than the subsoil due to the presence of humified organic matter. It is the major zone of root development, carrying many of the nutrients available to plants and supplying a large share of the water used by plants. Topsoil can usually be differentiated from subsoil by texture as well as color. Clay content usually increases in the subsoil. The depth of topsoil may vary widely. On severely eroded sites, it may be gone entirely (North Carolina Sediment and Control Commission et al. 2013).

Advantages of topsoil include its high organic matter content and friable consistence, water-holding capacity, and nutrient content. The texture and friability of topsoil are usually much more conducive to seedling emergence and root growth. In addition to being a better growth medium, topsoil is often less erodible than subsoils, and the coarser texture of topsoil vs subsoil increases infiltration capacity and reduces runoff.

Although topsoil serves as an excellent growth medium, there are disadvantages to its use:

- Stripping, stockpiling, and reapplying topsoil, or importing topsoil, may not always be cost-effective vs amending existing soil.
- Topsoiling can delay seeding or sodding, increasing the exposure time of denuded areas.
- Topsoil may contain undesirable weed species seeds that may compete with intended vegetation.

In site planning, the option of topsoiling should be compared with that of preparing a seedbed into properly amended subsoil. Some clay content in subsoils provides high moisture availability and deters leaching of nutrients and, when properly limed and fertilized and/or organically amended, subsoils may serve as a good growth medium that is generally free of weed seeds. In many cases, topsoiling may not be required for the establishment of less demanding, lower-maintenance plant material. **Topsoiling is strongly recommended where permanent vegetation is to be established.** Topsoiling is necessary when establishing vegetation on shallow (< 6 inches to rock) soils, soils containing potentially toxic materials, and soils of critically low pH (highly acidic; < pH 5.5 unless limed) levels.

If topsoiling is to be conducted, the following items should be considered:

- Topsoil will be spread at a settled depth of 4 inches on grades less than 3:1 (VDEQ 2022).
- Topsoil stockpiles should be located on disturbed areas, away from concentrated runoff, that do not interfere with work on the site.
- Allow sufficient scheduling for topsoil to be spread and stabilized before seeding, sodding, or planting.
- Care must be taken not to apply topsoil to subsoil if the two soils have strongly contrasting textures. Clayey topsoil over sandy subsoil is a particularly poor combination, as water may creep along the junction between the soil layers, causing the topsoil to saturate and slough. Sandy topsoil over a clay subsoil is equally likely to fail.
- The returned topsoil layer must adhere sufficiently to the underlying subsoil to ensure stability and resist planar slippage failure. It may be necessary to roughen the surface of the underlying subsoil (see Surface Roughening [C-SSM-03]), particularly materials with high clay content, which may smear when cut and manipulated when moist. Alternatives to topsoiling, including use of soil amendments and roughening of slopes, should be considered for steep slopes.
- Use of manufactured soils that meet the design criteria outlined below (Section 5.0) should be considered when natural topsoil materials are not available.

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization shall be applied to denuded areas within 7 days after reaching final grade on any portion of the site. Temporary soil stabilization shall be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization shall be applied to areas that can be left dormant for more than 1 year.

**MS-2: STOCKPILES, WASTE, AND BORROW AREAS** – During construction of the project, soil stockpiles and borrow areas shall be stabilized or protected with sediment trapping measures. The applicant is responsible for the temporary protection and permanent stabilization of all soil stockpiles on site as well as borrow areas and soil intentionally transported from the project site.

9VAC25-875-560.

## 5.0 Design Criteria

The site should be evaluated in the field to determine if there is sufficient topsoil of good quality to justify stripping. Topsoil should be friable and Natural Resources Conservation Service (NRCS) texture class loam (loam, sandy loam, silt loam, sandy clay loam, clay loam). Heavy loads of debris, trash, stumps, rocks, roots, and noxious weeds should not be present, and the soil should demonstrate the ability to support healthy vegetation.

All topsoil should be tested by a qualified laboratory for the following criteria:

1. Organic matter as humus content should be not less than 1.5% by weight.
2. pH range should be from 6.0 to 7.5. If pH is less than 6.0, lime should be added in accordance with soil test results or in accordance with the recommendations of the vegetative establishment practice being used.
3. Soluble salts concentrations should not exceed 500 parts per million (ppm).

If additional off-site or manufactured topsoil is needed, or if the topsoil is modified, it should meet these standards.

## 6.0 Construction Specifications

### 6.1 Stripping

Topsoiling should not be performed when the soil is wet or frozen. Stripping should be confined to the immediate construction area. A 4- to 6-inch stripping depth is common, but depth may vary depending on the soil. All perimeter dikes, basins, and other sediment controls should be in place before stripping.

### 6.2 Stockpiling

Select the stockpile location to avoid slopes, natural drainageways, and traffic routes. On large sites, respreading is easier and more economical when topsoil is stockpiled in small piles located near where the topsoil will be used.

Stabilize or protect stockpiles in accordance with Minimum Standard 2.

Sideslopes of the stockpile should not exceed 2H:1V (VDEQ 2022).

Perimeter control measures must be placed around the stockpile immediately to retain sediment, see Silt Fence (C-PCM-04) and Temporary Seeding (C-SSM-09) if the stockpile is to remain dormant for longer than 30 days (refer to Minimum Standards MS-1 and MS-2). 109

### 6.3 Site Preparation for Topsoiling

Before topsoiling, establish necessary erosion and sediment control practices such as diversions, grade stabilization structures, berms, dikes, level spreaders, waterways, and sediment basins. These practices must be maintained during topsoiling.

1. Grading: Previously established grades on the areas to be topsoiled should be maintained according to the approved plan.
2. Liming: Where the pH of the subsoil is 6.0 or lower, agricultural limestone should be spread in accordance with results of the soil test or the vegetative establishment practice being used.
3. Bonding: After the areas to be topsoiled have been brought to grade, and immediately before dumping and spreading the topsoil, the subgrade should be loosened by discing or scarifying to a depth of at least 2 inches to encourage adhesion of the topsoil to subsoil and limit slippage.

**6.4 Applying Topsoil**

Topsoil should not be placed during frozen or muddy conditions; when topsoil or subgrade is excessively wet; or in a condition that may otherwise be detrimental to proper grading, proposed sodding, or seeding.

After areas to be topsoiled have been brought to grade, and immediately before dumping and spreading the topsoil, the subgrade (subsoil) should be loosened by discing or scarifying to a depth of at least 2 inches to ensure bonding of the topsoil and subsoil.

The topsoil should be uniformly graded and distributed to a minimum settled depth of 2 inches on 3H:1V or steeper slopes and 4 inches on flatter slopes. See Table C-SSM-02-1 to determine volume of topsoil required for application to various depths.

*Topsoiling Application Failed*
*Source: Environment Canterbury Regional Council 2017*

Any irregularities in the surface resulting from topsoiling or other operations should be corrected to prevent the formation of depressions or water pockets.

It is necessary to grade and smooth the topsoil sufficiently to ensure good contact with the underlying mineral soil and to obtain a level seedbed, particularly for the establishment of high-maintenance turf.

Compaction is to be avoided, as it increases runoff velocity and volume and deters seed germination.

Surfaces that are not going to be mowed should be left rough in accordance with Surface Roughening (C-SSM-03).

**Table C-SSM-02-1 Volume (cubic yards) of Topsoil Required for Various Depths**

| Depth (inches) | Per 1,000 Square Feet | Per Acre |
|---|---|---|
| 1 | 3.1 | 134 |
| 2 | 6.2 | 268 |
| 3 | 9.3 | 403 |
| 4 | 12.4 | 537 |
| 5 | 15.5 | 672 |
| 6 | 18.6 | 806 |

## 7.0 Operations and Maintenance Considerations

Slopes and areas that will not be mowed may be left rough after spreading topsoil. A disc may be used to promote bonding at the interface between topsoil and subsoil.

After topsoil application, follow procedures for seedbed preparation, taking care to avoid excessive mixing of topsoil into the subsoil. Apply stabilization to areas that remain dormant for 7 days after topsoil has been spread.

## 8.0 References

Environment Canterbury Regional Council. 2017. Erosion and Sediment Control Toolbox for Canterbury. located at: www.esccanterbury.co.nz.

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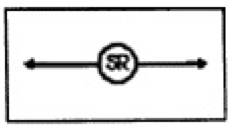
# C-SSM-03 Surface Roughening





## 1.0 Definition

Surface roughening is the practice of providing a rough soil surface with horizontal depressions to reduce runoff velocity, increase infiltration, aid the establishment of vegetation, and reduce erosion. For roughened surfaces within 50 feet of a surface water, and where blanketing of seeded areas is proposed as the means to achieving permanent stabilization, spray-on type blankets are recommended. Details for stair stepping, grooving, and tracking are provided in subsequent sections.

*Effective and Proper Surface Roughening*
*Source: USEPA 2021*

Surface roughening is also providing a rough soil surface with horizontal depressions created by operating a tillage or other suitable implement on the contour or leaving slopes in a roughened condition by not fine grading them.

– CAD C-SSM-03-1 Stair stepping Cut Slopes and CAD C-SSM-03-2 Grooving Slopes

– CAD C-SSM-03-3 Fill Slope Treatment and CAD C-SSM-03-4 Tracking

## 2.0 Purpose and Applicability of Best Management Practice

Use surface roughening to:

1. Aid the establishment of vegetative cover from seed.
2. Reduce runoff velocity and increase infiltration.
3. Reduce erosion and provide for sediment trapping.

This practice is recommended under the following conditions:

1. Surface roughening should be applied to slopes 3H:1V or steeper unless a stable rock face is provided or it can be shown that there is not a potential for sediment pollution to enter surface waters.
2. When slopes are steeper than 3H:1V, use stair-step grading, grooving, furrowing, or tracking if the slopes are to be stabilized with vegetation.
3. Areas with grades shallower than 3H:1V should have the soil surface lightly roughened and loose to a depth of 2 to 4 inches before seeding.
4. Areas that have been graded and will not be stabilized immediately may be roughened to reduce runoff velocity until seeding takes place.

Slopes with a stable rock face do not require roughening or stabilization.

## 3.0 Planning and Considerations

It is difficult to establish vegetation on smooth, hard surfaces due to reduced water infiltration and the potential for erosion. Although rough slope surfaces with uneven soil and rocks left in place may appear unattractive or unfinished at first, such conditions encourage water infiltration, speed the establishment of vegetation, and decrease runoff velocity.

Rough and loose soil surfaces give lime, fertilizer, and seed some natural coverage. Niches in the surface provide microclimates, which generally provide a cooler and more favorable moisture level than hard, flat surfaces and aid seed germination.

There are different methods for achieving a roughened soil surface on a slope, and the selection of an appropriate method depends on the type of slope. ***Roughening methods include stair-step grading, grooving, and tracking.*** Factors to be considered in choosing a method are slope steepness, mowing requirements, and whether the slope is formed by cutting or filling.

1. Disturbed areas that will not require mowing may be stair-step graded, grooved, or left rough after filling.
2. Stair-step grading is particularly appropriate in soils containing large amounts of soft rock. Each "step" catches material that sloughs from above and provides a level site where vegetation can become established.
3. Areas that will be mowed (these areas should have slopes less steep than 3H:1V) may have small furrows left by discing, harrowing, raking, or seed-planting machinery operated on the contour.
4. It is important to avoid excessive compacting of the soil surface when scarifying. Tracking with bulldozer treads is preferable to not roughening at all but is not as effective as other forms of roughening, as the soil surface is severely compacted and runoff is increased.

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization shall be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization shall be applied to areas that are to be left dormant for more than 1 year.

**MS-7: CUT AND FILL SLOPES** – Cut and fill slopes shall be designed and constructed to minimize erosion. Slopes found to be eroding excessively within 1 year of permanent stabilization shall be provided with additional slope stabilizing measures until the problem is corrected.

9VAC25-870-560

## 5.0 Design Criteria

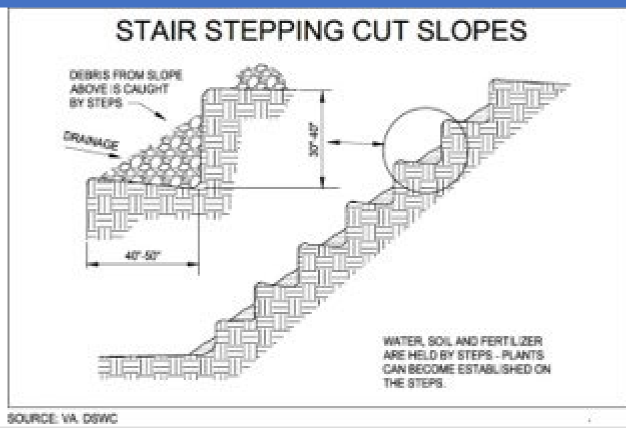
No formal design is required.

## 6.0 Construction Specifications

### **6.1 For Cut Slope Applications for Areas that Will Not Be** Mowed

Cut slopes with a gradient steeper than 3H:1V should be stair-step graded or grooved.

***Figure C-SSM-03-1 Stair Stepping Cut Slopes***




1. Stair-step grading may be carried out on any material soft enough to be ripped with a bulldozer. Slopes consisting of soft rock with some subsoil are particularly suited to stair-step grading (Figure C-SSM-03-1).

   The ratio of the vertical cut distance to the horizontal distance should be less than 1H:1V, and the horizontal portion of the "step" should slope toward the vertical wall.

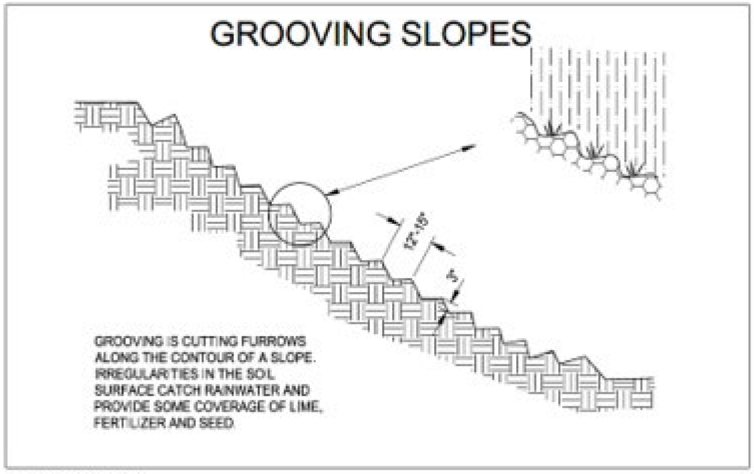
   Individual vertical cuts should not be more than 30 inches on soft soil materials and not more than 40 inches in rocky materials.

2. Grooving or tracking consists of using machinery to create a series of ridges and depressions that run perpendicular to the slope (on the contour).

   Grooves may be made with any appropriate implement that can be safely operated on the slope and that will not cause undue compaction.

3. Suggested implements include discs, tillers, spring harrows, and the teeth on a front-end loader bucket. Such grooves should not be less than 3 inches deep or further than 15 inches apart.

**Figure C-SSM-03-2 Grooving Slopes**




SOURCE: VA. DSWC

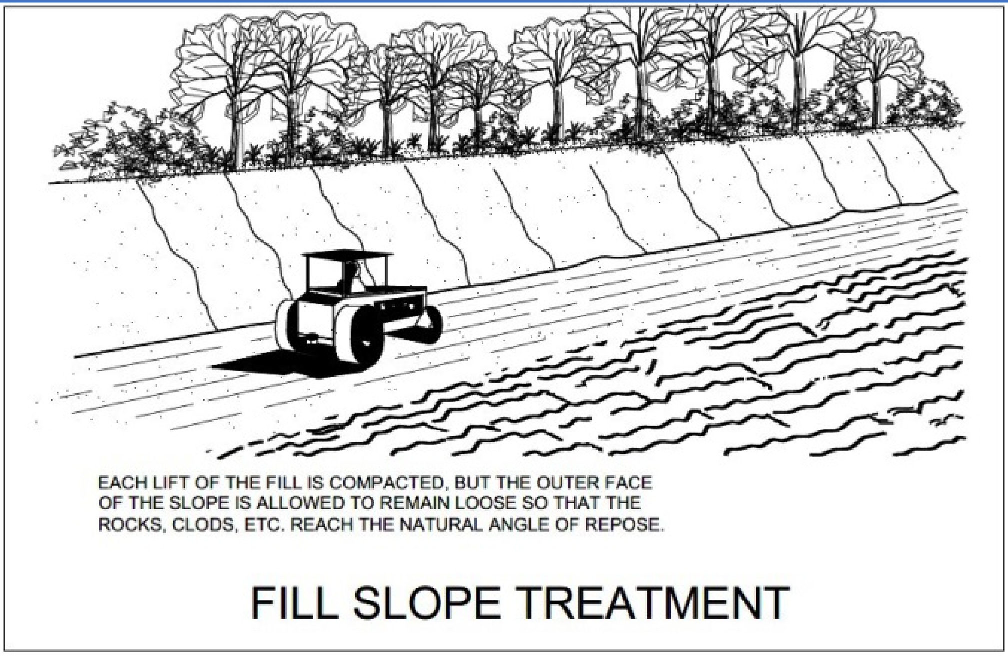
### 6.2 For Fill Slope Applications for Areas that Will Not Be Mowed

1. Fill slopes with a gradient steeper than 3H:1V should be grooved or allowed to remain rough as the slopes are constructed. Method (1) or (2) may be used.
2. Groove according to #2 in the previous section. As lifts of the fill are constructed, soil and rock materials may be allowed to fall naturally onto the slope surface. See Figure C-SSM-03-3.

   Colluvial materials (soil deposits at the bases of slopes or from old stream beds) should not be used in fills, as the materials flow when saturated. At no time should slopes be bladed or scraped to produce a smooth, hard surface.

*Surface Roughening Ignored on Side Slopes of Access Road*

*Figure C-SSM-03-3 Fill Slope Treatment*




SOURCE: VA. DSWC

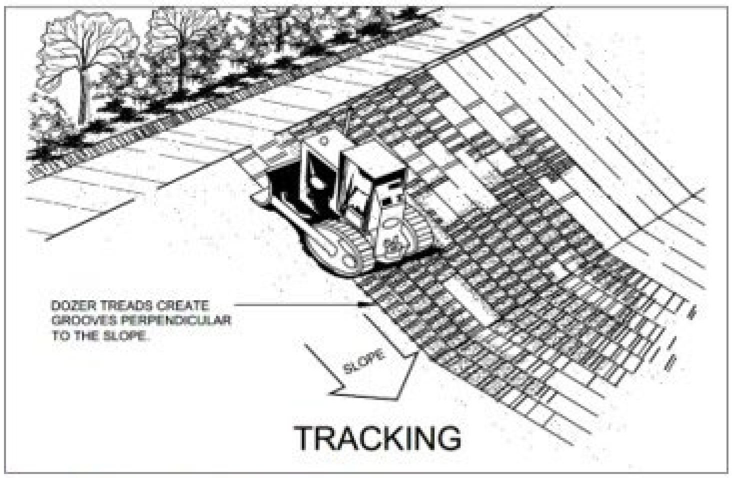
### 6.3 Cuts, Fills, and Graded Areas that Will Be Mowed

Mowed slopes should not be steeper than 3H:1V. Excessive roughness is undesirable where mowing is planned. These areas may be roughened with shallow grooves such as those that remain after tilling, discing, harrowing, raking, or use of a cultipacker-seeder. The final pass of any such tillage implement should be on the contour (perpendicular to the slope).

Grooves formed by such implements should be no less than 1 inch deep and not farther than 12 inches apart. Fill slopes that are left rough as constructed may be smoothed with a dragline or pick chain to facilitate mowing.

### 6.4 Roughening with Tracked Machinery

*Figure C-SSM-03-4 Tracking*




SOURCE: MICHIGAN SOIL EROSION AND SEDIMENTATION GUIDE

Roughening with tracked machinery on clayey soils is not recommended unless no alternatives are available. Undue compaction of surface soil results from this practice. Sandy soils do not compact severely and may be tracked. In no case is tracking as effective as the other roughening methods described.

When tracking is the chosen surface roughening technique (Figure C-SSM-03-4), it should be accomplished by operating tracked machinery up and down the slope to leave horizontal depressions in the soil. As few passes of the machinery should be made as possible to minimize compaction.

**6.5 Seeding**

Roughened areas should be seeded and mulched as soon as possible to obtain optimum seed germination and seedling growth. See Temporary Seeding (C-SSM-09), Permanent Seeding (C-SSM-10), and Mulching (C-SSM-11). Fill diversions and slope drains can be used to prevent concentrated flow over slopes while waiting for vegetative stabilization.

## 7.0 Operations and Maintenance Considerations

Periodically check the seeded slopes for rills and washes. Fill these areas slightly above the original grade, then reseed and mulch as soon as possible (North Carolina Sedimentation Control Commission et al. 2013).

Seeded slopes should be inspected after every recordable rain event. Seed should be reapplied in areas where it may have washed away during the previous rain event.

## 8.0 References

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

United States Environmental Protection Agency (USEPA). 2021. Stormwater Best Management Practice: Soil Roughening. EPA-832-F-21-028JJ. December.

Virginia Department of Environmental Quality. 1992. Virginia Erosion and Sediment Control Handbook. Third edition.

# C-SSM-04 Compost Blankets

## 1.0 Definition

A compost blanket is a layer of loosely applied composted material placed on the soil in disturbed areas to reduce stormwater runoff and erosion.

## 2.0 Purpose and Applicability of Best Management Practice

A compost blanket is a slope stabilization, erosion control, and vegetation establishment practice used on construction sites to stabilize bare, disturbed, or erodible soils. The compost material fills in small rills and voids to limit channelized flow, provides a more permeable surface to facilitate stormwater infiltration, and promotes revegetation.

*Example Compost Blanket Source: Full Circle Mushroom Compost, Inc. n.d.*

Compost blankets function as mulch, cover 100% of the soil surface, and therefore provide the beneficial effects characteristic to mulches including: reduced raindrop impact and splash erosion, reduced runoff energy and sheet erosion, buffered soil temperature for plants, decreased moisture evaporation, increased moisture holding capacity at the soil surface, reduced runoff volume and velocity, and increased infiltration.

Where planned and applied correctly to a properly prepared subgrade, compost blankets can aid in amending the soil. This can provide benefits to the soil's structure; increased aggregation, aeration, infiltration and percolation, activity of beneficial microbes, and availability of nutrients; increased plant health; and long-term site sustainability.

Seeds can be mixed into the compost before the blanket is applied to the surface.

Compost blankets may be used for temporary erosion control and in support of providing permanent vegetative cover. When the blanket is specified for permanent stabilization, incorporate vegetative cover with the compost at rates shown in the seeding specification on the approved plan and maintained until the permanent cover is established. Use Virginia native seed for incorporation into compost blankets for permanent stabilization. Where specified for temporary stabilization, install and maintain the blanket as specified in the construction sequence on the approved plan. Incorporate a temporary vegetative cover or nurse crop with temporary compost blankets.

## 3.0 Planning and Considerations

- Consider compost blankets when soil is poor. Compost blankets can be placed on any soil surface: flat, steep, rocky, or frozen.
- Only use compost blankets to control sheet flow from rainfall and not in areas of concentrated runoff.
- Take care not to apply compost where it can raise the nutrient level of streams.
- Do not place compost blankets in locations that receive concentrated or channeled flows either as runoff or a point source discharge.

- Do not use compost blankets in areas subject to vehicular traffic and use by heavy equipment.
- Avoid very coarse compost if the slope is to be landscaped or seeded, as it will make planting and crop establishment more difficult.

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization shall be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days.

Permanent stabilization shall be applied to areas that are to be left dormant for more than 1 year.

9VAC25-870-560

**Erosion Control Efficiency: HIGH**

**Sediment Removal Efficiency: LOW**

## 5.0 Design Criteria

The application of compost blankets is appropriate for erosion and sediment control on slopes up to a 2H:1V grade and for use in areas that have sheet flow drainage patterns.

Slopes steeper than 2H:1V may require special installation techniques such as additional blanket thickness, soil stabilization blankets or matting, and/or slope interruption devices (compost filter socks and berms).

The chemical, physical, and biological parameters of compost blankets recommended for use in this application are described in Table C-SSM-04-1.

| Table C-SSM-04-1 Design Criteria for Compost | | | | |
|---|---|---|---|---|
| Compost Parameters for Compost Blanket Use | | | | |
| **Parameter[a]** | **Unit** | **Acceptable Vegetative** | **Acceptable Non-Vegetative** | **Test Method** |
| Stability | mg CO2-C per g OM per day | <4 | <4 | TMECC 05.08-B |
| Maturity | % seed emergence & vigor | >80 | N/A | TMECC 05.05-A |
| Moisture Content | % wet weight basis | 30-60 | 30-60 | TMECC 03.09-A |
| Organic Matter Content | % dry weight basis | 25-65 | 25-100 | TMECC 05.07-A |
| Particle Size | Screen size to pass through | 99% passing 3"; 90-100% pass 1"; 65-100% pass 0.75"; 0-75% pass 0.25". Maximum particle size length 6" (152mm) | 99% passing 3"; 90-100% pass 1"; 65-100% pass ¾"; 0-75% pass ¼". Maximum particle size length 6" (152mm) | TMECC 02.12-B |
| pH | pH units | 6.0-8.5 | N/A | TMECC 04.11-A |

| Table C-SSM-04-1 Design Criteria for Compost | | | | |
|---|---|---|---|---|
| Compost Parameters for Compost Blanket Use | | | | |
| Soluble Salts (Electrical Conductivity) | dS/m (mmhos/cm) dry weight basis | <5 | N/A | TMECC 04.10-A |
| Physical Contaminants | % dry weight basis | <0.25 | <0.25 | Biological Assays |

**Notes:**

Source: US Composting Council n.d.

a Recommended test methodologies are provided in Test Methods for the Examination of Composting and Compost (TMECC; US Composting Council n.d.).

% = percent

“ = inch

dS/m = deciSiemens per meter

mg CO2-C per g OM per day = milligram of carbon dioxide mineralization per gram of Organic Matter per day

mm = millimeter

mmhos/cm = millimhos per centimeter

N/A = not applicable

## 6.0 Construction Specifications

Perform the following steps to install compost blankets for erosion and sediment control. Include this information in the construction sequence on the approved erosion and sediment control plan. Modifications to the construction sequence are subject to the approval of the certified plan reviewer.

1. Prepare the soil by removing all large rocks, dirt clods, stumps, roots, grass clumps, trash, and other obstructions from the soil surface to allow for direct contact between the soil surface and the compost blanket.
2. Select the method to apply the compost blanket. The compost blanket can be applied by hand, conveyor system, compost spreader, or pneumatic delivery (blower) system. A pneumatic blower is most cost-effective and most adaptive in applying compost to steep, rough terrain, and hard-to-reach locations.
3. Apply the compost blanket to 100% of the area as required on the approved plan. Cover 100% of the bare or disturbed area with the blanket such that no native soil is visible in or through the compost blanket. Apply the compost blanket at the application rates specified in Table C-SSM-04-2. Mix seed thoroughly with the compost before application or apply to the compost blanket at time of application at the appropriate rates prescribed by the approved plan.
4. Install compost blankets at least 10 feet over and beyond the shoulder of the slope and/or into the edge of existing vegetation to ensure that runoff does not undercut the blanket. Ensure that the existing root mat is not disturbed when installing compost blankets into the edge of existing vegetation.
5. Design and specify compost blanket application rates based on specific site (e.g., soil characteristics, existing vegetation) and climatic conditions, as well as project-related requirements and calculated stormwater runoff.
6. Track compost blankets installed on slopes greater than or equal to 4H:1V. Secure compost blankets placed on slopes greater than or equal to 3H:1V with adequate soil stabilization blankets

and matting. Install soil stabilization blankets or matting over the compost blanket where high winds and wind erosion are expected, regardless of slope. All other installation procedures and specifications will be as shown on the approved plan and described in the approved construction sequence. Uniformly apply the compost as described in the approved construction sequence with the appropriate equipment. If required, thorough watering may be used to improve settling of the blanket.

7. The compost blanket should extend at least 3 feet over the shoulder of the slope to ensure that stormwater runoff does not flow under the blanket.
8. If the slope is steep (>2H:1V), apply soil stabilization blankets or matting over the compost blanket. Then place compost filter socks across the slope to reduce the runoff velocity. Compost berms may be placed at the top of the slope to divert or diffuse concentrated runoff before it reaches the compost blanket.

*Improperly Installed Compost Blanket on Steep Slope*
*Source: ?*

| Table C-SSM-04-2 Compost Blanket Application Rates | | | |
|---|---|---|---|
| Compost Blanket Application Rates | | | |
| Annual Rainfall/ Flow Rate | Total Precipitation & Rainfall Erosivity Index | Application Rate for Vegetated[a] Compost Surface Mulch | Application Rate for Unvegetated Compost Surface Mulch |
| Low | 1”-25”; 20-90 | 1”-1.5” (25mm-37.5mm) | 1”-1.5” (25mm-37.5mm |
| Average | 26”-50”; 91-200 | 1”-1.5” (25mm-37.5mm) | 1.5”-2” (37mm-50mm) |
| High | >51”; >201 | 1”-2” (25mm-50mm) | 2”-4” (25mm-50mm) |

**Notes:**

Source: North Carolina Sediment Control Division et al. 2013, Chapter 6 Practice Standards and Specifications, Section 6.18 Compost Blankets.

[a] Only use the lower application rates in conjunction with seeding and for compost blankets applied during the prescribed planting season for the region.

“ = inch

mm = millimeter

## 7.0 Operations and Maintenance Considerations

- Inspect compost blankets weekly and after each runoff event. If failure or damage to the blanket occurs, or if vegetation does not establish within the expected germination time of the selected seed type, reapply compost and seed to the affected area to return it to the original condition.
- Take additional measures as necessary to establish permanent ground cover.
- Inspect compost blankets until permanent vegetation is established.
- Repair soil stabilization blankets or matting placed over the compost blanket if the blankets or matting have been moved or damaged by wind or stormwater runoff and/or if part of or the whole blanket is not in contact with the soil surface.

## 8.0 References

Full Circle Mushroom Compost, Inc. n.d. Compost Blanket. Web page. Available online at: https://www.fullcirclemushroomcompost.com/projects/mushroom-compost-blanket-pa/.

North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. North Carolina Department of Environmental Quality, Division of Energy, Mineral, and Land Resources in partnership with the North Carolina Sedimentation Control Commission, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

US Composting Council. n.d. Compost – Erosion Control Uses: Compost Blanket Class Specific Guide. Available online at: www.compostingcouncil.org/page/CompostErosionControlUses.

United States Environmental Protection Agency. 2012. Stormwater Best Management Practice: Compost Blankets. EPA 833-F-11-007. United States Environmental Protection Agency, Office of Water, 4203M. March. Available online at: https://www3.epa.gov/npdes/pubs/compostblankets.pdf or https://www.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater-construction.

# C-SSM-05 Soil Stabilization Blankets and Matting

## 1.0 Definition

Soil stabilization blankets and matting are a form of protective blanket (Treatment 1 or soil stabilization matting (Treatment II) on a prepared planting area of a steep slope, channel, or shoreline.

– CAD C-SSM-05-1 Typical Orientation of Treatment - 1 (Soil Stabilization Blanket)

– CAD C-SSM-05-2 Typical Treatment - 1 (Soil Stabilization Blanket) Installation Criteria

– CAD C-SSM-05-3 Stakes, Staples, & Pins for Installation of Treatment - 2 Soil Stabilization Matting

– CAD C-SSM-05-4 Typical Treatment-2 Soil Stabilization Matting Installation

– CAD C-SSM-05-5 Typical Treatment - 2 Soil Stabilization Matting Slope Installation

– CAD C-SSM-05-6 General Staple Pattern Guide and Recommendations for Treatment - 2 (Soil Stabilization Matting)

## 2.0 Purpose and Applicability of Best Management Practice

Soil stabilization blankets and matting aid in controlling erosion on critical areas by providing a microclimate that protects young vegetation and promotes its establishment. In addition, some types of soil stabilization mats are also used to raise the maximum permissible velocity of turf grass stands in channelized areas by “reinforcing the turf” to resist the forces of erosion during storm events.

Soil stabilization blankets and matting are applicable to short, steep slopes where erosion hazard is high, and planting is likely to be too slow to provide adequate protective cover; in vegetated channels where the velocity of design flow exceeds “allowable” velocity; on streambanks or tidal shorelines where moving water is likely to wash out new plantings; or where the forces of wind prevent standard mulching from remaining in place until vegetation becomes established.

*Source: East Coast Erosion Control*

Another application of this best management practice (BMP) is the stabilization of the slopes within sinkholes and slopes along ephemeral drainageways that terminate in sinkholes or other karst features.

***Soil stabilization blankets and matting do not effectively prevent slope failures. Where slope stability problems are anticipated or encountered, consider appropriate measures such as reducing slope steepness, diverting upslope runoff, reducing soil moisture, loading the toe of the slope, or buttressing the slope.***

## 3.0 Planning and Considerations

Soil stabilization blankets and mats can be applied to disturbed areas to supplement nature’s erosion control system (vegetation) in its initial establishment and provide a safe and “natural” conveyance for high-velocity stormwater runoff.

Soil stabilization blankets and mats are being used today in many applications where previously a structural lining would have been required.

Designers should choose the type of blanket or matting most appropriate for the specific needs of a project.

| Table C-SSM-05-1 Design Considerations for Soil Stabilization | |
|---|---|
| **Type** | **Notes on Proper Use** |
| Treatment 1 | *Treatment 1 is a degradable soil stabilization blanket* that includes “combination” blankets consisting of a plastic netting, which covers and intertwines with a natural organic or man-made mulch, or a jute mesh, which is typically homogeneous in design and can act alone as a soil stabilization blanket.<br><br>Use Treatment 1 soil stabilization blankets to help establish vegetation on previously disturbed slopes of 3H:1V or greater. Because the materials that comprise the soil stabilization blankets will deteriorate over time, use the blankets in permanent conveyance channels understanding that the system’s resistance to erosion is based on the type of vegetation planted and the existing soil characteristics.<br><br>During the establishment of vegetation, ensure that Treatment 1 blankets are not subjected to shallow or deep concentrated flows moving at rates greater than 4 feet per second (fps) or a shear stress over 2.25 $lb/ft^2$.<br><br>Treatment 1 provides the following benefits in the achievement of vegetative stabilization when properly applied over seed and required amendments:<br><br>• Protection of the seed and soil from raindrop impact and subsequent displacement;<br>• Thermal consistency and moisture retention for seedbed area;<br>• Stronger and faster germination of grasses and legumes;<br>• Leveling off excess stormwater runoff; and<br>• Prevention of sloughing of topsoil added to steeper slopes. |

| Table C-SSM-05-1 Design Considerations for Soil Stabilization | |
|---|---|
| **Type** | **Notes on Proper Use** |
| Treatment 2 | *Treatment 2 is a soil stabilization matting,* which consists of a non-degradable, three- dimensional plastic structure that can be filled with soil prior to planting.<br>This configuration provides a matrix for root growth in which the matting becomes entangled and penetrated by roots, forming continuous anchorage for surface growth and promoting enhanced energy dissipation. Use Treatment 2 matting on steep slopes (normally 3H:1V or greater) and in stormwater conveyance channels.<br>In addition to the benefits noted for Treatment 1, Treatment 2 provides the following benefits in the achievement of vegetative stabilization and in the replacement of more traditional channel linings such as concrete and riprap:<br>• Causes soil to drop out of stormwater and fill matrix with fine soils, which become the growth medium for the development of roots;<br>• When embedded in the soil within stormwater channels, acts with the vegetative root system to form an erosion-resistant cover that resists hydraulic lift and shear forces;<br>• Because Treatment 2 is non-degradable, the matting can be used in permanent conveyance channels and can withstand higher velocities of flow than the vegetation and soil would normally allow; and<br>• However, ensure that where Treatment 2 matting is used within a conveyance system, the matting is not subjected to a flow velocity greater than 10 fps or shear stress over 8 lb/ft$^2$. |

### 3.1 VDOT Nomenclature

Designers are cautioned that inclusion on the VDOT “Approved Products List” does not indicate compliance with the specifications in this Handbook or approval for use by VDEQ.

Designers should also note that these relationships are provided for informational purposes only. The specifications within this handbook apply to all projects outside of the VDOT right-of-way.

The following relationship exists between the two methods of naming the practice:

| Table C-SSM-05-2 VESCH to VDOT Equivalency | |
|---|---|
| **Virginia Erosion and Sediment Control Handbook (VESCH)** | **VDOT Specifications** |
| Treatment 1 (is equivalent to) | Standard EC-2 (Temporary Rolled Erosion Control Product [RECP]) |
| Treatment 2 (is equivalent to) | Standard EC-3 (Permanent RECP) |

## 4.0 Stormwater Performance Summary

### 4.1 MS-1: Stabilization

Permanent or temporary soil stabilization will be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization will be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization will be applied in areas to be left dormant for more than 1 year.

### 4.2 MS-3: Permanent Vegetation

A permanent vegetative cover will be established on denuded areas not otherwise permanently stabilized. Permanent vegetation will not be considered established until achievement of a ground cover that is uniform, mature enough to survive, and will inhibit erosion.

**Sediment Removal Efficiency: N/A**

**Erosion Control Efficiency: High**

## 5.0 Design Criteria

| Table C-SSM-05-3 Design Criteria for Soil Stabilization Blankets | |
|---|---|
| **Treatment 1 – Soil Stabilization Blanket** | |
| **Parameter** | **Notes on Proper Use** |
| Allowable Velocity and Shear Stress | Refer to Table C-SSM-05-5 for allowable velocity and shear stress values for linings. |
| Combination Blanket | Use combination blankets that consist of a photo-degradable plastic netting, which covers and is entwined in a natural organic or man-made mulching material.<br><br>Use a blanket with a mulching material that consists of wood fibers, wood excelsior, straw, coconut fiber, man-made fibers, or a combination of the same. Use a blanket that is a consistent thickness, with the mulching material/fibers evenly distributed over its entire length. Use a blanket that has the mulching material/fibers interlocked or entwined to form a dense layer, which not only resists raindrop impact but will allow vegetation to penetrate the blanket.<br><br>Use a blanket that is non-toxic to vegetation and to the germination of seed and is not injurious to the unprotected skin of humans. At a minimum, ensure the plastic netting covers the top side of the blanket and possess a high web strength. Ensure the netting is entwined with the mulching material/fiber to maximize strength and provide for ease of handling. |

| Table C-SSM-05-3 Design Criteria for Soil Stabilization Blankets | |
|---|---|
| Treatment 1 – Soil Stabilization Blanket | |
| Jute Mesh | Use a jute mesh material that is a uniform, open, plain weave of undyed and unbleached single jute yarn. Use a yarn that has a loosely twisted construction and does not vary in thickness by more than one half of its normal diameter. Use a jute mesh material that is new and conforms to the following criteria.<br>• Length of jute mesh is marked on each roll.<br>• There are 0.60-inch openings (± 25%) between strands, lengthwise.<br>• There are 0.90-inch openings (± 25%) between strands, lengthwise.<br>• Weight is an average 0.90 pound per square yard with a tolerance of 5%.<br>As previously noted, jute mesh provides such good coverage (large surface area of strands) and contains such small openings that it can be used alone as a blanket. |
| Other Treatment 1 Products | Use other Treatment 1 products that conform to manufacturer's specifications and are approved by the certified plan reviewer prior to being specified for a particular application. Install these products in accordance with manufacturer's recommendations, provided those recommendations are at least as stringent as this specification. Where used, ensure that these products cover more than 30% of the soil surface. |
| Staples | Use staples for anchoring Treatment 1 blankets that are No. 11-gauge wire or heavier with a minimum length of 6 inches. Use a larger staple with a length of up to 12 inches on loose, sandy, or unstable soils. |

| Table C-SSM-05-4 Design Criteria for Soil Stabilization Matting | |
|---|---|
| Treatment 2 – Soil Stabilization Matting | |
| **Parameter** | **Notes on Proper Use** |
| Allowable Velocity and Shear Stress | Refer to Table C-SSM-05-5 for allowable velocity and shear stress values for linings. |

| Table C-SSM-05-4 Design Criteria for Soil Stabilization Matting | |
|---|---|
| **Treatment 2 – Soil Stabilization Matting** | |
| Matting | Most of the Treatment 2 products provide a three-dimensional geo-matrix of nylon, polyethylene, or randomly oriented monofilaments, forming a mat. These products contain ultraviolet (UV) inhibiting stabilizers added to the compounds to ensure endurance and provide "permanent root reinforcement."<br><br>The three-dimensional feature creates an open space that is allowed to fill with soil. The roots of the grass plant become established within the mat itself, forming a synergistic root and mat system. As the grass becomes established, the two "reinforce" each other, preventing movement or damage to the soil. Allowable velocities and shear stress values are increased considerably over natural turf stands.<br><br>Selection of the appropriate matting materials, along with proper installation, become critical factors in the success of this practice. It is recommended that any velocities that exceed 10 fps or 8 lb/ft$^2$ be properly protected with some form of structural lining in accordance with Stormwater Conveyance Channel (C-ECM-09). |
| Staples | Staples or anchoring methods and recommendations vary by manufacturers. The expectation of high velocities will dictate the use of more substantial anchoring. Some of the typically recommended stakes, staples, and pins are depicted on Figure C-SSM-05-3. |

| Table C-SSM-05-5 Allowable Velocity and Shear Stress – Lined Ditches | | | |
|---|---|---|---|
| Type of Lining | | Maximum Allowable | Maximum Allowable Shear |
| **VESCH** | **VDOT Standard** | **Velocity (fps)** | **Stress (lb/ft$^2$)** |
| Treatment 1 | EC-2 (Type 1) | 4.0 | 1.50 |
| | EC-2 (Type 2) | | 1.75 |
| | EC-2 (Type 3) | | 2.0 |
| | EC-2 (Type 4) | | 2.25 |
| Treatment 2 | EC-3 (Type 1) | 7.0 | 6.0 |
| | EC-3 (Type 2) | 10.0 | 8.0 |
| | EC-3 (Type 3) | N/A | 10.0 |

Source: VDOT Drainage Manual

## 6.0 Construction Specifications

| Table C-SSM-05-6 Material Specifications for Soil Stabilization Blankets | |
|---|---|
| Treatment 1 Soil Stabilization Blanket Installation | |
| **Activity** | **Notes** |
| Site Preparation | After the site has been shaped and graded to approved design, prepare a friable seedbed relatively free from clods, rocks more than 1.5 inches in diameter, and any foreign material that will prevent uniform contact of the protective covering with the soil surface. If necessary, redirect runoff away from the channel or slope during installation. |
| Planting | Lime, fertilize, and seed in accordance with Temporary Seeding BMP C-SSM-09 or Permanent Seeding BMP C-SSM-10, MS#1, and the approved plan.<br><br>When using jute mesh on a seeded area, apply approximately one half the seed after laying the mat. The protective covering can be laid over sprigged areas in which small grass plants have been inserted into the soil. Where ground covers are to be planted, lay the protective covering first and then plant through the material as per planting design.<br><br>When open-weave nets are used, apply lime, fertilizer, seed, and mulch before laying the net. When a combination blanket (such as an “excelsior” blanket) is used, apply seed and soil amendments before the blanket is laid. |
| Orientation | Refer to Figure C-SSM-05-1 for orientation of Treatment 1 for different topographic conditions. |
| Laying and Stapling | If instructions have been followed, all needed check slots will have been installed, and the protective covering will be laid on a friable seedbed free from clods, rocks, roots, or other large matter that might impede good contact.<br><br>Start laying the protective covering from the top of the channel or top of slope and unroll down-grade.<br><br>Allow to the blanket lay loosely on soil; do not stretch.<br><br>Bury the upslope ends of the protective covering in an anchor slot no less than 6 inches deep. Tamp earth firmly over the material. Staple the material at a minimum of every 12 inches across the top end.<br><br>Staple the edges of the material every 3 feet. Where multiple widths are laid side-by- side, overlap the adjacent edges a minimum of 2 inches and staple together.<br><br>Place staples down the center, staggered with the edges at 3-foot intervals.<br>Refer to Figure C-SSM-05-1 for laying and stapling arrangement. |

| Table C-SSM-05-6 Material Specifications for Soil Stabilization Blankets | |
|---|---|
| **Treatment 1 Soil Stabilization Blanket Installation** | |
| **Activity** | **Notes** |
| Check Slots | On highly erodible soils and on slopes steeper than 4H:1V, make erosion check slots every 50 feet (see Figure C-SSM-05-2). Insert a fold of the material (separate piece) into a 6-inch trench and tamp firmly. Staple fold to “main” blanket at minimum 12-inch intervals across the upstream and downstream portions of the blanket.<br><br>Note: Many combination blankets are designed and manufactured to resist movement and uplift to a point at which check slots may not be required. Designers and plan reviewers should review manufacturers’ specifications before installation. |
| Joining Protective Coverings | Insert a new roll of material into an anchor slot, as with upslope ends. Overlap the end of the previous roll a minimum of 12 inches and staple across the end of the roll just below the anchor slot and across the material every 12 inches. |
| Terminal End | Where the material is discontinued, or at which time the protective covering meets a structure of some type, fold 4 inches of the material underneath and staple a minimum of every 12 inches. |
| At Bottom of Slopes | Lead net out onto a level area before anchoring. Turn ends under 4 inches, and staple across end a minimum of every 12 inches. |
| Final Check | After installation, check to ensure that the following installation conditions are in place:<br>• Protective blanket is in uniform contact with the soil.<br>• All lap joints are secure.<br>• All staples are driven flush with the ground.<br>• All disturbed areas have been seeded. |

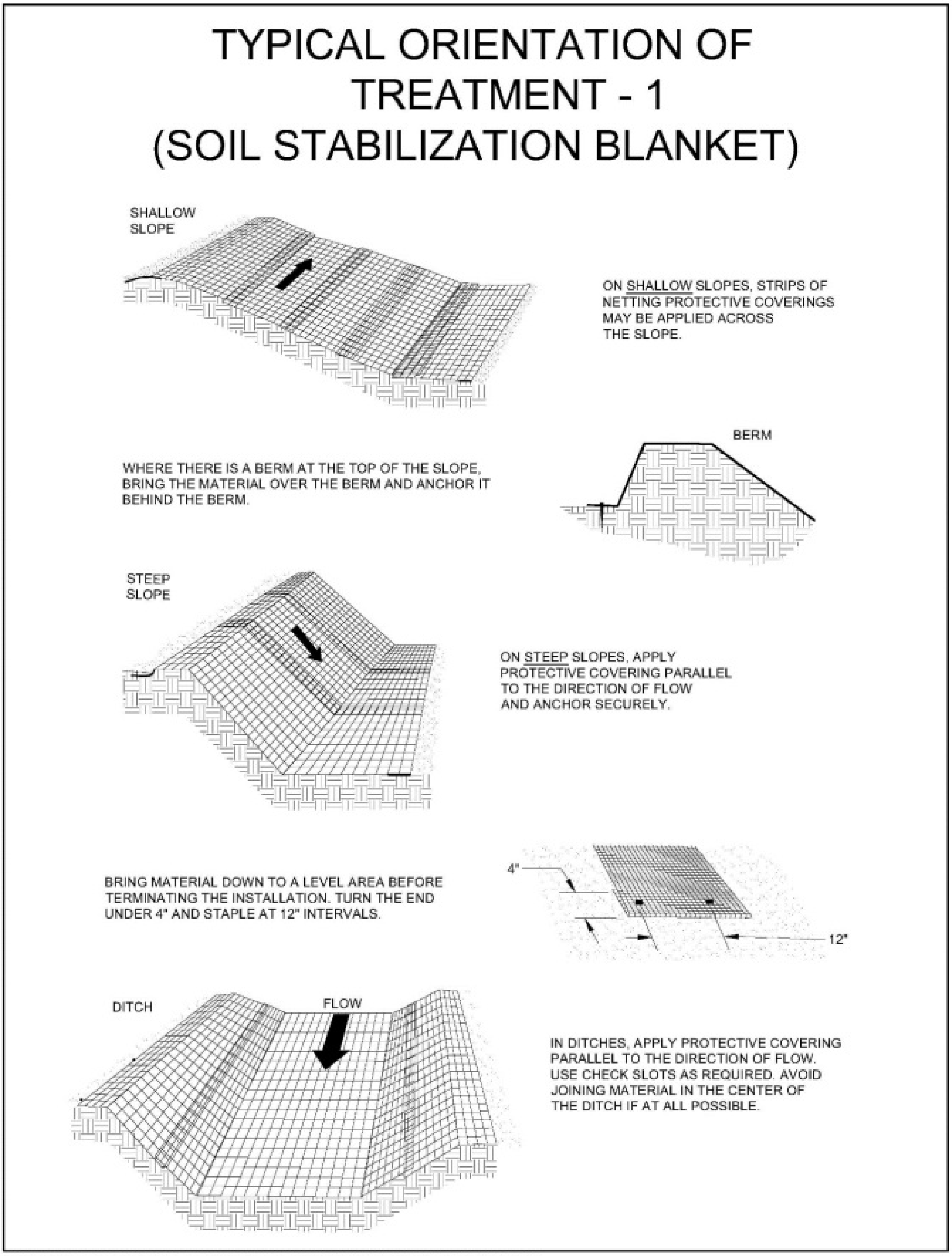
| Table C-SSM-05-7 Material Specifications for Soil Stabilization Matting | |
|---|---|
| **Treatment 2 Soil Stabilization Matting Installation** | |
| **Activity** | **Notes** |
| Site Preparation | After the site has been shaped and graded to approved design, prepare a friable seedbed relatively free from clods, rocks more than 1 inch in diameter, and any foreign material that will prevent uniform contact of the protective covering with the soil surface. If necessary, redirect runoff away from the channel or slope during installation. |
| Planting | Lime, fertilize, and seed in accordance with seeding (Temporary Seeding BMP C-SSM-09 or Permanent Seeding BMP C-SSM-10), MS#1, and the approved plan paying special attention to the plant selection that may have been chosen for the matted area. If the area has been seeded prior to installing the mat, make sure and reseed all areas disturbed during installation. |

| Table C-SSM-05-7 Material Specifications for Soil Stabilization Matting | |
|---|---|
| **Treatment 2 Soil Stabilization Matting Installation** | |
| Mulching | Apply mulch (normally straw) following installation of Treatment 2 matting at rates noted in Mulching (BMP C-SSM-11). |
| Laying and Stapling | Refer to Figure C-SSM-05-4, Figure C-SSM-05-5, and Figure C-SSM-05-6 for laying and stapling arrangements. The key to achieving desired performance is proper installation. |
| Check Slots | Refer to Figure C-SSM-05-4 for check slot installation for matting. Matting manufacturers vary significantly in their check slot requirements. Like the installation of Treatment 1, a check slot may be required when laying Treatment 2 to "correct" the flow of water if runoff has the potential to undermine the matting. Most authorities (including VDOT) require that the sides of the matting also be entrenched, creating a slope shelf for the material to rest on, preventing water from entering under the mat on the sides. |
| Securing the Material and Joining Mats | Again, product specifications vary – upstream and downstream terminal slots, new roll overlaps, and multiple width installations differ by product and manufacturer. |
| Final Check | After installation, check to ensure that the following installation conditions are in place:<br>• Soil stabilization mat is in uniform contact with the soil.<br>• All required slots and lapped joints are in place.<br>• The material is properly anchored.<br>• All disturbed areas are seeded. |

## 7.0 Operations and Maintenance Considerations

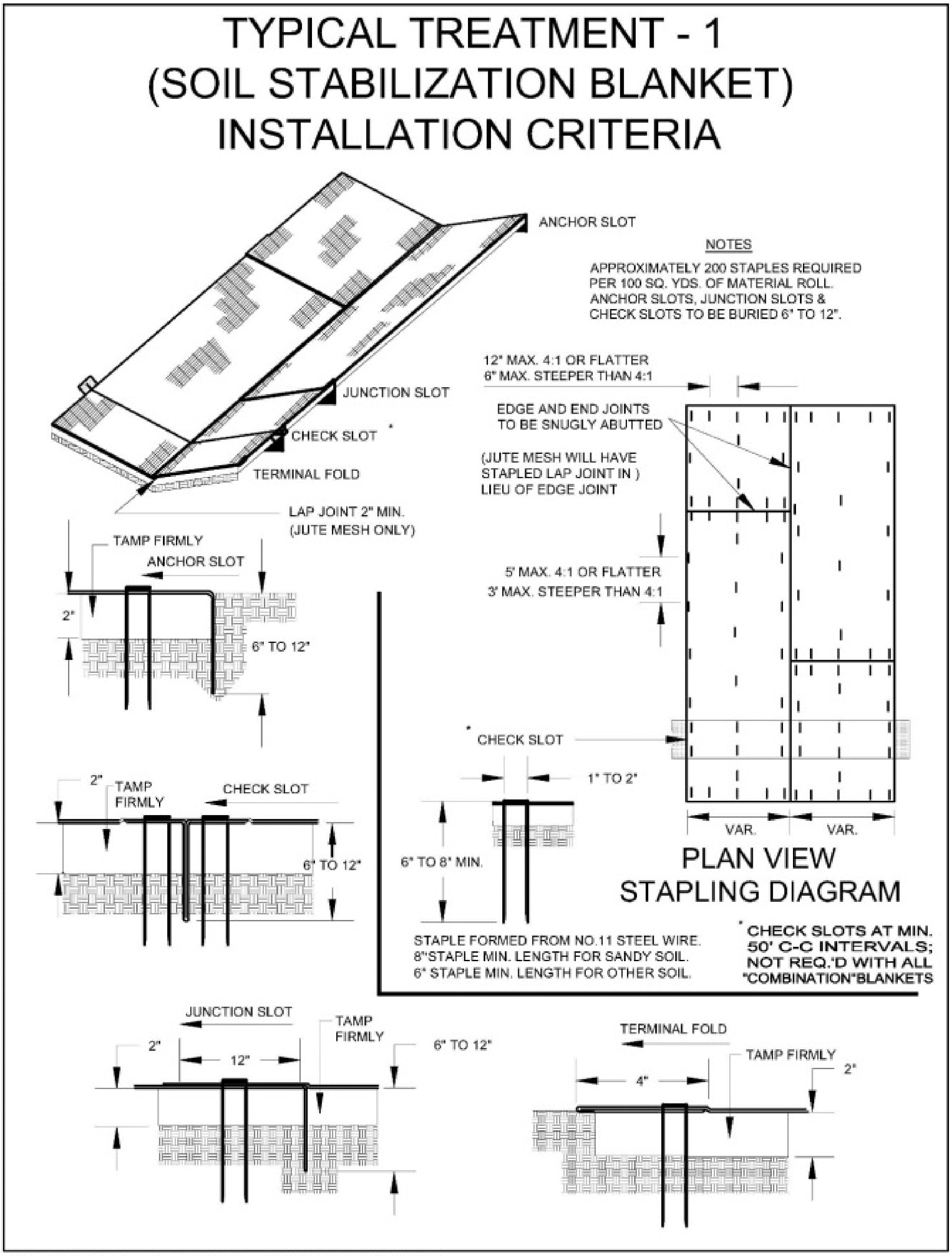
Inspect all soil stabilization blankets and matting periodically following installation, particularly after rainstorms, to check for erosion and undermining. Repair any dislocation or failure immediately. If washouts or breakage occurs, reinstall the material after repairing damage to the slope or channel. Continue to monitor these areas until they become permanently stabilized; at that time, an annual inspection is adequate.

## *Figure C-SSM-05-1 Typical Orientation of Treatment (Soil Stabilization Blanket)*



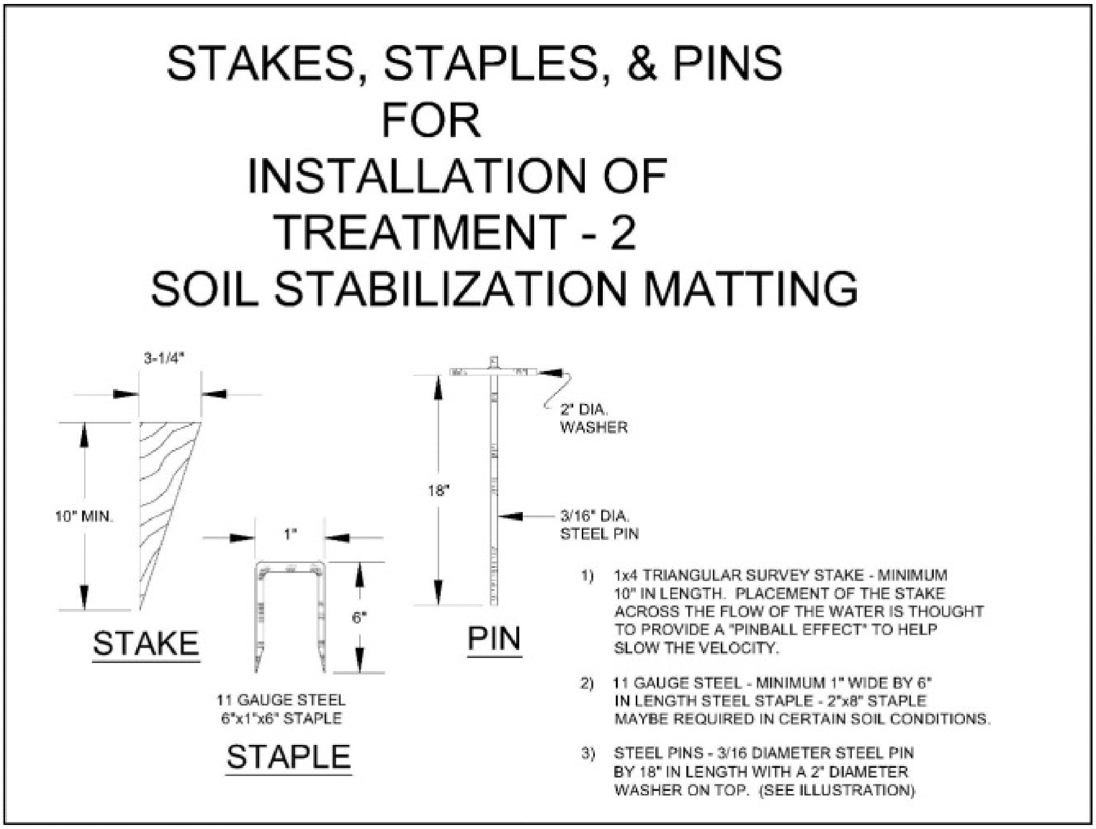

SOURCE: ADAPTED FROM LUDLOW PRODUCTS BROCHURE

***Figure C-SSM-05-2 Typical Treatment Installation Criteria (Soil Stabilization Blanket)***



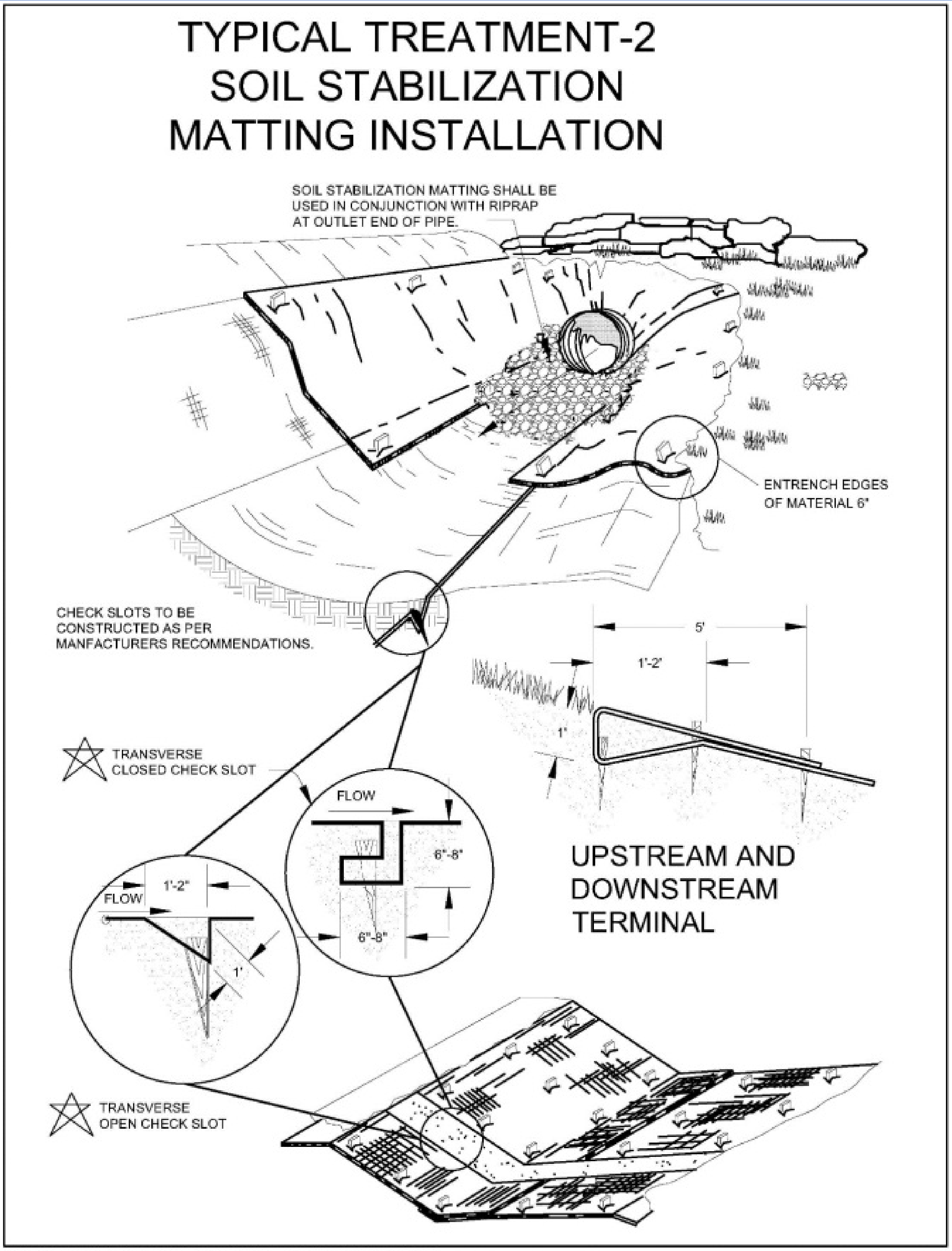

SOURCE: VDOT ROAD AND BRIDGE STANDARDS

***Figure C-SSM-05-3 Stakes, Staples, & Pins for Installation of Treatment (Soil Stabilization Matting)***



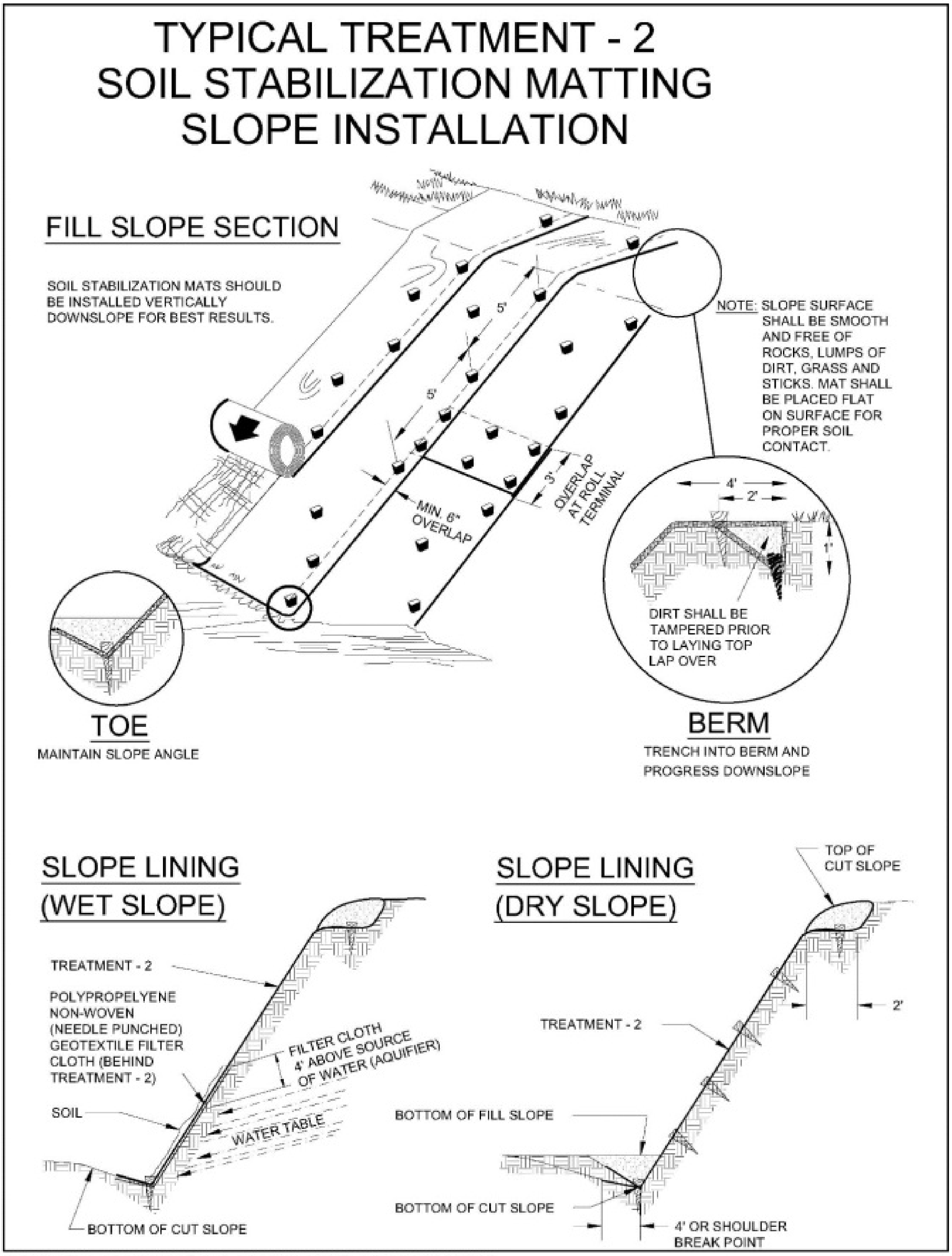

SOURCE: Greenstreak, Inc.

***Figure C-SSM-05-4 Typical Treatment Soil Stabilization Matting Installation***




SOURCE: VDOT ROAD AND BRIDGE STANDARDS

**Figure C-SSM-05-5 Typical Treatment Soil Stabilization Matting Slope Installation**




SOURCE: VDOT ROAD AND BRIDGE STANDARDS

**Figure C-SSM-05-6 General Staple Pattern Guide for Treatment 2**

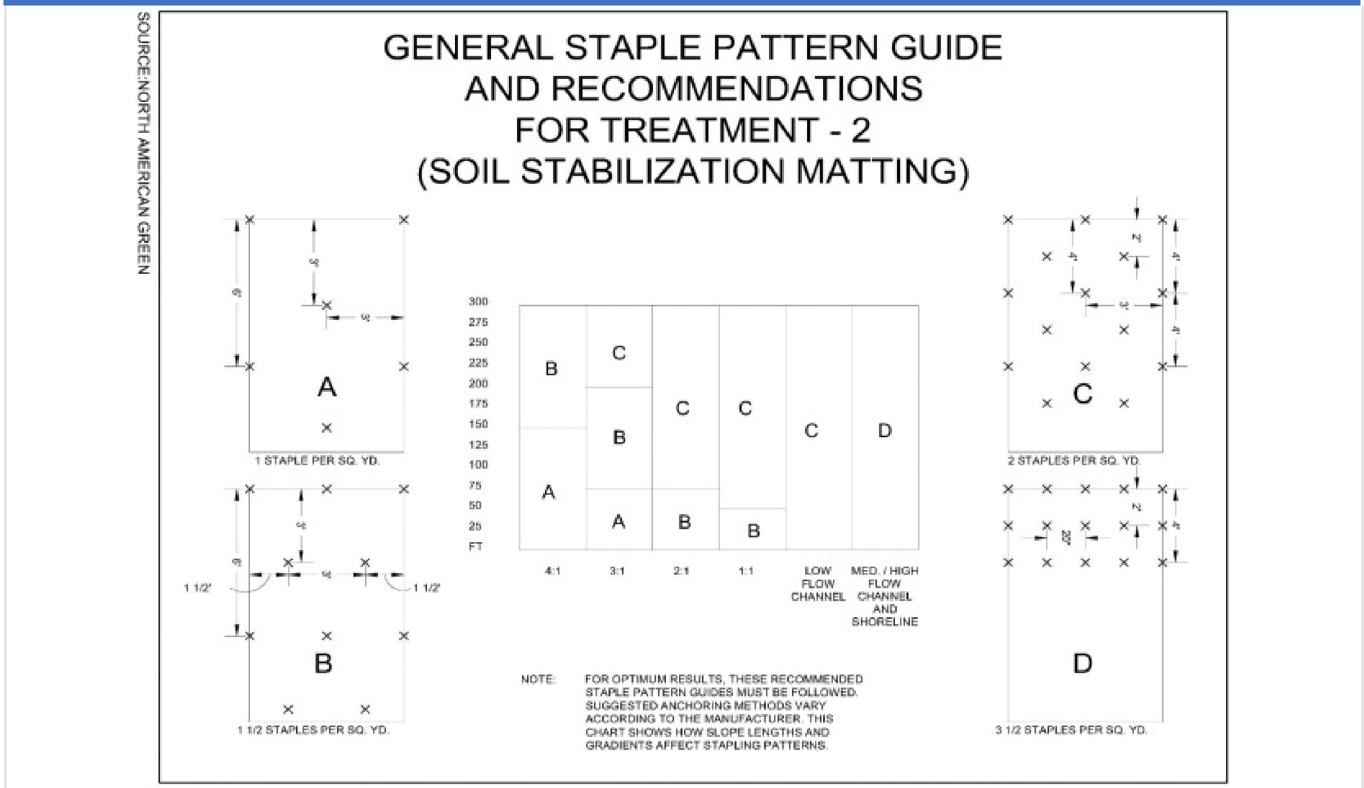


*Photo Credit: eastcoasterosion.com*


*Photo Credit: Michael D. DeVuono, PE*

## 8.0 References


East Coast Erosion Control. 2023. Erosion Control Products. Located at: www.eastcoasterosion.com/. Accessed 17 Apr. 2023.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

VDOT. 2023. Virginia Department of Transportation Drainage Manual. Revised Oct 30, 2023. Available online at: https://www.vdot.virginia.gov/doing-business/technical-guidance-and-support/technical-guidance-documents/drainage-manual/#d.en.46721


# C-SSM-06 Sodding

## 1.0 Definition

Sodding is permanent stabilization of areas by laying a continuous cover of grass sod over exposed soils (North Carolina Sediment Control Division et al. 2013).

– CAD C-SSM-06-1 Sodding

– CAD C-SSM-06-2 Sodded Waterways

## 2.0 Purpose and Applicability of Best Management Practice

Sodding is used to:

- Establish permanent turf immediately.
- Prevent erosion and damage from sediment and runoff by stabilizing the soil surface.
- Reduce the production of dust and mud associated with bare soil surfaces.
- Stabilize drainageways where concentrated overland flow will occur.
- Serve as a filtering device for sediments before achieving permanent stabilization.

Sodding should be practiced in areas that require immediate vegetative cover to stabilize the surface or where sodding is preferred to other means of grass establishment.

Locations particularly suited to stabilization with sod are:

- Waterways carrying intermittent flow;
- Areas around drop inlets or in grassed swales;
- Steep slopes (up to 2H:1V if not mowed, 3H:1V if mowed); and
- Residential or commercial lawns where quick use and/or aesthetics are factors.

## 3.0 Planning and Considerations

The successful establishment of quality turfgrass is difficult in Virginia. Extremes in temperature and moisture availability create severe stresses on both cool- and warm-season grasses. The selection of appropriate turf establishment methods requires a great deal of forethought.

A quality turf containing the recommended mixtures and species can be established with either seed or sod. Soil preparation for the two methods is the same. The advantages of properly installed sod include:

1. Immediate erosion and dust control;
2. An instant green surface with no dust or mud;
3. Nearly year-round establishment capability;
4. Less chance of failure than seed;
5. Freedom from weeds;
6. Rapid stabilization of surfaces for traffic areas, channel linings, or critical areas; and
7. The option of buying a quality-controlled product with predictable results.

It is initially more costly to install sod than to seed. However, this cost is justified where sod can perform better than seed in controlling erosion. In swales and waterways, where concentrated flow will occur, properly pegged sod is preferable to seed because there is no lag time between installation and the time at which the channel is protected by vegetation. Drop inlets that will be placed in grassed areas can be kept free of sediments, and the grade immediately around the inlet can be maintained by framing the inlet with sod strips. Sod can be laid during times of the year when seeded grass may fail, so long as there is adequate water available for irrigation in the early weeks. Cold temperatures are not favorable conditions for sodding. When correctly installed, sod can provide immediate permanent vegetative stabilization.

Ground preparation and proper maintenance are as important with sod as with seed. Sod is composed of living plants, and those plants must receive adequate care in order to stabilize a disturbed area. Irrigation is essential at all times of the year to install sod. Because sod is composed of living plants that must receive adequate care, final grading and soil preparation should be completed before sod is delivered. If left rolled or stacked, heat can build up inside the sod, causing severe damage and loss of costly plant material (North Carolina Sediment Control Division 2013).

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization shall be applied to denuded areas within seven days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within seven days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization shall be applied to areas that are to be left dormant for more than one year.

**MS-3: PERMANENT VEGETATION** – A permanent vegetative cover shall be established on denuded areas not otherwise permanently stabilized. Permanent vegetation shall not be considered established until a ground cover is achieved that is uniform, mature enough to survive, and will inhibit erosion.

9VAC25-75-560

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: Low**

## 5.0 Design Criteria

| Table C-SSM-06-1 Material Specifications | |
|---|---|
| **Design Criteria for Materials** | |
| Choosing Appropriate Types of Sod | The type of sod selected should be composed of plants adapted to both the site and the intended purpose. Species selection is primarily determined by region, availability, and intended use.<br><br>Availability varies across the state and from year to year. New varieties are continually being developed and tested. A complete and current listing of sod recommendations can be obtained from suppliers. Sod composed of a mixture of varieties may be preferred because of its broader range of adaptability (North Carolina Sediment Control Division et al. 2013). Use Table C-SSM-06-2 to select the type of sod best suited to your area. |
| Quality of Sod | • **VCIA Certified Sod**: If possible, sod used should be state-certified. Certified turfgrass sod is grown from certified seed inspected and certified by the Virginia Crop Improvement Association (VCIA) or the certifying agency in other states.<br>• **Non-VCIA Certified Sod:** High-quality sod is also available outside of the VCIA-certified sod program. High-quality sod will be free of serious disease, insect, or weeds. It will be dense, have good color, and hold together well.<br>• Sod should be machine-cut at a uniform soil thickness of 0.75 inch (±0.25 inch) at the time of cutting. This thickness should exclude shoot growth and thatch.<br>• Pieces of sod should be cut to the supplier's standard width and length, with a maximum allowable deviation in any dimension of 5%. Torn or uneven pads should not be accepted.<br>• Standard size sections of sod should be strong enough to support their own weight and retain their size and shape when suspended from a firm grasp on one end of the section. |

| Table C-SSM-06-2 Virginia Grasses for Sodding | |
|---|---|
| Types of Sod Available in Virginia and Recommended Uses | |
| Kentucky Bluegrass | Adapted to the Northern Piedmont and Mountain Regions. Individual varieties selected must make up not less than 10% or more than 35% of the total mixture by weight. All varieties must be certified. Selections can be made from Category I alone or various combinations of Categories I, II, and III as noted.<br>**Category I** – Recommended Kentucky bluegrass varieties<br>65% - 100% A-34, Abbey, Aspen, Asset, Baron, Blacksburg, Bristol, Cheri, Chateau, Classic, Coventry, Georgetown, Glade, Haga, Julia, Liberty, Loft's 1757, Merit, Midnight, Monopoly, Plush, Princeton 104, Rugby, Suffolk, Victa<br>**Category II** – Special use varieties. If used, must contain at least 65% Category I varieties<br><u>Shade Tolerant</u><br>10-35% Bristol, Columbia, Georgetown, Glade, Midnight<br><u>Low-Maintenance Tolerant</u><br>10-35% Bristol, Columbia, Georgetown, Glade, Midnight<br>**Category III** – Promising Kentucky bluegrass – Limited performance data or seed availability<br>10-35% Dawn, Estate, Freedom, Kelly |
| Tall Fescue | Adapted to the entire state.<br><u>Recommended tall fescue varieties</u><br>90-100%<br>Amigo, Apache, Bonanza, Chieftain, Finelawn 5GL, Mesa, Rebel II, Shenandoah, Tribute<br><u>Promising tall fescues</u><br>Certified Arriba, Austin, Avanti, Aztec, Cochise, Crossfire, Eldorado, Hubbard 87, Jaguar II, Maverick II, Monarch, Olympic II, Phoenix, Safari, Shortstop, Sundance, Taurus, Thoroughbred, Titan, Tradition, Vegas, Winchester, Wrangler<br>0-10%<br>Kentucky bluegrass: Baron, Cheri, Columbia, Monopoly, Nassau, Ram I, Victa |
| Bermudagrass | Tufcote is adapted to the Richmond-Danville-Newport News triangle. Midiron may be used east of Roanoke and south of Charlottesville. Tifgreen and Tifway may be used to the east and south of Richmond. Vamont may be used east of Roanoke and at lower elevations in southwestern Virginia.<br>Certified Midiron, Tifgreen[#], Tifway, Tifway II, Tufcote and Vamont |

| Table C-SSM-06-2 Virginia Grasses for Sodding | |
|---|---|
| **Types of Sod Available in Virginia and Recommended Uses** | |
| Zoysiagrass | This sod performs best in southeastern Virginia.<br>Meyer, Emerald# |

**Note**: Common Bermudagrass is not recommended for sod production.

# Only recommended in southeastern Virginia.

## 6.0 Construction Specifications

### 6.1 Soil Preparation

1. Before soil preparation, bring areas to be sodded to final grade in accordance with the approved plan.
2. Determine the exact requirements for lime and fertilizer using soil tests conducted by the State Laboratory at Virginia Polytechnic Institute and State University or a reputable commercial laboratory. Information on state soil tests is available from county or city agricultural extension agents.
3. Before laying sod, clear the soil surface of trash, debris, large roots, branches, stones, and clods more than 1 inch in length or diameter. Sod should not be applied to gravel or other non-soil surfaces.
4. Fill or level any irregularities in the soil surface resulting from topsoiling or other operations to prevent the formation of depressions or water pockets.
5. Areas to be topsoiled and topsoil used should fulfill the requirements of Topsoiling (C-SSM-02). No sod should be spread on soil that has been treated with soil sterilant or any other toxic herbicides until enough time has elapsed to permit dissipation of toxic materials.

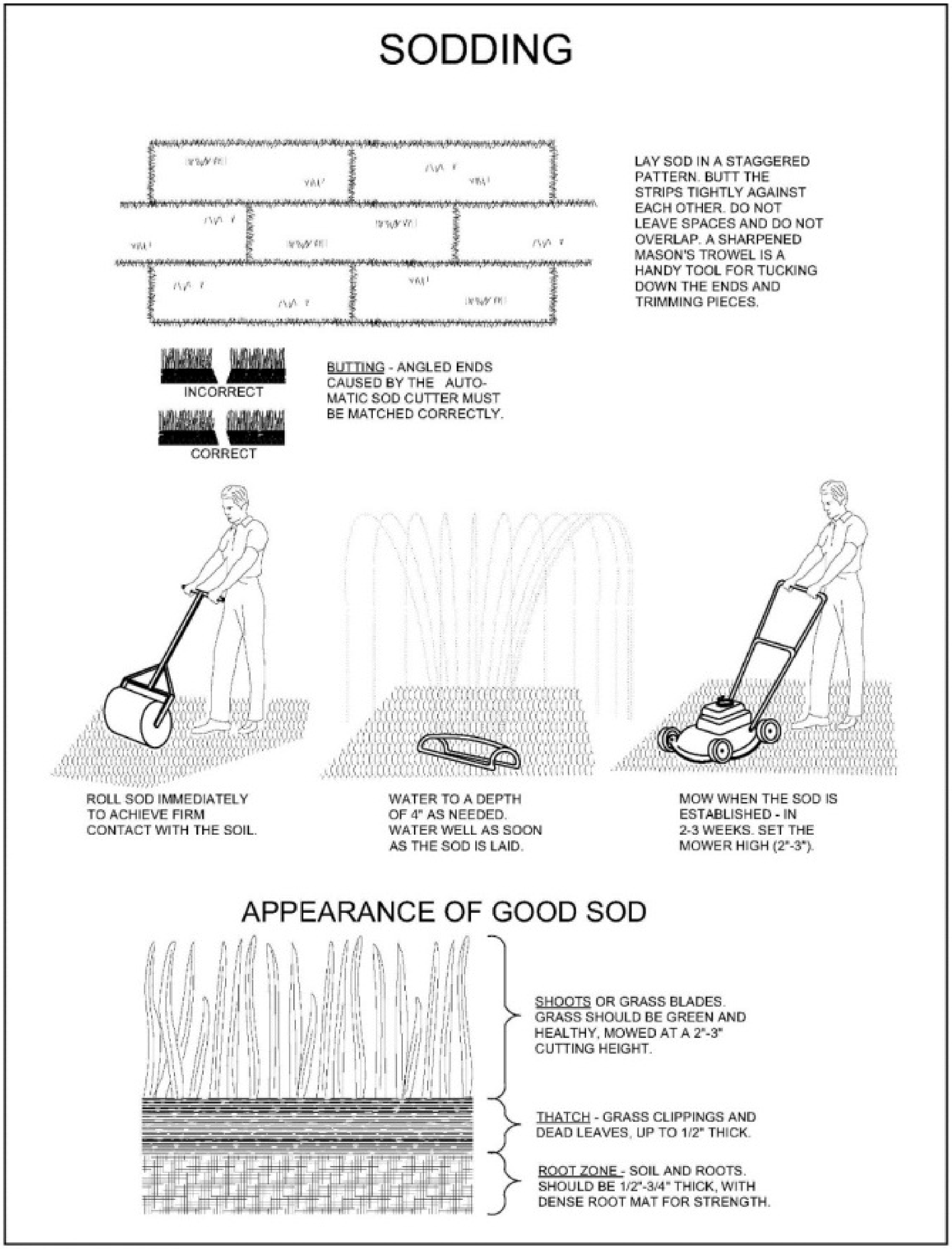
### 6.2 Sod Installation (See Table C-SSM-06-1)

Unclean and Poor Sod Installation

1. Frozen soil surfaces are not suitable for sodding. When presented with frozen soil or other unfavorable sodding conditions, the contractor should establish perimeter control measures (if not already installed) and delay final surface stabilization until thaw.
2. Sod should not be cut or laid in excessively wet or dry weather.
3. Sod should be harvested, delivered, and installed within 36 hours.
4. Moistening the sod after it is unrolled helps maintain its viability. Store it in the shade during installation (North Carolina Sediment Control Division et al. 2013).
5. Rake/till the soil surface to loosen and break the crust just before laying sod. During periods of high temperature, the soil should be lightly irrigated immediately before laying the sod to cool the soil and reduce root burning and dieback.
6. The first row of sod should be laid in a straight line, with subsequent rows placed parallel to and butting tightly against each other. Lateral joints should be staggered to promote more uniform growth and strength. Care should be exercised to ensure that sod is not stretched or overlapped and that all joints are butted tight to prevent voids, which would cause drying of the roots.
7. On slopes 3H:1V or greater, or where erosion may be a problem, sod should be laid with staggered joints and secured by stapling or other approved methods. Sod should be installed with the length perpendicular to the slope (on the contour).

8. As sodding of clearly defined areas is completed, sod should be rolled or tamped to provide firm contact between roots and soil.
9. Fill any spaces between sod match edges with topsoil.
10. After rolling, sod should be irrigated to a depth sufficient that the underside of the sod pad and the soil 4 inches below the sod are thoroughly wet.
11. Until a good root system develops, in the absence of adequate rainfall, watering should be performed as often as necessary to maintain moist soil to a depth of at least 4 inches.
12. The first mowing should not be attempted until the sod is firmly rooted, usually after 2 to 3 weeks. Not more than one third of the grass leaf should be removed in a single cutting.

***Figure C-SSM-06-1 Sodding***



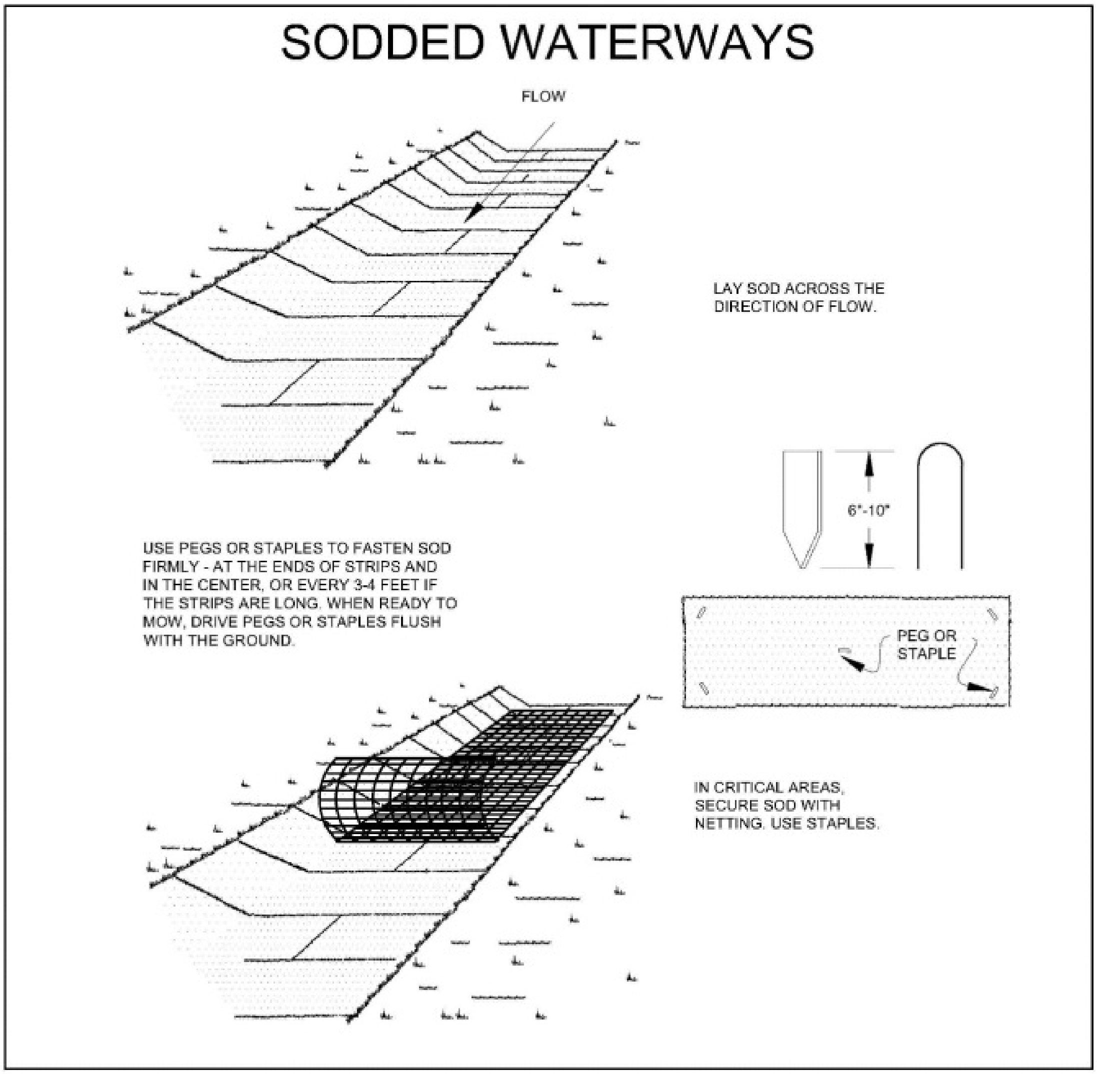

SOURCE: VA. DSWC

### 6.3 Sodded Waterways (See Figure C-SS-06-2)

1. Care should be taken to prepare the soil adequately in accordance with this specification. The sod type should consist of plant materials able to withstand the designed velocity; see Stormwater Conveyance Channels (C-ECM-09).

2. Sod strips in waterways should be laid perpendicular to the direction of flow. Care should be taken to butt ends of strips tightly.
3. After rolling or tamping, sod should be pegged or stapled to resist washout during establishment.
4. All other specifications for this practice should be adhered to when sodding a waterway.

***Figure C-SSM-06-2 Sodded Waterways***



SOURCE: VA. DSWC

## 7.0 Operations and Maintenance Considerations

1. During the 2- to 3-week establishment stage, sod should be watered as necessary to maintain adequate moisture in the root zone and prevent dormancy of sod.
2. No more than one third of the shoot (grass leaf) should be removed in any mowing. Grass height should be maintained between 2 and 3 inches unless otherwise specified.
3. After the first growing season, established sod will require fertilization and may require lime. Follow soil test recommendations when possible or apply maintenance levels as outlined in Table C-SSM-06-3.

| Table C-SSM-06-3 Sodding Maintenance |
| --- |
| **Maintenance Fertilization of Established Sod** |
| **Cool-Season Grasses** |
| 4 lbs. nitrogen per 1,000 $ft^2$/year |
| 1 lb. phosphorus per 1,000 $ft^2$/year |
| 2 lbs. potash per 1,000 $ft^2$/year |
| 75% of the total requirements should be applied between September 1 and December 31. The balance should be applied during the remainder of the year. |
| **Warm-Season Grasses** |
| Apply 4 to 5 lbs. nitrogen per 1,000 $ft^2$ per year (between May 1 and August 15). |
| Phosphorus and potash should only be applied according to soil test results. |
| Maintenance fertilization should use slow-release fertilizers, which reduce the number of applications per year and subsequently reduce adverse impacts on groundwater. |

## 8.0 References


North Carolina Sediment Control Division, North Carolina Department of Environment and Natural Resources, and North Carolina Agricultural Extension Service. 2013. Erosion and Sediment Control Planning and Design Manual. Available online at: https://www.deq.nc.gov/about/divisions/energy-mineral-and-land-resources/erosion-and-sediment-control/erosion-and-sediment-control-planning-and-design-manual.

Virginia Crop Improvement Association. Virginia Turfgrass Variety Recommendations. 1991.

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Specification 3.33. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.


# C-SSM-07 Bermudagrass and Zoysiagrass Establishment

## 1.0 Definition

Bermudagrass and Zoysiagrass establishment is the establishment of vegetative cover with hybrid Bermudagrass or Zoysiagrass by planting sprigs, stolons, or plugs of these types of grasses.

## 2.0 Purpose and Applicability of Best Management Practice

The purposes of Bermudagrass and Zoysiagrass establishment are as follow:

1. To reduce erosion and decrease sediment yield from disturbed areas;
2. To stabilize disturbed areas with a specific plant material suited to the site at a cost lower than would be incurred by installing sod; and
3. To establish vegetative cover more rapidly than would be possible using seed.

Conditions for which Bermudagrass and Zoysiagrass establishment applies:

1. Where hybrid Bermudagrass or Zoysiagrass is the desired plant material and establishment with sod is not preferred;

2. Droughty, sandy sites or situations in which high salt content is a problem. The grasses should not be used in shaded areas or on poorly drained sites; and
3. Where irrigation can be made available during establishment.

## 3.0 Planning and Considerations

Bermuda and Zoysia are warm-season, permanent grasses that are well-suited to erosion control, as the grasses have vigorous rhizomes and stolons (runners). There are two types of Bermudagrass grown in Virginia: common and hybrid. Whenever possible, the design engineer (in coordination with the contractor) should make all efforts possible to use Virginia native species of grass for all applicable erosion and sediment control measures.

| Table C-SSM-07-1 Grass Types | |
|---|---|
| Grass Types | |
| **Common Bermudagrass** | Produces seed and may be established with seed. However, it has the potential to become a weed problem because it spreads vigorously; it is also coarse and not suitable for fine turf. Common Bermudagrass has little cold tolerance and winterkills frequently. |
| **Hybrid Bermudagrasses and Zoysiagrass** | Established mainly by sodding, sprigging, or plugging. Recent developments in the turf industry have allowed hybrid Bermudagrass stands to establish from seed; however, the technology is relatively new. These grasses produce a fine, tight turf; do not spread as vigorously as common Bermudagrass; exhibit good cold tolerance; and can withstand many adverse conditions. For these reasons, hybrid Bermudagrass and Zoysiagrass are the warm-season permanent turf grasses of choice for Virginia. |
| **Sprigging** | A sprig is a small section of rhizome (underground stem) 3 to 5 inches long, with at least one node or joint. Leaves should be present at the nodes. Stolons (runners) are aboveground stems that spread by creeping on the soil surface. A mixture of sprigs and stolons is usually used in "sprigging." Sprigs may be planted by machine or hand. |
| **Plugging** | Plugs are small sections of sod pressed into precut holes in the soil so that top growth is flush to the surface and leaves are exposed. Plugs are usually planted by hand; however, plugging machines are also available. |

Notably, where speed is essential and cost is not an overriding constraint, sod should be used; see Sodding (BMP C-SSM-06).

Both Zoysia and Bermuda are particularly suited for use in grass-lined waterways. Depending on the soil type, an established stand can tolerate intermittent concentrated flows of water on slopes up to 10 percent. It is important to divert runoff from the waterway during the first 3 weeks of establishment to permit the grass to take root. If this cannot be accomplished, the center of the waterway should be sodded to prevent washout.

Bermudagrass is drought-tolerant, salt-tolerant, and tolerates floods of short duration. It prefers a pH range of 6.0 to 7.0 with high nitrogen fertilization during the growing season. Most Bermudagrasses are adapted to the warmer climates in Southeastern Virginia; however, turf research has developed several varieties that continue to perform very well in the western part of the state. Currently, all varieties of Bermudagrass will be dormant in winter and will turn brown at that time.

The Bermudagrass hybrids most frequently used in Virginia differ in appearance, cold tolerance, and suitability for turf use. The following varieties are suggested for rough- and fine-turf areas:

| Table C-SSM-07-2 Varieties for Rough-Turf Areas | |
|---|---|
| Varieties for Rough-Turf Areas | |
| **Midland** | A cold-hardy variety adapted in all areas of the state at medium to low elevations. Adapted for forage production, this is a tall-growing Bermuda (12 to 18 inches) and should be used in low- maintenance areas. |
| **Coastal** | Also a forage type for low-maintenance areas. Can be used as far west and north as Chatham, Charlotte Courthouse, and Warsaw, but will winterkill during severe winters at these locations. |

| Table C-SSM-07-3 Varieties for Fine-Turf Areas | |
|---|---|
| Varieties for Fine-Turf Areas | |
| **Midiron** | A fine-turf type. Has a good chance of surviving most winters as far west and north as Blacksburg and Charlottesville. |
| **Vamont** | Similar cold tolerance and texture to Midiron but far more aggressive. |
| **Tufcote** | A fine-turf type. Less cold hardy than Midiron. |
| **Tifway** | A fine-textured turf type. Good survival east and south of Richmond in most years. Not as cold- hardy as Tufcote. |

Research continues on successful establishment of Zoysiagrass in Virginia. It has been determined that Zoysia has limited potential for use in athletic field development due to recovery problems and slow establishment. Establishment is commonly achieved by sprigs or plugs and seeds pre-treated with potassium hydroxide. The following Zoysiagrass varieties are presently listed on the Virginia Crop Improvement Association (VCIA) recommended list:

| Table C-SSM-07-4 Zoysiagrass Types | |
|---|---|
| Zoysiagrass Types | |
| **Meyer** | A broad blade is prevalent. This variety is considered more winter-hardy than others. |
| **Emerald** | A fine-turf type. A much finer blade than that found on Meyer. This variety is also much less winter-hardy. |

## 4.0 Stormwater Performance Summary

**MS-1: STABILIZATION** – Permanent or temporary soil stabilization shall be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization shall be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization shall be applied in areas to be left dormant for more than 1 year.

9VAC25-875-560.

**Erosion Control Efficiency: High**

**Sediment Removal Efficiency: High**

## 5.0 Design Criteria

No formal design is required.

## 6.0 Construction Specifications

### 6.1 Soil Preparation

Procedures for preparing the soil are the same for sprigging and plugging.

1. Bermuda and Zoysia require soils that are well drained, loose enough for root penetration, have a pH range between 6.0 and 7.0, and are free of toxic amounts of materials harmful to plant growth. If any of these criteria cannot be met, topsoil should be applied in accordance with Topsoiling (BMP C-SSM-02).
2. Necessary erosion and sediment control practices will be installed before establishment of Bermudagrass. Final grading will be carried out according to the approved plan.
3. Surfaces will be roughened in accordance with Surface Roughening (BMP C-SSM-03).
4. The soil should be free of debris, trash, large roots, and weeds.

### 6.2 Lime and Fertilizer

Soil should be tested to determine the exact requirements for lime and fertilizer. Soil tests may be conducted by the State Laboratory at Virginia Polytechnic Institute and State University or a reputable commercial laboratory. Information on state soil tests is available from county or city agricultural extension agents.

Under difficult circumstances, where it is not possible to obtain a soil test, the following soil amendments will be made:

| Table C-SSM-07-5 Lime and Fertilizer Specifications | |
|---|---|
| Lime and Fertilizer Specifications | |
| **Pulverized agricultural limestone** | Apply 90 lbs./1,000 sq. ft. (2 tons/acre) of an agricultural grade of limestone. |
| **Fertilizer** | Apply **10-10-10** fertilizer at a rate of **500** lbs. /acre or **12** lbs. / 1,000 $ft^2$. Apply additional phosphorus and potassium 30 to 60 days later based on the results of a soil test. Apply an additional equivalent of 1 lb./1,000 $ft^2$ of nitrogen when the phosphorus and potassium are applied. Never apply more than 1 pound of water-soluble nitrogen per 1,000 $ft^2$ within a 30- day period and no more than 2 yearly lbs. N/1,000 $ft^2$. |

These amendments should be spread evenly over the area to be sprigged and incorporated into the top 3 to 6 inches of the soil by discing, harrowing, or other acceptable means. Any irregularities in the soil surface resulting from topsoiling or other operations should be filled or leveled to prevent the formation of water pockets.

Soil preparation, liming, and fertilizing should be completed before requesting delivery of sprigs or sod. This material is perishable and should not remain on a pallet or in crates longer than 36 hours from the time of digging. The presence of mildew or distinct yellowing of the leaves usually indicates damage to turf.

### 6.3 Sprigging and Plugging

#### 6.3.1 Sources

Sprigs can be purchased as sod and then shredded or can often be purchased by the bushel. For turf-type Bermudagrasses, certified or approved sod sources (bearing the label of the VCIA) should be used. Plugs may be cut from sod as needed or purchased pre-cut. Coastal and midland Bermudagrasses may be available through agricultural sources. Interested persons should contact the county or city agricultural extension agent or the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) district office for information on where these materials may be obtained. Sprigs should be 3 to 5 inches long, having several nodes (joints). Plugs should have a minimum diameter of 2 inches.

**Table C-SSM-07-6 Quantities of Material Needed**

| Quantities of Material Needed | |
|---|---|
| **Sprigging** | Eight to 12 bushels/1,000 $ft^2$ or 350 to 500 bushels/acre. One bushel of sprigs is approximately equal to 1 square yard ($yd^2$) of sod (with soil removed). |
| **Plugging** | Approximately 12 $yd^2$ of sod/1,000 $ft^2$, or 530 $yd^2$ of sod/acre. |

### 6.3.2 When to Plant

To establish quickly, many feel that Bermudagrass should not be in a dormant state (leaves should be green). However, research shows some success with dormant installations. Nonetheless, so that plants may develop adequate root structure before cold weather begins, they should be planted no later than midsummer. May 1 through July 15 is the optimum season for Bermudagrass establishment. Some cultivars may be established as late as mid-August in the southeastern part of the state.

### 6.3.3 How to Plant

**Table C-SSM-07-7 How to Plant**

| How to Plant | |
|---|---|
| **Sprigging** | Sprigs may be broadcast over the surface by hand, planted in rows by machine, or applied with a hydro-sprigger. Machines are available that will insert sprigs properly and firm the soil over them. When sprigs are broadcast or hydro-sprigged, the sprigs should be partially covered with soil by light discing or topdressing with good soil. Ideally, half of the sprig should be covered with soil, and half (including some leaves) should be exposed. Soil should be firmed over the sprigs using a cultipacker or by rolling or tamping. When planted in rows, sprigs should be placed no more than 12 inches apart in rows that are 12 to 18 inches apart. Closer spacing is recommended for slopes, waterways, and highly erodible soils. |
| **Plugging** | Plugs should be inserted in the soil surface so that leaf tips are above the surrounding soil and tamped firmly in place. Plugs should be placed in a grid pattern on 12- to 18-inch centers.<br><br>Closer spacing is recommended on critical areas. Plugs are usually placed by hand, but machines are available that can plug automatically. |

### 6.3.4 Ideal Conditions

The following are essential for good Bermudagrass or Zoysiagrass growth:

1. Adequate moisture – water immediately after planting, and water enough to keep soil moist to a depth of 4 inches during the first 4 weeks and as needed thereafter to sustain growth.
2. Sunlight – do not permit mulches, other plantings, or structures to shade new Bermudagrass stands.
3. Freedom from erosive forces – keep concentrated flows of water off new plantings for 2 weeks to 1 month.

#### 6.3.5 Weed Control

To become effectively established, Bermudagrass must not have to compete with weeds for sunlight, water, or space. Cultivating is impractical, as growing stolons may be injured.

Oxadiazon or equivalent, applied immediately following sprigging at a rate of 100 to 150 lbs./acre (depending on time of year), provides excellent control of most broadleaf and grassy weeds; use 2 to 3 lbs. of active ingredient/acre. For control of broadleaf weeds only, apply Dicamba (0.25 to 0.5 lb. active ingredient/acre) and 2,4-D (1 lb. active ingredient/acre). Use these herbicides when weeds are 2 to 3 inches tall, but not before grass is well-rooted.

## 7.0 Operations and Maintenance Considerations

Bermudagrass and Zoysiagrass sprigs and plugs can be expected to root in 5 to 10 days under optimum conditions. Full coverage of the soil by spreading plants can be obtained in 8 to 12 weeks with good growing conditions and proper maintenance.

Stands may be mowed when growth requires. Coastal and midland growths may be left un-mowed except for annual trimming to 6 inches. Turf-type Bermudagrasses may be cut at 1 to 1.5 inches.

For maintenance purposes, apply 1 lb. actual nitrogen/1,000 sq. ft. at 30- to 45-day intervals after initial installation until August 15. Nitrogen in fertilizer should be 50 percent or more water insoluble.

## 8.0 References


VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.


# C-SSM-08 Trees, Shrubs, Vines, and Ground Cover

## 1.0 Definition

Stabilizing disturbed areas by establishing vegetative cover with trees, shrubs, vines, or ground covers.

– CAD C-SSM-08-1 Benefits of Trees

– CAD C-SSM-08-3 Spacing Trees for Safety and Effective Landscaping

– CAD C-SSM-08-4 Planting Bare-Rooted Seedlings

– CAD C-SSM-08-5 Planting Balled-&-Burlapped & Container-Grown Trees

## 2.0 Purpose and Applicability of Best Management Practice

1. To stabilize the soil where vegetation other than turf, grass, or legumes are preferred;
2. To provide food and shelter for wildlife where wildlife habitat is desirable; and
3. To provide windbreaks or screens.

This practice applies:

1. Where turf establishment is difficult;

2. On steep or rocky slopes, where mowing is not feasible;
3. Where native, non-invasive ornamental plants are desirable for landscaping purposes; and
4. Where woody plants are desirable for soil conservation or to establish wildlife habitat.
5. Conserved Open Spaces and Riparian Buffer areas that will be reforested.

## 3.0 Planning and Considerations

Disturbed areas may be stabilized in many ways. Most frequently, a permanent vegetative cover of grasses and legumes is established. There are locations, however, where other types of vegetation are preferred. The following situations are examples of ways in which trees, shrubs, vines, and ground covers may be used.

1. On cut and fill slopes adjacent to paved areas of shopping centers, schools, industrial parks, or other non-residential projects, woody plants, and ground cover can be used to control erosion. They will also help to control foot traffic, will not require as much maintenance as mowed lawns, and will be more attractive than un-mowed grass cover.
2. In residential areas, slopes too steep to be mowed and areas along rights-of-ways or easements may be planted in trees, shrubs, vines, or ground covers to reduce maintenance needs and improve appearance.
3. The interested homeowner or small project developer may use ornamental plants in problem areas – shade, steep slopes, inaccessible places – as alternatives to grass. Ground cover may be used to reduce or eliminate the need for mowing grass on level areas.

Many different plants may be used for these purposes. The plants discussed in this practice are those known to be adapted to Virginia, easy to grow, and commonly available from commercial nurseries. Many plants suitable for use are not mentioned here. Information on such plants can be obtained from local nurseries, landscape architects, and extension agents. To the extent that site planners and designers specify native species for a site, they should refer to the DCR invasive species list as part of the process of selecting plant materials. (See DCR 2022). This serves two purposes: to avoid use of invasive species to the extent possible; and to ensure plant selection is based on the most current information available.

Because many types of woody plants and ground cover are discussed, and site conditions and land use vary so widely, it is not practical to give specific requirements for the establishment of every plant mentioned. However, this practice does provide a set of general guidelines for growing trees, shrubs, vines, and ground covers on disturbed land.

### 3.1 Zones of Adaptation

Zones of climatic adaptation of landscape plants are referred to as "Plant Hardiness Zones." Table C-SSM-08-5 provides a detailed list of trees suitable for planting in Virginia. The table provides information such as: appropriate zone, mature tree height, pH range, and other factors that should be considered by a landscape architect or similar person choosing a tree for a specific site.

## 4.0 Stormwater Performance Summary

### 4.1 MS-1: STABILIZATION

Permanent or temporary soil stabilization will be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization will be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization will be applied to areas that are to be left dormant for more than 1 year.

**MS-5: EARTHEN STRUCTURE STABILIZATION -** Stabilization measures shall be applied to earthen structures such as dams, dikes and diversions immediately after installation.

**MS-7: CUT AND FILL SLOPES -** Cut and fill slopes shall be designed and constructed in a manner that will minimize erosion. Slopes that are found to be eroding excessively within one year of permanent stabilization shall be provided with additional slope stabilizing measures until the problem is corrected.

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: N/A**

## 5.0 Design Criteria

Consider the spacing of trees from structures and properly provide necessary coverage through mature canopy size. Refer to BMP Figure C-SSM-08-3 for spacing of trees away from homes/structures.

### 5.1Critical Root Zone, Structural Root Zone, and Diameter at Breast Height

Determine the critical root zone (CRZ) of a tree when planting near aboveground or underground structures. The CRZ, along with the structural root zone (SRZ), are essential for the health and stability of the tree. Determine the root zone radius from the diameter at breast height (DBH) of the tree using the following equations.

DBH = Tree trunk diameter at 4.5 feet above grade

CRZ = Radius protection of 1.5 feet per inch of DBH

SRZ = Radius protection of 0.5 foot per inch of DBH

Planting a tree in areas with underground utilities and structures within the CRZ may cause health issues for the tree and cause root growth within the utility or structure.

For further information on proper planting and protection, refer to Tree Preservation and Protection (BMP C-SSM-01).

## 6.0 Construction Specifications

As noted in MS-1, disturbed soil between trees and shrubs must be mulched or planted with permanent vegetation to prevent erosion. Refer to the other vegetative practices to select a method for stabilizing these areas.

| Table C-SSM-08-1 Construction Specifications for Trees | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Selecting the Right Trees | In urban and suburban environments, trees may be exposed to insufficient light and water; high-velocity winds; salt from highway ice control programs; heat radiation from roads and buildings; pollutants from cars and industry; root amputation for water, sewer, and gas lines; topping to prevent interference with power lines; and covering of roots by pavement. New species and varieties of trees are being selected for the modern environment based on their ability to withstand those difficult conditions and still provide the benefits associated with having trees (see Table C-SSM-08-1).<br><br>While trees are being selected, evaluate the site where the trees will be planted. Consider the previous use of the land; adverse soil conditions such as poor drainage or acidity; exposure to wind; temperature extremes; locations of utilities, paved areas, and security lighting; and traffic patterns. |
| Tree Characteristics | Selection of trees depends on the desired function of the tree, whether it be shade, privacy screening, noise screening, appearance, enhancement of wildlife habitat, or a combination of these. Consider the following characteristics of the tree when making choices. Some of these characteristics are identified in Table C-SSM-08-6 for trees commonly grown in Virginia.<br><br>Hardiness – "Hardiness zones" are based on average annual minimum temperature. Trees are adapted to the various zones in Virginia (Figure C-SSM-10-2).<br>Mature Height and Spread – Consider the eventual height of a tree in relation to planting location to avoid future problems with power lines and buildings (see Figure C-SSM-08-3).<br>Growth Rate – Some trees attain mature height at an early age, while others take many years. If "instant shade" is desired, rapid growth is needed. Slow-growing trees are usually less brittle and live longer.<br><br>Root System – Some trees obstruct underground pipelines with fibrous roots.<br>Cleanliness – Maintenance problems can be avoided by not selecting trees that drop seedpods, flowers, or twigs in large amounts.<br><br>Moisture and Fertility Requirements – If good soil and drainage are not available, select trees tolerant of poor growing conditions.<br><br>Ornamental Effects – If a tree is unusually attractive, some other shortcomings may be overlooked.<br><br>Evergreen vs. Deciduous – Evergreens retain their leaves throughout the year and are useful for privacy screens and noise screens. Deciduous trees drop their leaves in fall and are preferable for shade trees. |

| Table C-SSM-08-1 Construction Specifications for Trees | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Sources of Trees and How They May Be Bought | Container-grown trees can be planted at any time of year in which the ground is not frozen if sufficient water is provided. Purchase and plant trees when quite young (less than 2-inch diameter trunk) to avoid dealing with root-bound plants.<br>Balled and burlapped trees are usually larger; check to be sure that soil around roots was dug with the tree and not just packed around bare roots. Keep the soil around the roots moist.<br>Tree seedlings are available commercially and are also sold in lots of 50, 100, 500, or 1,000 by the state forest nurseries. State nurseries are located in New Kent, Augusta, and Cumberland. About 20 species of trees are usually available during the height of the planting season at nominal prices. These seedlings are not to be used as ornamentals or for fine landscaping and are intended to be used as conservation plantings for erosion control, reforestation, and development of wildlife habitat. Because 50 seedlings will only plant an area of 3,000 square feet, small areas can be planted if the purpose is conservation. More information about this program is available through the Virginia Department of Forestry (https://dof.virginia.gov). |
| Planting Bare-Rooted Tree Seedlings | Handle trees to be planted as bare-rooted seedlings only while dormant in spring or after leaf fall in autumn. Refer to Figure C-SSM-08-4 for planting instructions. When stabilizing the disturbed area between tree plantings, do not use grasses or legumes, which will overshade the new seedlings. Where possible, a circle of mulch around seedlings will help them to compete successfully with herbaceous plants. |
| Transplanting Trees | Transplanting trees refers to planting balled, burlapped, and container-grown trees. Hardwoods should be transplanted in the late fall following their leaf drop. There is a single exception to this rule: “Willow” oaks seem to survive at a greater rate when the trees are transplanted in the spring. Evergreens may be transplanted beginning with the fall cooldown period (normally September) and may continue into spring before elongation of the new growth. |
| Tree Preparation | Proper digging of a tree includes the conservation of as much of the root system as possible, particularly the fine roots. Ensure the soil adhering to the roots is damp when tree is dug and kept moist until planting. Ensure the soil (or “root”) ball is 12 inches in diameter for each inch of diameter of the trunk. Carefully excavate the tree, wrap the soil ball in burlap, and tie with rope. Use of a mechanical tree spade is also acceptable.<br>Bind the branches of evergreens or any trees to be transported for a distance with soft rope to prevent damage. |
| Site Preparation | Rather than digging a planting hole, rototill or loosen with a shovel a shallow area the depth (height) of the soil ball and the width of five times the diameter of the soil ball or container. Organic material can be added to the loosened soil as long as the new material is used uniformly throughout the area. Heavy or poorly drained soils are not good growth media for trees. When it is necessary to transplant trees into such soils, take extra care. Properly installed drain tile will improve drainage; refer to Subsurface Drain (BMP C-ECM-09). |

| Table C-SSM-08-1 Construction Specifications for Trees | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Setting the Tree | At the center of the prepared area, dig a shallow hole to set the tree. Ensure the hole allows the root ball to sit on solid ground rather than loose soil. Ensure the upper surface of the root ball is level with the existing soil. The tree may be set just a few inches higher than its former location, especially if soil is poorly drained. Do not set the tree lower than it was previously positioned. Ensure the soil to be placed around the root ball is moist but not wet (see Figure C-SSM-08-5).<br><br>Set the tree in the hole and remove the rope that holds the burlap. Cut away the burlap or, at a minimum, push it back into the bottom of the excavation. Do not break the soil of the root ball. Fill the hole with soil halfway and tamp firmly around the root ball. Add water to settle the soil and eliminate air pockets. When the water has drained off, fill the hole the remainder of the way and tamp as before.<br><br>Use extra soil to form a shallow basin around the tree, somewhat smaller than the diameter of the root ball (Figure C-SSM-08-5). The shallow basin will be for holding water when the tree is irrigated. Level the ground and eliminate these basins when winter sets in, as ice forming in the basin might injure the trunk. |
| Supporting the Tree | Newly planted trees may need artificial support, especially in windy areas, to prevent excessive swaying. Use stakes or guy wires as shown on Figure C-SSM-08-4. Use rubber hose and allow some slack in the guy to encourage strengthening of the plant. Remove all supports within 6 months of planting. |
| Watering | Thoroughly water the soil around the tree after the tree is set in place. When the soil becomes dry, water the tree deeply but not too often. Mulching around the base of the tree is helpful in preventing roots from drying out. |
| Maintenance of Tree Plantings | Like all plants, trees require water and fertilizer to grow. Water young trees with an inch of water each week for the first 2 years after planting. When rain does not supply this need, water the tree deeply but not any more frequently than once per week.<br><br>Fertilize transplanted trees 1 year or so after planting. Simple methods of fertilizing are adequate (application of the fertilizer to the surface of the soil or mulch around the tree). The best material for small trees is well-rotted stable manure. Add the manure as a 2-inch layer of mulch around the tree annually.<br><br>If chemical fertilizers are used, a formulation such as 10-8-6 or 10-6-4 (NPK) is preferred. Use about 2 pounds per inch of trunk diameter measured 4 feet from the ground. Thus, if the trunk diameter at 4 feet was 5 inches, then 10 pounds of fertilizer would be applied. For evergreens, use one half the recommended amount of chemical fertilizer or use only organic fertilizers such as cottonseed meal, bone meal, or manure. Fertilizer must contact the roots to benefit the tree. A straightforward way to ensure contact is to make holes in the tree's root area with a punch bar, crowbar, or augur. Ensure holes are 18 inches deep, spaced about 2 feet apart, and located around the drip line of the tree. Distribute the necessary fertilizer evenly into these holes and close the holes with the heel of the shoe or by filling with topsoil or peat moss. Fertilize trees in late fall or in early spring before leaves emerge. |

| Table C-SSM-08-2 Construction Specifications for Shrubs | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Shrubs | Much of what has been said about trees also applies to shrubs. A shrub is a solid, woody plant less than 15 feet tall, usually with several trunks rising from a common base. Some shrubs have the appearance of small trees, and some lie close to the ground. |
| Selecting Appropriate Shrubs | There are so many ornamental shrubs available that advising on the choice of any one is difficult. Table C-SSM-08-6 provides the basic characteristics of shrubs commonly available at commercial nurseries in Virginia, which are recommended for conservation planting because they enrich or hold the soil or encourage development of wildlife habitat. Information on other shrubs is available from nurserymen and extension agents. |
| Planting Shrubs | Follow the general procedure for tree planting when planting shrubs. |

| Table C-SSM-08-3 Construction Specifications for Vines and Ground Cover | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Vine and Ground Cover Selection | Low-growing plants that sprawl, trail, spread, or send out runners come in many leaf types, colors, and growth habits. Some are suitable only as part of a maintained landscape, and some can stabilize large areas with little care.<br>In addition to stabilizing disturbed soil, vines and ground covers can perform the following functions:<br>• Maintain cover in areas where turf will not thrive.<br>• Provide attractive cover that does not need mowing.<br>• Help to define traffic areas and control pedestrian movement. People are more likely to walk on the grass than to walk on a prickly planting of juniper.<br>Table C-SSM-08-7 provides the characteristics of some commonly used vines and ground covers suitable for Virginia. Information on others is available from nurserymen. |
| Site Preparation | Ground covers are plants that naturally grow close together, causing severe competition for space, nutrients, and water. Well prepared soil for ground covers is essential. A well-drained soil high in organic matter is best.<br>If the area to be planted is so large that adding amendments to the soil as a whole would be impractical, organic matter may be added only to each planting hole. Lime and fertilize the ground according to soil test or add 5 pounds of 10-10-10 (N-P-K) and 10 pounds of ground agricultural limestone to every 100 square feet. Incorporate into the top 4 to 6 inches of the soil. Add organic matter up to one third of the total soil volume, either over the whole area (a layer 2 inches deep mixed into the top 6 inches) or in each planting hole if the area is large. |
| Planting | Most ground covers perform best when planted in the spring. Container-grown plants can be planted throughout the growing season if adequate water is provided. Plant vines and ground cover such as pachysandra on 1-foot centers; large plants, such as juniper, can be spaced on 3-foot centers.<br>Most ground covers are planted from container-grown nursery stock. Transplant to the prepared seedbed using a small trowel or a spade. Make a hole large enough to accommodate the roots and soil. Backfill and firm the soil around the plant, water immediately, and keep well-watered until established. |

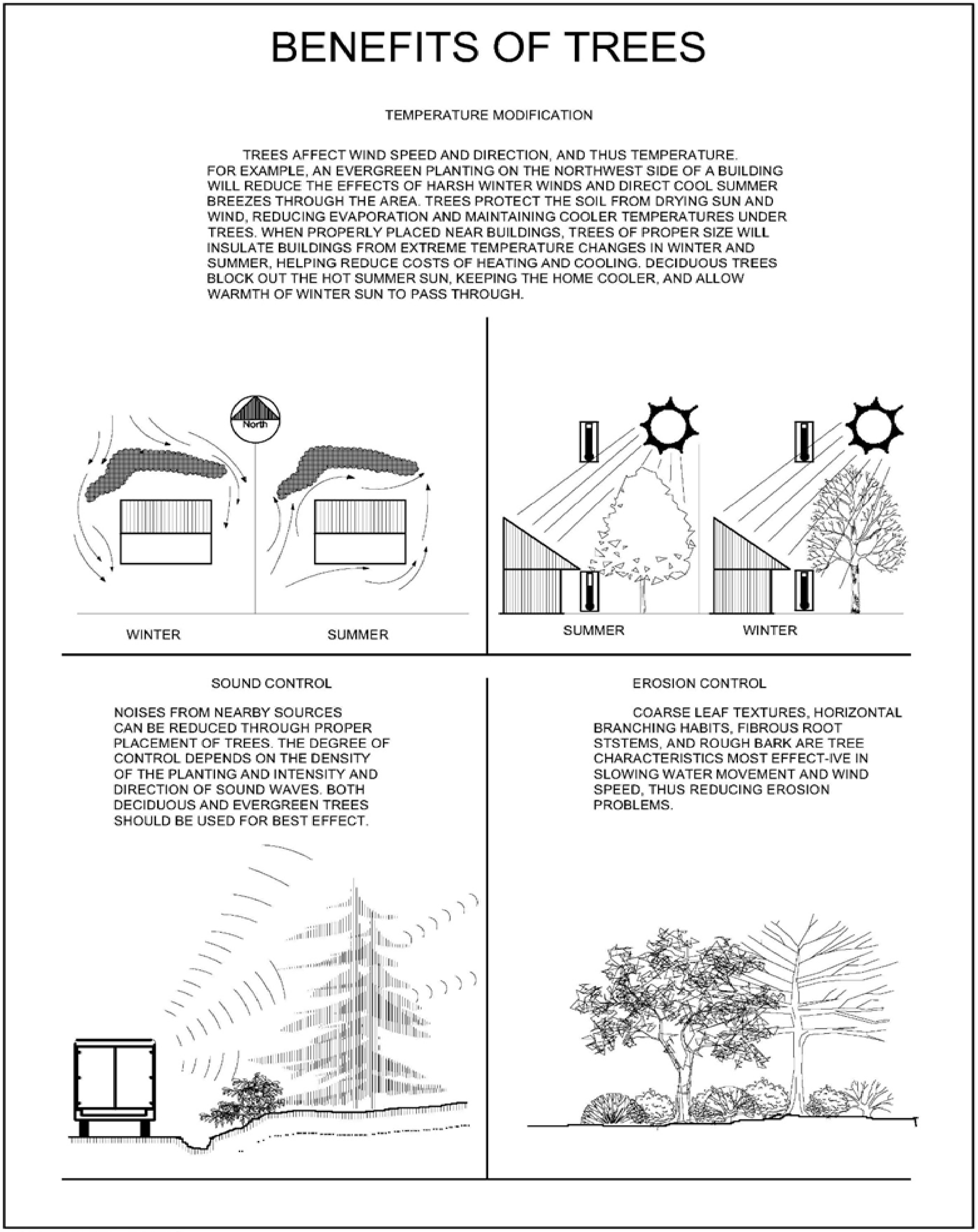
| Table C-SSM-08-4 Construction Specifications for Mulching | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Mulching | Plant the soil between trees and shrubs with cover vegetation or install mulch. When establishing ground covers, it is not desirable to plant species that will compete strongly with the ground cover or will make maintenance difficult. To prevent erosion and reduce weed problems, install a thick, durable mulch such as shredded bark or wood chips. Pre-emergent herbicides may be necessary where weeding is not practical.<br><br>On slopes where erosion may be a problem, Soil Stabilization Blankets and Matting (BMP C-SSM-05) may be installed before planting, and plants can be tucked into the soil through slits in the net. Install such plants in a staggered pattern to minimize erosion. |

## 7.0 Operations and Maintenance Considerations

Proper pruning, watering, and application of fertilizer every 3 or 4 years will keep shrubs healthy. Maintain the mulch cover or turf cover surrounding the shrubs. A heavy layer of mulch reduces weeds and retains moisture.

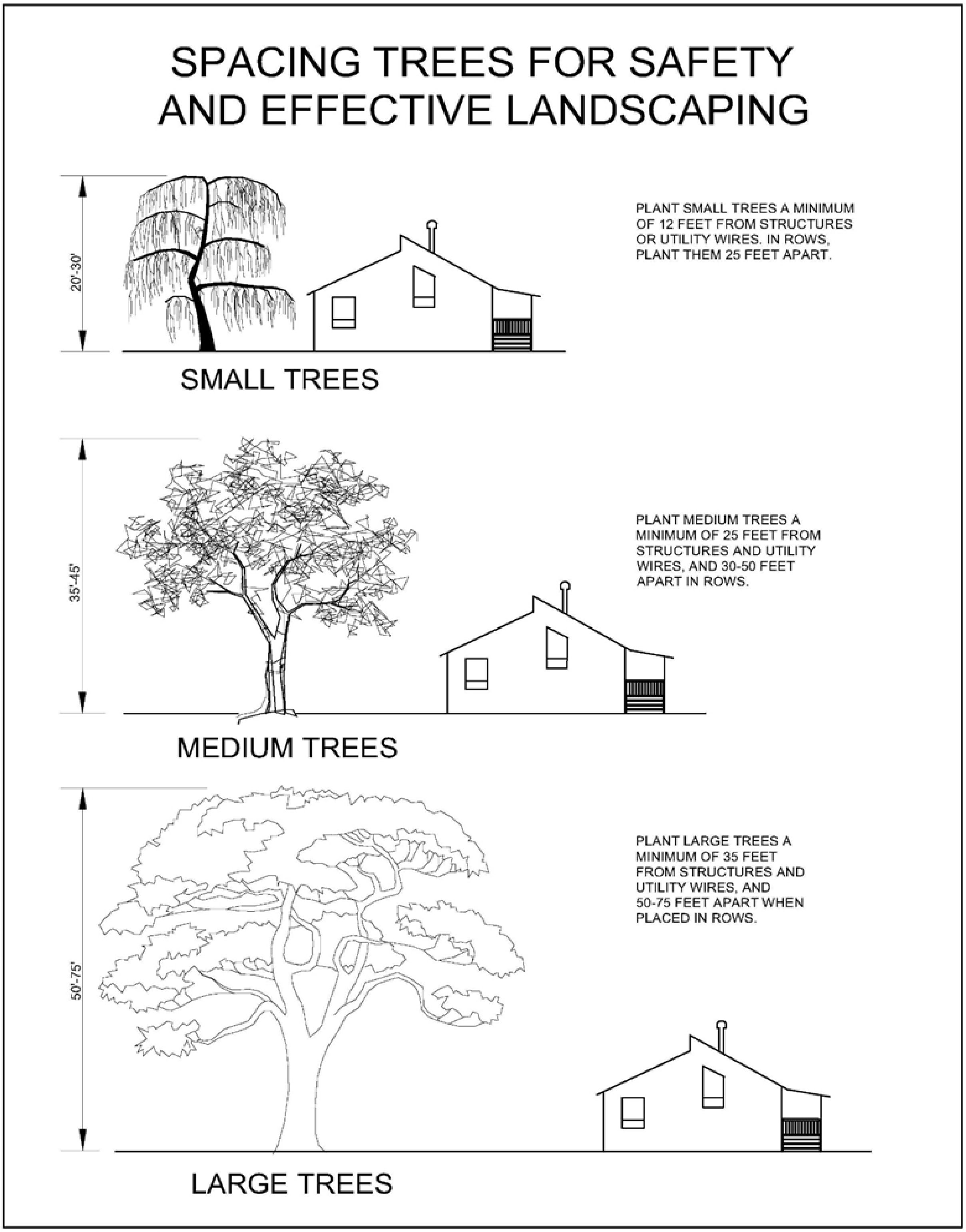
Trim old growth as needed to improve the appearance of ground covers. Most covers need annual trimming to promote growth. Maintain mulch cover with additions of mulch where needed. Fertilize as described above every 3 to 4 years.

***Figure C-SSM-08-1 Benefits of Trees***



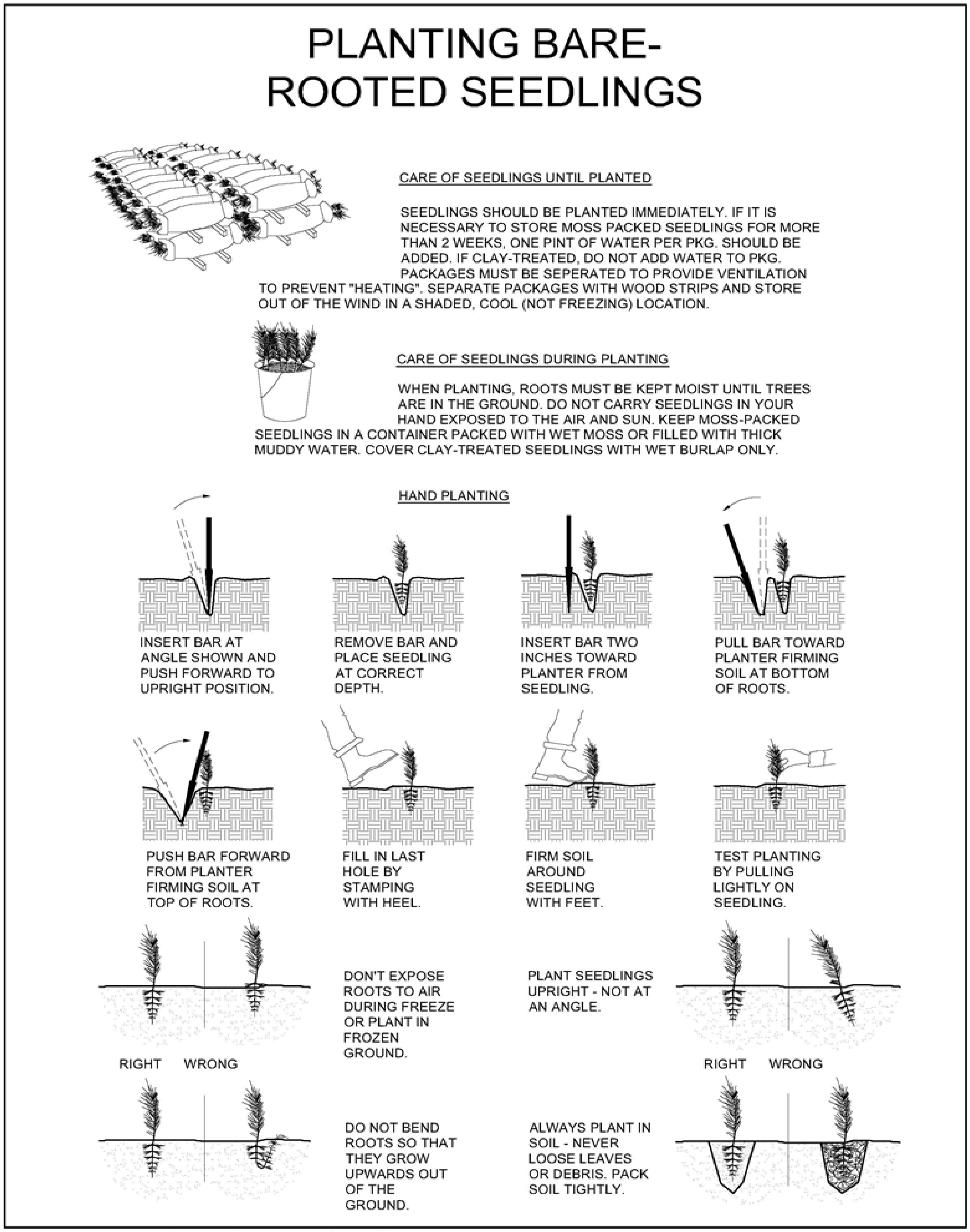

SOURCE: VA. DSWC

## *Figure C-SSM-08-3 Spacing Trees for Safe and Effective Landscaping*



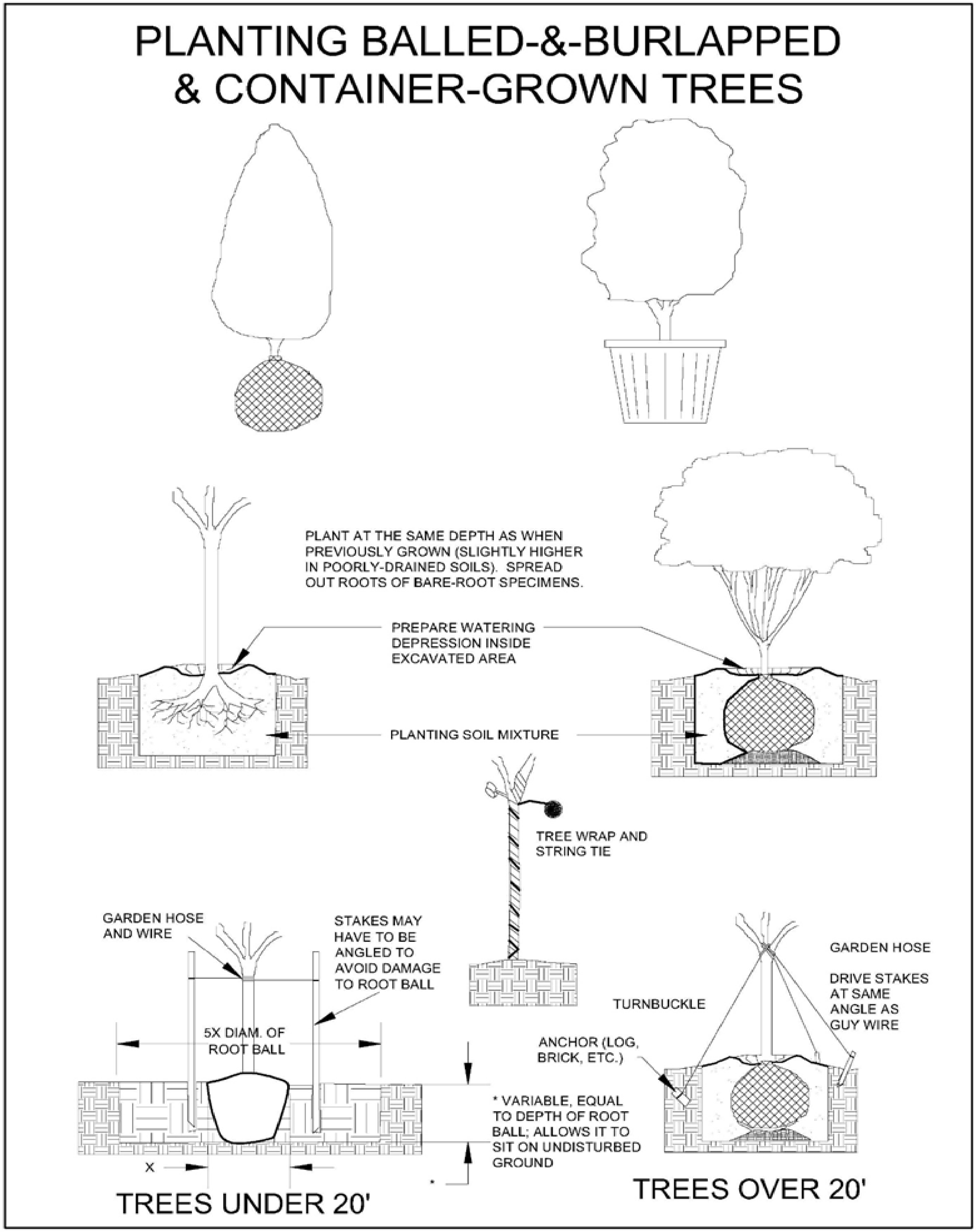

SOURCE: VA. DSWC

**Figure C-SSM-08-4 Planting Bare Rooted Seedlings**




SOURCE: Va. DEPARTMENT OF FORESTRY

## *Figure C-SSM-08-5 Planting Bald/Burlapped/Container-Grown Trees*




SOURCE: VA. DEPTARTMENT OF FORESTRY

| Table C-SSM-08-5 Tree Selection | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trees for Landscaping, Erosion Control and Soil Conservation in Virginia** | | | | | | | | | | | | | | | | |
| Common Name (Botanical Name) | Leaf Type | Zones in VA | Mature Size (ft) | Soil Moisture Preferred | | | pH Range | Uses | | | Disease/Pest Resistance | Salt Tolerance | Pollution Tolerance | | | Remarks (Suggested Varieties) |
| | | | | Dry | Med | Wet | | Lawns | Street | Seashore | | | $O^3$ | $SO^2$ | F | |
| Beech (*Fagus grandifolia*) | D | 6 7 8 | 70 - 120 | | X | | 6.5 - 7.5 | X | | | fair | S | - | S | - | Long-lived. Has edible nuts. Needs lots of space. |
| Birch, River (*Betula nigra)* | D | 7 8 | 50 - 80 | X | X | | 4.0 - 5.0 | X | | | good | - | S | S | - | Prefers deep, moist soils such as streambanks. Graceful form. |
| Cedar, Eastern Red (*Juniperus virginiana*) | E | 7 8 | 20 - 50 | X | X | X | 6.0 - 6.5 | X | | | good | - | T | T | T | Long-lived. |
| Chickasaw Plum, (*Prunus angustifolia*) | D | 6 7 8 | 15 - 20 | | X | X | 6.0 - 8.0 | X | X | | good | - | - | - | T | Mildly poisonous if seeds are ground up and consumed. [1] |
| Crabapple (*Malus angustifolia*) | D | 6 7 8 | 15 - 20 | | X | | 4.5 - 8.0 | X | X | X | fair | I | S | S | - | White or pink flowers, edible fruit. [2] |
| Cucumber Tree (*Magnolia acuminata*) | D | 6 7 | 50 - 80 | X | X | | 4.0 - 7.0 | X | | | good | - | - | - | - | Grows rapidly. Green flowers; scarlet fruits in fall. |
| Dogwood, Flowering (*Comus florida*) | D | 6 7 8 | 30 - 40 | | X | | 5.0 - 6.5 | X | X | | good | - | T | T | T | Ideal street tree. White or pink flowers. Has poor drought resistance. |
| Ginkgo (*Ginkgo biloba*) | D | 6 7 8 | to 100 | | X | X | 6.0 - 6.5 | X | X | | very good | - | T | T | T | Plant male trees only - fruit has an offensive odor. |
| Hackberry, Dwarf (*Celtis tenuifolia*) | D | 6 7 8 | 80 - 90 | X | X | X | 6.5 - 7.5 | X | X | | good | T | T | T | - | Tolerant of parking lot conditions. [3] |
| Hawthorne (*Crataegus spp.*) | D | 6 7 8 | 15 - 25 | | X | | 6.0 - 7.5 | X | X | | good | I | - | S | - | Thorny, Washington, and Lavalle types are good ornamentals. Tolerant of parking lot conditions. |
| Holly (*Ilex opaca*) | E | 6 7 8 | 40 - 50 | X | X | X | 4.0 - 6. | X | X | X | good | I | - | T | T | Slow-growing. Shade-tolerant. Red berries appear only on female trees. |
| Hornbeam (Ironwood) (*Carpinus caroliniana*) | D | 6 7 8 | 10 - 30 | X | X | X | 6.5 - 7.5 | X | X | | good | S | - | T | I | Prefers low, moist bottomlands. Will tolerate shade. Yeddo hornbeam and European hornbeam preferred. |
| Locust, Black (*Robinia pseudo-acacia*) | D | 6 7 8 | 30 - 50 | | X | X | 5.0 - 7.5 | | | X | fair | I | S | T | I | Suited only to erosion control on seriously disturbed areas. |
| Maple, Striped (*Acer pensylvanicum*) | D | 6 7 | 15 - 35 | | X | X | 4.5 - 6.0 | X | | | fair | - | T | T | I | Prefers well drained, deep, fertile soil. May be used in clipped hedges. [4] |
| Maple, Red (*Acer rubrum*) | D | 6 7 8 | 50 - 80 | X | X | | 4.5 - 7.5 | X | X | X | good | S | T | T | - | Grows rapidly when young. Good tree for suburbs, but not city (Gerling, Tilford). |
| Maple, Sugar (*Acer saccharum*) | D | 6 | 50 - 70 | X | X | X | 6.5 - 7.5 | X | | | fair | I | T | T | - | Outstanding fall foliage. Suburban, but not city, tree. Slow-growing and shapely (Green Mountain). |

| Table C-SSM-08-5 Tree Selection | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trees for Landscaping, Erosion Control and Soil Conservation in Virginia** | | | | | | | | | | | | | | | | |
| Common Name (Botanical Name) | Leaf Type | Zones in VA | Mature Size (ft) | Soil Moisture Preferred | | | pH Range | Uses | | | Disease/Pest Resistance | Salt Tolerance | Pollution Tolerance | | | Remarks (Suggested Varieties) |
| | | | | Dry | Med | Wet | | Lawns | Street | Seashore | | | $O^3$ | $SO^2$ | F | |
| Oak, Chestnut (*Quercus montana*) | D | 6 | 60 - 70 | | X | X | 6.0 - 6.5 | X | | | good | T | S | TI | | Grows well in sandy, gravelly, or rocky soils. |
| Oak, Pin (*Quercus palustris*) | D | 6 7 8 | 60 - 80 | X | X | X | 5.5 - 6.5 | X | X | | good | T | S | S | I | Most easily transplanted of the oaks (Sovereign). |
| Oak, Red, Northern (*Quercus rubra borealis*) | D | 6 7 8 | 70 - 90 | | X | X | 4.5 - 6.0 | X | X | X | good | T | T | T | I | Most rapid-growing oak. Needs plenty of space. |
| Oak, Red, Southern (*Quercus falcata*) | D | 7 8 | 70 - 80 | | | X | 4.0 - 5.0 | | | X | good | - | T | T | I | Characteristically an upland tree. Prefers dry, infertile soils. |
| Oak, Scarlet (*Quercus coccinea*) | D | 6 7 | 60 - 80 | | | X | 6.0 - 6.5 | X | X | | good | T | S | TI | | Prefers sandy or gravelly soils. |
| Oak, White (*Quercus alba*) | D | 6 7 8 | 60 - 80 | | X | X | 6.5 - 7.5 | X | X | X | fair | T | S | S | I | Long-lived, stately tree. Grows slowly. |
| Oak, Willow (*Quercus phellos*) | D | 7 8 | 40 - 50 | X | X | X | 4.0 - 6.5 | X | | | good | T | S | TI | | Long-lived, but grows quickly. Easy to transplant. Prefers fertile, acid soil. |
| Pine, Table Mountain (*Pinus pungens*) | E | 6 7 | 20 - 40 | X | X | | 4.0 - 8.0 | X | | | good | T | - | - | - | Very hardy and rapid growing. Will tolerate shallow soil and drought. [5] |
| Pine, Loblolly (*Pinus taeda*) | E | 7 8 | 90 - 120 | X | X | | 4.0 - 6.5 | | | X | good | - | - | S | S | Use only for conservation plantings, not as an ornamental. |
| Pine, Shortleaf (*Pinus echinate Miller*) | E | 6 7 | 80 - 100 | | X | 8 X | 4.0 - 6.5 | X | | | good | - | - | - | - | Attractive shape. Prefers well drained, sandy or gravelly soil. |
| Pine, Marsh (*Pinus serotina*) | E | 6 7 | 60 - 90 | | | X | 4.0 - 6.5 | X | | | fair | I | S | S | S | Resistant to fire but susceptible to wind damage due to their height. [6] |
| Pine, Virginia (*Pinus virginiana*) | E | 7 8 | 30 - 40 | | X | X | 4.0 - 6.5 | X | | | good | I | S | S | - | Tolerates poor soil. Use for conservation plantings, not as an ornamental. Shallow-rooted. |
| Pine, White (*Pinus strobus*) | E | 6 | 80 - 100 | | | X | 4.0 - 6.5 | X | | | fair | S | S | S | S | Very attractive, rapid-growing tree. Prefers deep, sandy loam. Subject to white pine blister rust. |
| Sycamore, American (*Platanus occidentalis*) | D | 6 7 8 | 75 - 100 | | X | X | 4.5 - 9.5 | X | X | X | good | - | - | T | T | Good city tree.[7] |
| Eastern Redcedar (*Juniperus virginiana*) | E | 6 7 8 | 30-40 | X | X | X | 4.0- 9.0 | X | X | X | fair | T | - | - | - | Mildly toxic if consumed. [10] |
| Tupelo (Blackgum) (*Nyssa sylvatica*) | D | 6 7 8 | 60 - 80 | X | X | | 5.0 - 6.0 | X | | X | good | I | T | T | - | Scarlet fall foliage. Suitable for swampy areas. |

| Table C-SSM-08-5 Tree Selection | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trees for Landscaping, Erosion Control and Soil Conservation in Virginia | | | | | | | | | | | | | | | | | |
| Common Name (Botanical Name) | Leaf Type | Zones in VA | Mature Size (ft) | Soil Moisture Preferred | | | pH Range | Uses | | | Disease/Pest Resistance | Salt Tolerance | Pollution Tolerance | | | Remarks (Suggested Varieties) |
| | | | | Dry | Med | Wet | | Lawns | Street | Seashore | | | $O^3$ | $SO^2$ | F | |

**Notes:**

For hardiness zones in Virginia, see Figure C-SSM-08-2.

Leaf Type: “E” = Evergreen; “D” = Deciduous.

Pollution Tolerance: “S” = Sensitive, will show physical damage; “T” = Tolerant; “I” = Intermediate, damage depends on growing conditions; “-” = No information at this time.

| Table C-SSM-08-6 Shrub Selection | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shrubs for Vegetating Disturbed Areas | | | | | | | | | | | | |
| Common Name (Botanical Name) | Leaf Type | Drainage Tolerance | | | | | Shade Tolerance | pH Range | Mature Height (ft) | Flowers | Fruit | Uses |
| | | Droughty | Well-Drained | Moderately Well-Drained | Somewhat Poorly Drained | Poorly Drained | | | | | | |
| Arrowwood Vibrurnum (*Viburnum denatum*) | D | | X | X | X | | fair | 4.5 - 8.0 | 5 - 10 | white clusters | navy berries | Hedges and borders. Winter food for birds and wildlife. [8] |
| California Privet (*Ligustrum ovalifolium*) | E | | X | X | | | fair | 6.0 - 7.0 | 12 - 18 | -- | -- | Hedges and windbreaks. Grows rapidly. Do not use in Mountain Region. |
| Bayberry (*Myrica pennsylvanica*) | E | X | X | X | | | poor | 5.0 - 6.0 | 6 - 8 | -- | waxy, gray berries | Revegetating sand dunes; ornamental for droughty areas; fixes nitrogen in soil. |
| Beach Plum (*Prunus maritima*) | D | X | X | X | | | fair | 6.0 - 8.0 | 7 | white | edible, purple plum-like fruits | Revegetating sand dunes/ droughty areas. Fruit used for jelly and baking, also favored by wildlife. |
| Bristly Locust (*Robinia hispida*) | D | X | X | X | | | poor | 5.0 - 7.5 | 10 | pink | Bristly pods | Steep slopes, Resistant to drought. Spreads by sprouting from roots. [9] |
| Elderberry (*Sambucus canadensis*) | D | | X | X | X | X | fair | 6.0 - 7.5 | 12 | white | edible purple berries | Provides food for birds and deer. Fruit in 4 to 5 yrs. |
| Ground Juniper (*Juniperus communis var. depressa*) | E | | X | X | X | | good | 5.0 - 6.0 | 3 - 4 | -- | -- | Used as ground cover or ornamental. Set plants 2 feet apart for cover in 2 to 3 years. [11] |
| American Yew (*Taxus canadensis*) | E | | X | X | X | | good | 6.0 - 7.0 | – 3 - 5 | -- | red berries | Used in riparian buffers and along steep slopes. [12] |
| Virginia Rose (*Rosa virginiana*) | D | | X | X | | | poor | 4.5 - 8.0 | 4 - 6 | yellow, pink | red hips in 1-2 yrs. | Stabilizing sand dunes and landscaping. Food and cover for songbirds and rabbits. Sprawling growth habit, but not aggressive. [13] |
| Sweet Fern (*Comptonia peregrina*) | D | X | X | | | | poor | 5.0 - 6.0 | 2 - 4 | -- | -- | Pleasantly scented. Fixes nitrogen. Spreads by underground stems. Stabilizes droughty areas. Do not use in Coastal Plain. |
| Red Honeysuckle (*Lonicera dioica*) | D | | X | X | X | | good | 6.0 - 8.0 | 3 - 6 | red | Orange or burgundy berries | Woody, twining vine that is found in moist areas as well as sandy or rocky ground. [14] |

| Table C-SSM-08-6 Shrub Selection | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Shrubs for Vegetating Disturbed Areas** | | | | | | | | | | | | |
| Common Name (Botanical Name) | Leaf Type | Drainage Tolerance | | | | | Shade Tolerance | pH Range | Mature Height (ft) | Flowers | Fruit | Uses |
| | | Droughty | Well-Drained | Moderately Well-Drained | Somewhat Poorly Drained | Poorly Drained | | | | | | |
| Winterberry (*Ilex verticillata*) | D | | X | X | X | X | fair | 5.0 - 6.0 | 10 | -- | red berries in 3-4 years | Ornamental screens. Winter food for songbirds. |

**Notes:**

E = Evergreen

D = Deciduous

* = Where no comment is made, fruit or flowers are inconspicuous.

| Table C-SSM-08-7 Ground Cover and Vine Selection | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ground Covers and Vines for Erosion Control** | | | | | | | | | | |
| Common Name (Botanical Name) | Leaf Type | Drainage Tolerance | | | | | Shade Tolerance | pH Range | Flowers | Characteristics |
| | | Droughty | Well-Drained | Moderately Well-Drained | Somewhat Poorly Drained | Poorly Drained | | | | |
| Bearberry (*Arctostaphylos uva-ursi*) | E | X | X | | | | good | 4.5 - 6.0 | --* | Trailing shrub. Low-fertility sandy areas, dunes. Set plants 18 in. apart for cover in 2 to 4 years. |
| Blazing Star (*Liatris spicata*) | D | X | X | X | X | X | poor | 4.0 - 8.0 | purple, pink, or white, stacked in a cylindrical shape | Narrow leaves up to a foot long. Can be planted up to 3' apart. Highly attractive to pollinators.[15] |
| Smooth Purple Coneflower (*Echinacea laevigata*) | D | | X | X | X | | fair | 6.0 - 9.5 | pink or purple with large centers | Pest and disease resistant. Used by bees for nectar and birds in the winter if seed heads are left intact. [16] |
| Lily-Of-The-Valley (*Convallaria pseudomajalis*) | E | X | X | X | X | | good | 4.5 - 6.0 | fragrant white bells on short stalks | Highly toxic to humans if consumed. [20] |
| Sea Oats *(Uniola paniculata)* | E | X | X | X | | | poor | 4.5 - 9.5 | -- | Slow-growing and long-lived plant with deep taproots and lateral rhizomes that work to hold soil in place. [19] |
| Thimbleweed (*Anemone virginiana*) | D | | X | X | X | | excellent | 4.5- 8.0 | Small yellow or white flowers | Sap may cause skin irritation. Highly resistant to pests and diseases. [18] |
| Virginia Creeper (*Parthenocissus quinquefolia*) | D | X | X | | | | fair | 5.0 - 7.5 | --* | Ground cover for dunes and other dry areas; will climb trees. Attractive crimson foliage in fall. Berries eaten by songbirds. Set plants 18 in. apart for cover in 1-2 years. |
| Virginia Heartleaf *(Asarum virginicum)* | E | | X | X | | | excellent | 4.0- 6.0 | -- | Low growing plant spreads via a creeping rhizome. [17] |

**Notes:**

E = Evergreen

D = Deciduous

* = Where no comment is made, fruit or flowers are inconspicuous.

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[2] https://plants.ces.ncsu.edu/plants/malus-angustifolia/

[3] https://plants.ces.ncsu.edu/plants/celtis-tenuifolia/

[4] https://plants.ces.ncsu.edu/plants/acer-pensylvanicum/

[5] https://plants.ces.ncsu.edu/plants/pinus-pungens/

[6] https://plants.ces.ncsu.edu/plants/pinus-serotina/

[7] https://plants.ces.ncsu.edu/plants/platanus-occidentalis/

[8] https://plants.ces.ncsu.edu/plants/viburnum-dentatum/

[9] https://plants.ces.ncsu.edu/plants/robinia-hispida/

[10] https://plants.ces.ncsu.edu/plants/juniperus-virginiana/

[11] https://plants.ces.ncsu.edu/plants/juniperus-communis-var-depressa/

[12] https://plants.ces.ncsu.edu/plants/taxus-canadensis/

[13] https://plants.ces.ncsu.edu/plants/rosa-virginiana/

[14] https://plants.ces.ncsu.edu/plants/lonicera-dioica/

[15] https://plants.ces.ncsu.edu/plants/liatris-spicata/

[16] https://plants.ces.ncsu.edu/plants/echinacea-laevigata/

[17] https://plants.ces.ncsu.edu/plants/asarum-virginicum/

[18] https://plants.ces.ncsu.edu/plants/anemone-virginiana/

[19] https://plants.ces.ncsu.edu/plants/uniola-paniculata/

[20] https://plants.ces.ncsu.edu/plants/convallaria-pseudomajalis/

# C-SSM-09 Temporary Seeding

## 1.0 Definition

The establishment of a temporary vegetative cover on disturbed areas by seeding with appropriate rapidly growing annual plants.

## 2.0 Purpose and Applicability of Best Management Practice

1. To reduce erosion and sedimentation by stabilizing disturbed areas that will not be brought to final grade for a period of more than 14 days.
2. To reduce damage from sediment and runoff to downstream or offsite areas, and to protect bare soils exposed during construction until permanent vegetation or other erosion control measures can be established.

Conditions Where Practice Applies:

This best management practice (BMP) applies where exposed soil surfaces are not to be fine-graded for periods longer than 14 days. Such areas include bare areas, soil stockpiles, dikes, dams, sides of sediment basins, temporary road banks, non-vegetated cuts and fills, and diversions (see MS #1 and MS #2).

Apply a permanent vegetative cover to areas that will be left dormant for a period of more than 1 year.

## 3.0 Planning and Considerations

Sheet erosion, caused by the impact of rain on bare soil, is the source of most fine particles in sediment. To reduce this sediment load in runoff, protection of the soil surface is necessary. The most efficient and economical means of controlling sheet and rill erosion is to establish vegetative cover with at least 75 percent living vegetative cover with a maximum contiguous bare area of less than 500 square feet. Annual plants that sprout rapidly and survive for only one growing season are suitable for establishing initial or temporary vegetative cover. Temporary seeding is encouraged when possible to aid in controlling sediment losses and sheet flow from construction sites and other partially disturbed and non-vegetated areas.

Temporary seeding is essential to preserve the integrity of earthen structures used to control sediment such as dikes, diversions, and the banks and dams of sediment basins. Temporary seeding also prevents costly maintenance operations on other erosion control systems. For example, sediment basin cleanouts will be reduced if the drainage area of the basin is seeded where active grading and construction are not taking place. Perimeter dikes will be more effective if not choked with sediment.

Proper seedbed preparation and the use of quality seed are important in this practice, as with permanent seeding. Failure to carefully follow sound agronomic practices, such as beginning with well-conditioned soil and on a well-prepared seedbed, will often result in an inadequate stand of vegetation that provides little or no erosion control.

Temporary seeding provides protection for no more than 1 year, during which time permanent stabilization is initiated. Multiple temporary seeding efforts may be necessary for extended durations (> 6 months) that involve both cool and warm seasons.

## 4.0 Stormwater Performance Summary

### 4.1 MS-1: Stabilization

Permanent or temporary soil stabilization will be applied to bare soil within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization will be applied within 7 days to bare soil areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization will be applied to areas to be left dormant for more than 1 year.

**4.2 MS-2: Stockpiles, Waste, and Borrow Areas**

During construction of the project, soil stockpiles and borrow areas will be stabilized or protected with sediment trapping measures. The applicant is responsible for the temporary protection and permanent stabilization of all soil stockpiles onsite as well as borrow areas and soil intentionally transported from the project site.

**Sediment Removal Efficiency: N/A**

**Erosion Control Efficiency: High**

## 5.0 Design Criteria

No formal design criteria.

## 6.0 Construction Specifications

Prior to seeding, complete grading and install necessary erosion control practices such as dikes, waterways, and basins.

**Table C-SSM-09-1 Construction Specifications for Temporary Seeding**

| Activity | Notes on Proper Performance |
|---|---|
| Plant Selection | Select plants appropriate to the season and site conditions from Table C-SSM-09-3 and Table C-SSM-09-4. Note that Table C-SSM-09-3 presents plants that can be used without extensive evaluation of site conditions; Table C-SSM-09-4 presents more in- depth information on the plant materials. |
| Seedbed Preparation | To control erosion on bare soil surfaces, plants must be able to germinate and grow. Good seedbed preparation is essential to successful plant establishment. A good seedbed is loose and uniform, with at least 35 percent soil-sized particles (<2mm). Where hydroseeding methods are used, the surface may be left with a more irregular surface of large clods and stones. Minimize steep slopes because steep slopes challenge seedbed preparation and increase the erosion hazard. |
| Liming | Determine if lime is necessary for temporary seeding. In most soils, it may take several months for a pH adjustments to fully occur following the application of lime. Therefore, it may be difficult to justify the cost of liming a temporary site, especially when the soil will later be moved and regraded. Table C-SSM-09-2 may be used to determine the actual need along with suggested application rates if the soil pH is known.<br><br>If the pH of the soil is not known, an application of ground agricultural limestone at the rate of 1 to 1.5 tons per acre on coarse-textured soils and 2 to 3 tons per acre on fine- textured soils is usually sufficient.<br><br>Apply limestone uniformly and incorporate into the top 4 to 6 inches of soil. Soils with a pH of 6 or higher need not be limed. However, any soil with a pH of 5.5 should receive lime application. All liming materials should be Virginia Department of Agriculture and Consumer Services (VDACS) certified agricultural limestone or other approved liming products based on their calcium carbonate equivalent. |

| Table C-SSM-09-1 Construction Specifications for Temporary Seeding | |
|---|---|
| **Activity** | **Notes on Proper Performance** |
| Fertilizer | Apply fertilizer at a rate of 600 pounds per acre (14 pounds per 1,000 square feet) using 10-20-10 fertilizer or equivalent nutrients. Incorporate lime and fertilizer into the top 4 to 6 inches of the soil if possible. If a hydraulic seeder is used, do not mix seed and fertilizer more than 30 minutes before application. |
| Surface Roughening | If the area has been recently loosened or disturbed, no further roughening is required. When the area is compacted, crusted, or hardened, loosen the soil surface by discing, raking, harrowing, or other acceptable means according to Surface Roughening (BMP C-SSM-03). |
| Tracking | Tracking with bulldozer cleats is most effective on sandy soils. This practice often causes undue compaction of the soil surface, especially in clayey soils, and does not aid plant growth as effectively as other methods of surface roughening. |
| Seeding | Evenly apply seed with a broadcast seeder, drill, cultipacker seeder, or hydroseeder. Plant small grains no more than 1.5 inches deep. Plant small seeds, such as Kentucky Bluegrass, no more than 0.25 inch deep. Plant other grasses and legumes between 0.25 inch to 0.5 inch deep. |
| Mulching | Mulch seedings made in fall for winter cover and during hot and dry summer months according to Mulching (BMP C-SSM-11) except those of hydro-mulch (fiber mulch), which are not considered adequate (>70% vegetative cover) for mid-winter or mid- summer seedings. Use straw mulch during these periods.<br>Temporary seedings made under favorable soil and site conditions during optimum spring and fall seeding dates may not require mulch. |
| Reseeding | Areas that fail to establish vegetative cover adequate to prevent rill erosion will be reseeded as soon as such areas are identified. Do not mow. Protect from traffic as much as possible. |

| Table C-SSM-09-2 Liming | |
|---|---|
| **Liming Requirements for Temporary Sites** | |
| **pH Test** | **Recommended Application of Agricultural Limestone** |
| below 4.2 | 3 tons per acre |
| 4.2 to 5.2 | 2 tons per acre |
| 5.2 to 6 | 1 ton per acre |
| Source: Va. DSWC | |

| Table C-SSM-09-3 Plant Material for Temporary Seeding | | |
|---|---|---|
| Acceptable Temporary Seeding Plant Materials "Quick Reference for all Regions" | | |
| **Planting Dates** | **Species** | **Rate (pounds per acre)** |
| Sept. 1 – Feb. 15 | 50/50 Mix of annual ryegrass (*Lolium multi-florum*) & cereal (winter) rye (*Secale cereale*) | 50 – 100 |
| Feb. 16 – Apr. 30* | Annual ryegrass (*Lolium multi-florum*) | 60 – 100 |
| May 1* – Aug. 31 | German millet (*Setaria italica*) | 50 |

* The shift date for annual rye to German millet should be April 15 for the Piedmont and Coastal Plain, rather than May 1.

| Table C-SSM-09-4 Temporary Seeding Applications | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Temporary Seeding Plant Materials, Seeding Rates, and Dates | | | | | | | | | |
| **Species** | **Seeding Rate** | | **North**[a] | | | **South**[b] | | | **Plant Characteristics** |
| | **lbs./ acre** | **lbs./ 1,000 ft²** | **3/1 - 4/30** | **5/1 - 8/15** | **8/15 - 11/1** | **2/15 - 4/30** | **5/1 - 9/1** | **9/1 - 11/15** | |
| Oats (*Avena sativa*) | 50 – 100 | 2.0 | X | - | -- | X | - | - | Use spring varieties (e.g., Noble). |
| Rye[d] (*Secale cereale*) | 50 – 110 | 2.5 | X | - | X | X | - | X | Use for late fall seedings, winter cover. Tolerates cold and low moisture. |
| German millet (*Setaria italica*) | 50 | 1.0 | - | X* | - | - | X* | - | Warm-season annual. Dies at first frost. May be added to summer mixes. |
| Annual ryegrass[c] (*Lolium multi-florum*) | 60 | 1.5 | X* | - | X | X* | - | X | May be added in mixes. Will mow out of most stands. |
| Korean Lespedeza[c] (*Lespedeza stipulacea*) | 25 | 1.5 | X | X | - | X | X | - | Warm-season annual legume. Tolerates acid soils. May only be used in a mix with another grass (e.g., annual or cereal rye); it is not suitable as a pure seeding for this purpose. |

| Table C-SSM-09-4 Temporary Seeding Applications |
|---|
| Temporary Seeding Plant Materials, Seeding Rates, and Dates |

a. Northern Piedmont and Mountain regions. See Figure C-ENV-01-1 and Figure C-ENV-01-2.

b. Southern Piedmont and Coastal Plain.

c. May be used as a cover crop with spring seeding.

d. May be used as a cover crop with fall seeding.

Xe. May not be planted between these dates.

-f May be planted between these dates.

*** The shift date for annual rye to German millet should be April 15 for the Piedmont and Coastal Plain, rather than May 1.**

## 7.0 Operations and Maintenance Considerations

Inspect seeded areas every 7 calendar days and within 24 hours after each rainfall event that produces 0.5 inch or more of precipitation. Reseed any bare areas > 500 square feet.

Cover seeded area with straw or mulch to moderate soil moisture and temperature during the initial germination period.

Supply temporary seeding with adequate moisture. Supply water as needed, especially in abnormally hot or dry weather or on adverse sites. Control water application rates to prevent runoff.

## 8.0 References


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# C-SSM-10 Permanent Seeding

## 1.0 Definition

Permanent seeding is the establishment of perennial vegetative cover on disturbed areas by planting seed.

## 2.0 Purpose and Applicability of Best Management Practice

The purposes of permanent seeding are:

1. To reduce erosion and decrease sediment yield from disturbed areas;
2. To permanently stabilize disturbed areas in a manner that is economical, adaptable to site conditions, and allows selection of the most appropriate plant materials;

3. To improve wildlife habitat; and
4. To enhance natural beauty.

Permanent seeding applies in:

1. Disturbed areas where permanent, long-lived vegetative cover is needed to stabilize the soil; and
2. Rough-graded areas that will not be brought to final grade for 1 year or more.

## 3.0 Planning and Considerations

Vegetation controls erosion by reducing the velocity and volume of overland flow and protecting the bare soil surface from raindrop impact.

Areas that must be stabilized after the land has been disturbed require vegetative cover. The most common and economical means of establishing this cover is by seeding grasses and legumes. Permanent vegetative covers must meet the requirements of Minimum Standard #3.

Advantages of seeding over other means of establishing plants include the small initial establishment cost, the wide variety of grasses and legumes available, low labor requirement, and ease of establishment in difficult areas.

Disadvantages include the potential for erosion during establishment, a need to reseed areas that fail to establish, limited periods during the year suitable for seeding, the potential need for weed control during establishment, and a need for water and appropriate climatic conditions during germination.

There are so many variables in plant growth that an ideal outcome cannot be guaranteed. Much can be done in the planning stages to increase the chances for successful seeding. Selection of the right plant materials for the site, good seedbed preparation, and conscientious maintenance are important.

An establishment and persistence of 75 percent or more living overall perennial vegetation of the intended species mix and a maximum contiguous bare area of < 500 square feet is required to effectively limit sheet and rill erosion and permanently stabilize the soil surface.

| Table C-SSM-10-1 Design Considerations for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Proper Design** |
| Selecting Plant Materials | The factors affecting plant growth are climate, soils, and topography. In Virginia, there are three major physiographic regions that reflect changes in soil and topography. When selecting appropriate plant materials, the characteristics of the physiographic region in which the project is located should be considered (see Figure C-SSM-10-1). |
| Physiographic Regions | Coastal Plain: Soils on the Coastal Plain are deeply weathered, stratified deposits of sand and clay that are generally acidic and low in plant nutrients. The sandy soils are hot and droughty in summer. This region receives more rain and is warmer than the other regions of the state. The land is fairly level, and many areas are poorly drained. Warm-season grasses traditionally perform well in these areas.<br><br>Piedmont: Soil characteristics on the Piedmont Plateau vary widely. These soils tend to be shallow with clayey subsoils. Piedmont soils are usually low in pH and P unless in active agricultural production and are often highly eroded to expose red/yellow highly acidic clayey subsoil materials. Soils derived from mica schist are highly erodible. Topography is rolling and hilly. The southern Piedmont has much the same climate as the Coastal Plain and is often referred to as the “transition zone” in planting. This region contains areas that will support both warm- and cool-season grasses.<br><br>Appalachian and Blue Ridge Region:<br><br>This region is divided into mountains, valleys and dissected plateaus. Soils on mountain ridges and dissected plateaus tend to be shallow, acidic, and may erode rapidly on steep slopes. Shaley intermediate slopes are often unstable and droughty. Soils in limestone valleys generally occur on more rolling landforms and are usually much deeper. This area is cooler and often drier than the rest of the state. The rugged to rolling topography complicates plant establishment. Cool-season grasses and legumes are normally recommended in this region. |
| Soils | Overall, soils in Virginia always require some nitrogen fertilization to establish plants. Phosphorus and potassium are usually needed. Except for some small pockets of shallow limestone soils, lime is universally needed.<br><br>Soils can be modified with lime and fertilizer, but climate cannot be controlled. For this reason, the State of Virginia has been divided into two major climatic regions (referred to as the Northern Piedmont and Mountain Region and the Southern Piedmont and Coastal Plain Region) for grass and legume selection (see map on Figure C-SSM-10-2).<br><br>Microclimate, or localized climate conditions, can affect plant growth. A south-facing slope is drier and hotter than a north-facing slope and may require drought-tolerant plants. Consider that shaded areas require shade-tolerant plants, the windward side of a ridge will be drier than the leeward, and other conditions. |

| Table C-SSM-10-1 Design Considerations for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Proper Design** |
| Land Use | A prime consideration in selecting plants to establish is the intended use of the land. All these uses – residential, industrial, commercial, recreational – can be separated into two major categories: high-maintenance and low-maintenance.<br><br>High-Maintenance Areas – will be mowed frequently, limed, and fertilized regularly, and will either be subject to intense use (e.g., athletics) or require maintaining to an aesthetic standard (home lawns). Use grasses for these areas that are fine-leaved and visually appealing, able to form tight sod, and be long-lived perennials. The grasses must be well-adapted to the geographic area in which they are planted because constant mowing puts turf under great stress. Sites where high- maintenance vegetative cover is desirable include homes, industrial parks, schools, churches, athletic playing surfaces, and some recreational areas.<br><br>Low-Maintenance Areas – will be mowed infrequently or not at all, lime and fertilizer may not be applied regularly, and the areas will not be subjected to intense use or required to have a uniform appearance. These plants must be able to persist with little maintenance over long periods of time. Grass and legume mixtures are preferred for these sites because legumes are capable of fixing nitrogen from the air for their own use and the use of the plants around them. Such mixed stands are better able to withstand adverse conditions. Sites that would be suitable for low- maintenance vegetation include steep slopes, stream or channel banks, some commercial properties, and “utility turf” areas such as road banks. |
| Seedbed Preparation | Modification of the soil on a disturbed site provides the optimum environment for seed germination and seedling growth.<br><br>For water infiltration and root penetration to occur, the surface soil needs to be loose and non-compacted to at least six inches. Deeper loosening (de-compaction) may be required on compacted fill or smeared cut slopes. To ensure that soil pH (balance of acidity vs. alkalinity) is adequate and reduce root toxicities, VDACS approved liming materials should be applied to adjust the pH to between 6.0 and 7.5. Sufficient N-P-K will need to be added as fertilizers or other approved soil amendments (e.g. compost). After the seed is in place, protect the new seedlings with mulch, applied over or with seeding, to retain moisture and moderate temperature extremes. Mulch also helps to stabilize the disturbed site against sediment losses until the vegetation establishes. |

| Table C-SSM-10-1 Design Considerations for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Proper Design** |
| Non-Native, Invasive & Pollinator Friendly Plant Considerations | Many of the plant species commonly utilized for permanent seedings are not native to Virginia and are considered by Virginia DCR (20~~17~~22) to be invasive with respect to their ability to move into adjacent relatively natural areas. This is primarily due to their higher probability of success for establishing and persisting in highly disturbed environments vs. available native grasses and forbs. Therefore, revegetation planners and practitioners should take these concerns into account when determining seed mixtures for a given site. Greater emphasis is also being placed upon establishment of "pollinator friendly" flowering species into revegetation protocols for disturbed sites. In general, establishment and maintenance of native grasses and pollinator friendly species mixes requires a higher level of establishment and management inputs than the more conventional seeding mixtures described later in this guidance. |

## 4.0 Stormwater Performance Summary

### 4.1 MS-1: Stabilization

Permanent or temporary soil stabilization will be applied to bare soil areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization will be applied within 7 days to bare soil areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization will be applied in areas to be left dormant for more than 1 year.

### 4.2 MS-3: Permanent Vegetation

A permanent vegetative cover will be established on bare soil areas not otherwise permanently stabilized. Permanent vegetation will not be considered established until achievement of a ground cover that is uniform, mature enough to survive, and will inhibit erosion.

**Sediment Removal Efficiency: N/A**

**Erosion Control Efficiency: High**

## 5.0 Design Criteria

No formal design criteria.

## 6.0 Construction Specifications

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Selection of Plant Materials | Selection of plant materials is based on climate, topography, soils, land use, and planting season. To determine which plant materials are best adapted to a specific site, use Table C-SSM-10-4 and Table C-SSM-10-5, which describe plant characteristics and list recommended varieties. The species listed in Table C-SSM-10-4 to C-SSM-10-8 are not exclusive and other species and varieties may be suitable for use in Virginia based on emerging research by VDOT and the revegetation industry. However, use of aggressive or invasive species as identified by VA DCR where viable native substitutes are available is discouraged. Information about invasive species is available on the DCR website. (See DCR 2022)<br><br>Suggested basic seeding mixtures for site conditions in Virginia are provided in Tables C-SSM-10-6, C-SSM-10-7, and C-SSM-10-8. These mixtures are designed for general use and have proven to be successful over time on typical sites. See Tables CSSM- 10-4 and C-SSM-10-5 for recommended varieties. However, it is strongly suggested that all low maintenance seed mixtures contain at least two different species of both grasses and legumes in addition to an appropriate seasonal cover species.<br><br>More extensive descriptions of plant materials (grasses and legumes), their usage, and pictorial representations are provided in Table C-SSM-10-1.<br><br>When using some varieties of turf grasses, the Virginia Crop Improvement Association (VCIA) recommends that turf grass mixtures may also be used. Consumer protection programs have been devised to identify quality seed of the varieties recommended by the Virginia Cooperative Extension Service. These will bear a label indicating that they are approved by the Association. Mixtures may be designed for a specific physiographic region or based on intended use. Special consideration is given to plant characteristics, performance, and other attributes.<br><br>Site planners and designers should refer to the DCR invasive species list as part of the process of selecting plant materials for a site. (See DCR 2022). This serves two purposes: to avoid use of invasive species to the extent possible; and to ensure plant selection is based on the most current information available. |

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Seed Quality Criteria | Where certified seed is not available, use grass and legume seed in vegetative establishment that meets the minimum requirements as provided below.<br>Ensure all tags on containers of seed are labeled to meet the requirements of the state seed law.<br><br>Ensure all seed is subject to re-testing by a recognized seed laboratory that employs a registered seed technologist or by a state seed lab.<br><br>Ensure all seed used has been tested within 12 months.<br><br>Ensure the inoculant added to legume seed in the seed mixtures is a pure culture of nitrogen-fixing bacteria prepared for the species. Do not use inoculants after the date indicated on the container. Use twice the supplier's recommended rate of inoculant on dry seedings; five times the recommended rate if hydroseeded. Delay addition of the inoculant until no more than 30 minutes prior to hydroseeding to avoid loss of viability<br><br>Ensure the quality of the seed used is shown on the bag tags to conform to the guidelines documented in Table C-SSM-10-9.<br><br>All seeding rates shown in Tables C-SSM-10-4 to C-SSM-10-9 should be applied on a "pure live seed" (PLS) basis calculated as the sum of readily germinable and hard seed, but not inert matter or other weedy species. |

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Seedbed Requirements | Do not establish vegetation on slopes that are unsuitable due to inappropriate soil texture, poor internal structure or internal drainage, volume of overland flow, or excessive steepness until these problems have been corrected. To maintain a good stand of vegetation, ensure the soil meets the following minimum requirements as a growth medium:<br>• Sufficient fine grained soil material (> 25% < 2 mm) to maintain adequate soil moisture and nutrient supply. Areas that do not meet this requirement will require topsoiling (C-SSM-02) or application of compost and/or manufactured soil materials to be viable;<br>• Sufficient pore space to permit root penetration. An in situ surface soil bulk density of between 1.35 g/cm3 (clayey soils) and 1.75 g/cm3 (sandy soils) following site preparation and soil amendment indicates sufficient pore space for water holding and enhanced infiltration.;<br>• Sufficient soil depth to provide an adequate root zone. Ensure the depth to rock or impermeable layers (such as hardpans) is a minimum of 12 inches, except on slopes steeper than 2H:1V, where the addition of soil is not feasible;<br>• A favorable pH range for plant growth. If the soil is so acidic that a pH range of<br>6.0 to 7.0 cannot be attained by addition of pH-modifying materials, then the soil is considered an unsuitable environment for plant roots, and further soil modification is required;<br>• Free from toxic amounts of materials harmful to plant growth; and<br>• Free from excessive quantities of roots, branches, large stones, large clods of earth, or trash of any kind. Clods and stones may be left on slopes steeper than 3H:1V if they do not significantly impede good seed-to-soil contact.<br>If any of these criteria cannot be met (i.e., if the existing soil is too coarse, dense, shallow, acidic, or contaminated to foster vegetation), apply topsoil in accordance with Topsoiling (C-SSM-02).<br>Install the necessary structural erosion and sediment control practices before seeding. Carry out grading according to the approved plan. Roughen surfaces in accordance with Surface Roughening (C-SSM-03). |

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Soil Conditioners and Amendments at Seeding | To modify the texture, structure, or drainage characteristics of a soil, the following materials may be added. Any product labeled as a soil conditioner, horticultural growing medium, liming material or fertilizer in VA must be approved by VDACS.<br><br>Peat: Peat is a very costly conditioner but works well. If added, use sphagnum moss peat, hypnum moss peat, reed-sedge peat, or peat humus from freshwater sources. Shred and condition peat in storage piles for at least 6 months after excavation. Use a wetting agent unless aged peat is available.<br><br>Sand: Use sand that is clean and free of toxic materials. Sand modification is ineffective unless added at a rate of 80 to 90 percent by volume, which is extremely difficult to achieve onsite. If this practice is considered, consult a professional authority to ensure that it is conducted properly.<br><br>Animal Manure: Any application of animal manures must follow applicable VDEQ waste management regulations and may be subject to VA DCR nutrient management planning (NMP) guidance. Fully composted (per criteria in C-SSM-04) manure products can be utilized as soil conditioners with input from a waste management professional.<br><br>Rotted Sawdust or Wood Waste Materials: Thoroughly rotted sawdust or stabilized wood waste materials that is free of sticks, stones and toxic materials may be used as a soil conditioner, but may require additional N fertilizer to offset high C:N ratio limitations based on input from a waste management professional.<br>Biosolids: Utilization of biosolids (treated sewage sludge) is a proven beneficial practice for a wide range of agricultural and disturbed land remediation and revegetation practices. All land application of biosolids is regulated by VDEQ on a producer x site-specific application basis in conformance with USEPA Part 503 regulations. Conformance with DCR Nutrient Management Planning (NMP) criteria is also generally required. Certain biosolids products (Class A; EQ) have been treated, processed and tested to an extent that they are available for general use without a site-specific permit. Biosolids are an effective soil amendment that can supply organic matter and essential macro/micronutrients when applied and utilized properly. Application rates may vary from < 5 to 35 dry tons per acre per depending on site-specific soil conditions and nutrient management/loss considerations. Certain composted products also contain biosolids and are available for use as a revegetation soil amendment. |

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Lime | Determine lime needs by soil tests, which may be performed by the Cooperative Extension Service Soil Testing Laboratory at Virginia Polytechnic Institute and State University (VPI&SU) or by a reputable commercial laboratory. Information concerning the State Soil Testing Laboratory is available from county extension agents.<br><br>Reference Table C-SSM-10-10 for liming applications needed to correct undesirable pH for various soil types.<br><br>Under unusual conditions, where it is not possible to obtain a soil test, apply an agricultural grade of limestone at the following rates.<br>Coastal Plain — 2 tons/acre (90 lbs./1,000 ft2)<br>Piedmont and Appalachian Region — 2 tons/acre (90 lbs./1,000 ft2)<br><br>Liming materials should be labeled and approved by VDACS. |
| Fertilizer | Determine fertilizer needs by soil tests, which may be performed by the Cooperative Extension Service Soil Testing Laboratory at VPI&SU (https://www.soiltest.vt.edu/) or by a reputable commercial laboratory. Information concerning the Soil Testing Laboratory is available from county extension agents. All fertilizer materials should be VDACS approved and labeled.<br><br>Under unusual conditions, where it is not possible to obtain a soil test, apply a fertilizer at the following rates.<br><br>Mixed Grasses & Legumes: 1,000 lbs./acre (23 lbs./1,000 $ft^2$) of 10-20-10 ($N$-$P_2O_5$-$K_2O$) or equal. These rates apply to establishment needs only and subsequent post-establishment fertilization with N will be required for pure grass stands or stands where at least a 25% legume component does not persist. Follow-up applications of P2O5 may also be required for exposed fine-textured, acidic and high clay subsoil materials. These subsoils are typically red to reddish yellow in color. Additional K2O is also required for frequently mowed stands or on very sandy soils. All fertilizer application should be based on soil testing by the Virginia Tech Soil Testing Laboratory or another DCR approved laboratory.<br>Legume Stands Only: 1,000 lbs./acre (23 lbs./ 1,000 $ft^2$) of 5-20-10 is preferred 1,000 lbs./acre (23 lbs./ 1,000 $ft^2$) of 10-20-10 or equal<br><br>Grass Stands Only: 1,000 lbs./acre (23 lbs./1,000 $ft^2$) of 10-20-10 or equal Use other fertilizer formulations, including slow-release sources of nitrogen (preferred from a water quality standpoint), provided these fertilizers can supply the same amounts and proportions of plant nutrients. |
| Incorporation | Incorporate lime and fertilizer into the top 4 to 6 inches of the soil by discing or other means whenever possible. For erosion control, when applying lime and fertilizer with a hydroseeder, apply to a rough, loose surface. |

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Seeding | Certified Seed: use certified seed for all permanent seeding whenever possible. Certified seed is inspected by the VCIA or the certifying agency in other states. Use seed that meets the published state standards and bears an official "Certified Seed" label (see Seed Quality Criteria in row 2 of this table).<br><br>Legume Seed: Use legume seed inoculated with the inoculant appropriate to the species. Scarify seed of the lespedezas and the clovers species to promote uniform germination.<br><br>Application: Apply seed uniformly with a broadcast seeder, drill, culti-packer seeder, or hydroseeder on a firm, friable seedbed. Ensure the seeding depth is between 0.25 to 0.5 inch.<br><br>Hydroseeding: To avoid poor germination rates because of seed damage during hydroseeding, add 50 percent more seed to the tank if machinery breaks down for 30 minutes to 2 hours based on the proportion of the slurry remaining in the tank. Beyond 2 hours, a full rate of new seed may be necessary.<br><br>Often, hydroseeding contractors prefer not to apply lime in their rigs, as it is abrasive. In inaccessible areas, apply lime separately in pelletized or liquid form. Surface roughening is particularly important when hydroseeding, as a roughened slope will provide some natural coverage of lime, fertilizer, and seed. Apply inoculants at five times the recommended rate when inoculant is included in the hydroseeder slurry. |
| Mulching | Mulch all permanent seeding immediately upon completion of seed application in accordance with Mulching (C-SSM-11). |
| Maintenance of New Seedings | In general, a stand of vegetation cannot be determined to be fully established until it has been maintained for 1 full year after planting. |
| Irrigation | Supply new seedings with adequate moisture. Supply water as needed, especially late in the season, in abnormally hot or dry weather, or on adverse sites. Control water application rates to prevent excessive runoff. Inadequate amounts of water may be more harmful than no water. |
| Reseeding | Inspect seeded areas for failure and make necessary repairs and reseedings within the same season if possible.<br><br>If vegetative cover is inadequate to prevent rill erosion, over-seed and fertilize in accordance with soil test results.<br><br>If a stand has less than 40 percent cover, re-evaluate choice of plant materials and quantities of lime and fertilizer. Test the soil to determine if acidity or nutrient imbalances are responsible. Re-establish the stand following seedbed preparation and seeding recommendations. |

| Table C-SSM-10-2 Construction Specifications for Permanent Seeding | |
|---|---|
| **Parameter** | **Notes on Execution** |
| Post-<br>Establishment Fertilization | Begin fertilization of intensively managed/mowed cool-season grasses 90 days after planting to ensure proper stand and density. Begin fertilization of intensively managed/mowed warm-season grasses at 30 days after planting.<br><br>Apply maintenance levels of fertilizer as determined by soil test. In the absence of a soil test, conduct fertilization as follows:<br><br>Cool-Season Grasses<br><br>4 lbs. nitrogen per 1,000 $ft^2$ per year<br><br>1 lb. phosphorus per 1,000 $ft^2$ per year<br><br>2 lbs. potash per 1,000 $ft^2$ per year<br><br>Apply 75 percent of the total requirements between September 1 and December 31. Apply the balance during the remainder of the year. Do not apply more than 1 lb. of soluble nitrogen per 1,000 $ft^2$ at any one time.<br><br>Warm-Season Grasses<br>Apply 4 to 5 lbs. nitrogen per 1,000 $ft^2$ per year between May 1 and August 15. Apply phosphorus and potash according to soil test.<br><br>Note: The use of slow-release fertilizer formulations for maintenance of turf is encouraged to reduce the number of applications and the impact on groundwater. Less intensive post-establishment fertilizer applications may be required for low-intensity un-mowed stands, particularly when at least 25% legumes are present. However, stand density and vigor should be evaluated periodically if lower fertilization rates are employed. Soil testing should be utilized for routine P and K prescriptions over time, but not for N recommendations. Maintenance of pH > 5.5 is essential for both grass and legume persistence in permanent seedings. |
| Other Additives | A wide range of other soil amendments including byproduct limes, digestates, biochar, and various processed animal manure products are available for utilization in permanent seeding applications. However, users should ensure that any soil bulk soil amendment has been approved for such use by VDACS, VDEQ or DCR and that application complies with appropriate labeling or NMP limitations. |

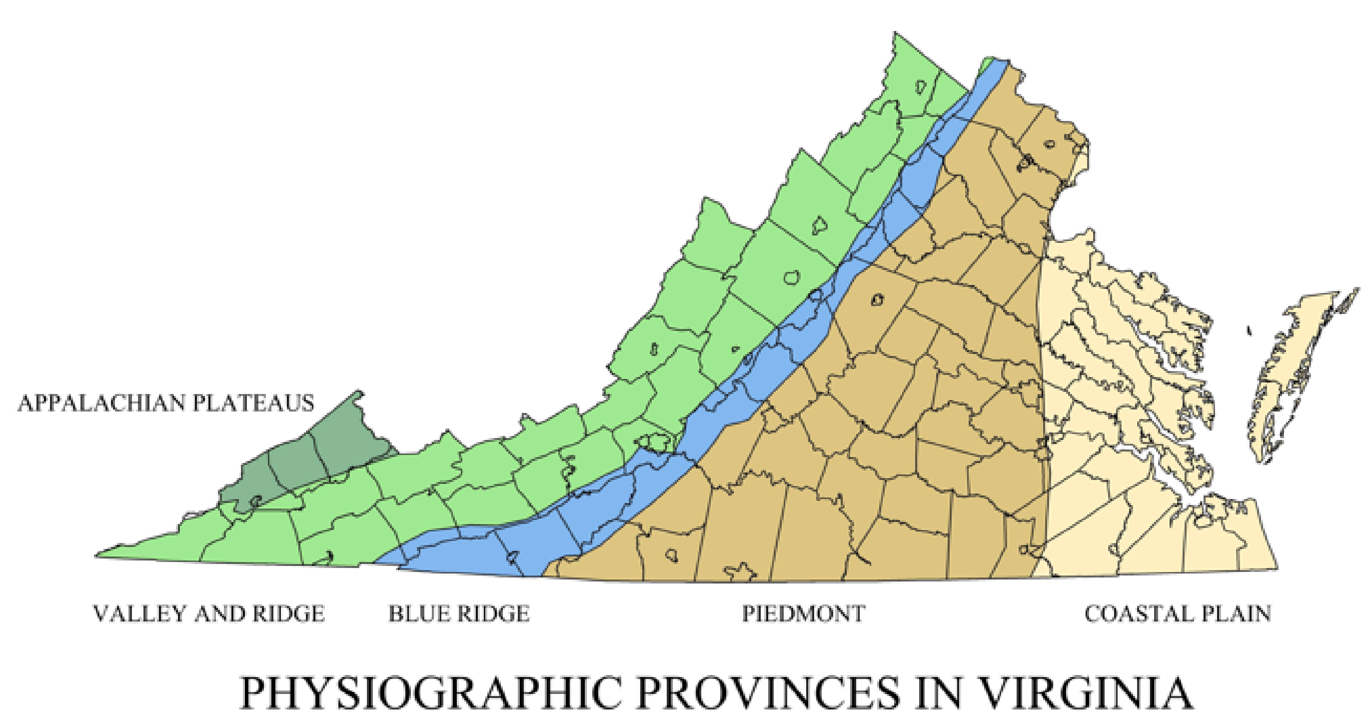
| Table C-SSM-10-3 Keys to Successful Establishment of Grasses and Legumes | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Planning | Where feasible, plan grading around optimal seeding dates for the region. The most effective times for establishing perennial grasses and legumes in Virginia generally extend from March through May and from August through October. Outside these dates, the probability of failure is much higher. If the time of year is not suitable for seeding a permanent cover (perennial species), plant a temporary cover crop. Temporary seeding of annual species (small grains, ryegrasses, or millets) often succeeds during periods that are unsuitable for seeding permanent (perennial) species.<br><br>Variations in weather and local site conditions can modify the effects of regional climate on seeding success. For this reason, mixtures including both cool- and warm-season species are preferred for low-maintenance cover, particularly in the Coastal Plain. Such mixtures promote cover that can adapt to a range of conditions. Many of these mixtures are not desirable, however, for high-quality lawns, in which variation in texture of the turf is inappropriate. It is important to note that, in Virginia, the successful establishment of 100 percent warm-season grasses in a high-quality lawn is limited to the extreme eastern portions of the Coastal Plain. |
| Selection | Consider species selection early in the preparation of an erosion and sediment control plan. A variety of vegetation can be established in Virginia due to the diversity in both soils and climate. However, for practical and economic stabilization and long-term protection of disturbed sites, select species judiciously.<br><br>Consider seasonality when selecting species. Grasses and legumes are usually classified as warm- or cool-season in reference to their season of growth. Cool-season plants realize most of their growth during the spring and fall and are relatively inactive or dormant during the hot summer months. Therefore, fall is the most favorable time in which to plant them. Warm-season plants “green up” late in the spring, grow most actively during the summer, and go dormant at the time of the first frost in fall. Spring and early summer are preferred planting times for warm-season plants. |

| Table C-SSM-10-3 Keys to Successful Establishment of Grasses and Legumes | |
|---|---|
| **Activity** | **Notes on Proper Execution** |
| Seed Mixtures | As previously noted, the establishment of high-quality turf frequently involves planting a single species. However, in seedings for erosion control purposes, consider the inclusion of more than one species. Mixtures need not be excessive in poundage or seed count.<br><br>The addition of a quick-growing annual provides early protection and facilitates establishment of one or two perennials in a mix. More complex mixtures might include a quick-growing annual, one or two legumes, and more than one perennial grass. The fast-growing nurse crop provides shade and temperature buffering for the establishing perennials and also takes up soluble N-P-K from soil solution to limit leaching/runoff losses which is then recycled over time to the established perennial stand via litterfall and root turnover.<br><br>The addition of a “nurse” crop (quick-growing annuals added to permanent mixtures) is a sound practice for soil stabilization, particularly on difficult sites (those with steep slopes; poor, rocky, erosive soils; those seeded outside the optimum seeding periods) or where the development of permanent cover is likely to be slow. The nurse crop germinates and grows rapidly, holding the soil until the slower-growing perennial seedlings become established. Utilization of diverse seed mixes, particularly use of two or more perennial grasses and legumes (each) is strongly recommended for extensively disturbed and regraded cut/fill sites and areas with strongly contrasting aspects and slope/topographic positions.<br><br>Consideration should be given to use of native grasses and flowering species when compatible with short-term, site-specific erosion control and longer-term management needs. |

## 7.0 Operations and Maintenance Considerations

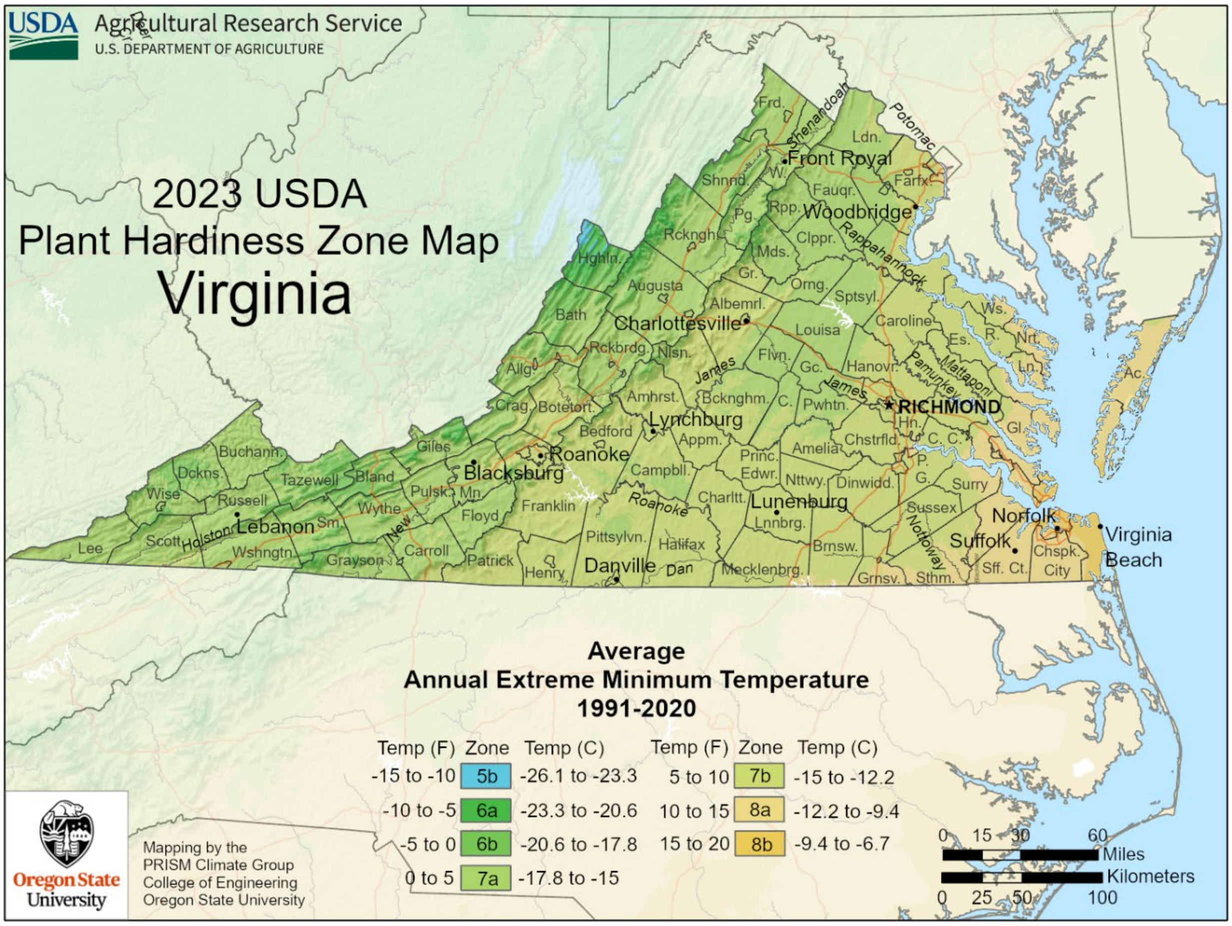
Even with careful, well-planned seeding operations, failures can occur. When plants have not germinated on an area or have died, reseed these areas immediately to prevent erosion damage. However, it is extremely important to determine why germination failed and take any corrective action necessary before reseeding the area. Healthy vegetation is the most effective erosion control available.

**Figure C-SSM-10-1 Physiographic Provinces of Virginia**




*Source: Va. DSWC*

## Figure C-SSM-10-2 Plant Hardiness Zones in Virginia




Source: Adapted from Virginia Climate Advisory 1979.

| Table C-SSM-10-4 Characteristics of Commonly Selected Grasses | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Name (Botanical Name) | Life Cycle | Season | pH Range | Germination Time (days) | Optimum Germination Temperature (˚ F) | Winter Hardiness | Drought Tolerance | Fertility | Soil Drainage Tolerance | Seeding Rate (lbs/acre) PLS | Maintenance Requirements | Remarks | Suggested Varieties for Virginia |
| Tall fescue (*Festuca arundinacea*) (*Schedonorus arundinaceus*) | P | C | 5.5 - 6.2 | 10 - 14 | 60 - 85 | F | F | M | SPD | 75* | Low when used for erosion control; high when used in lawn | Better suited for erosion control and rough turf application. | Ky 31 |
| Tall fescues (Improved) | P | C | 5.5 - 6.2 | 10 - 14 | 60 - 85 | F | G | M | SPD | 50 | Responds well to high maintenance. | Excellent for lawn and fine turf. | See current VCIA list.** |
| Kentucky bluegrass (*Poa pratense*) | P | C | 6.0 - 6.5 | 14 | 60 - 75 | G | P | M | SPD | 35 | Needs fertile soil, favorable moisture. Requires several years to become well established. | Excellent for fine turfs. Takes traffic, mowing. Poor drought/heat tolerance. | See current VCIA list. |
| Perennial ryegrass (*Lolium perenne*) | P | C | 5.8 - 6.2 | 7 - 10 | 60 - 75 | F | F | M-H | SPD | 30 | Will tolerate traffic. | May be added to mixes. Improved varieties will perform well all year. | See current VCIA list. |

| Table C-SSM-10-4 Characteristics of Commonly Selected Grasses | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Common Name (Botanical Name)** | **Life Cycle** | **Season** | **pH Range** | **Germi-nation Time (days)** | **Optimum Germi-nation Temp-erature (˚ F)** | **Winter Hardi-ness** | **Drought Tolerance** | **Fertility** | **Soil Drainage Tolerance** | **Seeding Rate (lbs/acre) PLS** | **Maintenance Requirements** | **Remarks** | **Suggested Varieties for Virginia** |
| Hard fescue (*Festuca Longifolia or Festuca ovina or Festuca brevipila)* | P | C | 5.0 - 6.2 | 10 - 14 | 60 - 80 | VG | G | L | MWD | 50 | Grows well in sun or shade and will tolerate infertile soils; improved disease resistance. | Exceeds all fine fescues in most tests. Excellent for low-maintenance situations. | See Current VCIA list. |
| Chewings fescue (F. rubra) | P | C | 5.0 - 6.2 | 10 - 14 | 60 - 80 | VG | G | L | MWD | 50 | Tolerates shade; dry, infertile soils. | Poor traffic tolerance, less thatch than other fine fescues. | See Current VCIA list. |
| Red fescue (others) (*Festuca rubra*) | P | C | 5.0 - 6.2 | 10 - 14 | 60 - 80 | VG | G | L | MWD | 50 | Low to medium fertility requirements. Requires well-drained soil. | Spreads by rhizomes, tillers, and stolons. Will not take traffic – very shade-tolerant. | Long-fellow, Victory |
| | | | | | | | | | | | | | |
| Redtop (*Agrostis gigantea)* | P | C | 5.8 - 6.2 | 10 | 65 - 85 | G | F | L | PD | 25 | Will tolerate poor, infertile soils; deep- rooted. | Does well in erosion control mixes - not for lawns. | No named varieties. |

| Table C-SSM-10-4 Characteristics of Commonly Selected Grasses | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Name (Botanical Name) | Life Cycle | Season | pH Range | Germi-nation Time (days) | Optimum Germi-nation Temp-erature (˚ F) | Winter Hardi-ness | Drought Tolerance | Fertility | Soil Drainage Tolerance | Seeding Rate (lbs/ acre) PLS | Maintenance Requirements | Remarks | Suggested Varieties for Virginia |
| Weeping lovegrass (*Evagrostis curvula*) | P | W | 4.5 - 6.2 | 14 | 65 - 85 | F-P | G | L-M | SPD | 25 | Low fertility requirements; excellent drought tolerance. | Fast-growing, warm-season bunch grass. Excellent cover for erosion control. | Common |
| Bermudagrass (*Cynodon dactylon*) | P | W | 5.8 - 6.2 | 21 | 70 - 95 | P | G | M-H | SPD | 15 | High nitrogen utilization, excellent drought tolerance. Some varieties adapted to western VA. | Common varieties used for erosion control. Hybrids used for fine turf. | See current VCIA list. |
| Orchardgrass (*Dactylis glomerata*) | P | C | 5.8 - 6.2 | 18 | 60 - 75 | F | F | M | SPD | 50 | Does best on well- drained, loamy soil. | Good pasture selection; may be grazed. | Takena Potomac |
| Annual ryegrass (*Lolium multiflorum*) | A | C | 5.8 - 6.2 | 7 | 60 - 70 | G | P | M-H | SPD | 15 | Will grow on most Virginia soils. Do not use in fine-turf areas. | May be added into mixes or established alone as temporary cover in spring and fall. | Common |

| Table C-SSM-10-4 Characteristics of Commonly Selected Grasses | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Common Name (Botanical Name)** | **Life Cycle** | **Season** | **pH Range** | **Germi-nation Time (days)** | **Optimum Germi-nation Temp-erature (˚ F)** | **Winter Hardi-ness** | **Drought Tolerance** | **Fertility** | **Soil Drainage Tolerance** | **Seeding Rate (lbs/acre) PLS** | **Maintenance Requirements** | **Remarks** | **Suggested Varieties for Virginia** |
| Cereal Rye (*Secale cereale*) | A | C | 5.8 - 6.2 | 7 | 55 - 70 | VG | G | L-M | SPD | 40 | Will establish in most all Virginia soils. Do not use in fine-turf areas. | May be added into mixes or established alone for late fall/ winter cover. | Abruzzi, Balboa |
| German/Foxtail millet (*Setaria italica*) | A | W | 5.8 - 6.2 | 10 | 65 - 85 | VP | G | M | MWD | 40 | Establishes well during summer. Very low moisture requirements. | May be added to erosion control mixes or established alone. | Common, German |
| Spring Oats (Avena sativa) | A | C | 5.8 - 6.5 | 7 | 55-70 | G | G | L-M | MWD-WD | 50 | Will establish in most all Virginia soils. Do not use in fine-turf are | May be added into mixes or established alone for late fall/ winter cover. | Noble Otee, Ogle |

| Table C-SSM-10-4 Characteristics of Commonly Selected Grasses | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Name (Botanical Name) | Life Cycle | Season | pH Range | Germi-nation Time (days) | Optimum Germi-nation Temp-erature (˚ F) | Winter Hardi-ness | Drought Tolerance | Fertility | Soil Drainage Tolerance | Seeding Rate (lbs/acre) PLS | Maintenance Requirements | Remarks | Suggested Varieties for Virginia |

**Key:**

A = Annual

P = Perennial

C = Cool-Season Plant

W = Warm-Season Plant

G = Good

F = Fair

P = Poor

VP = Very Poor

H = High

M = Medium

L = Low

SPD = Somewhat Poorly Drained

MPD = Moderately Poorly Drained

PD = Poorly Drained

VPD = Very Poorly Drained

* Rate for mixed stands, increase by 2X for pure high maintenance stands.

**VCIA/VDOT Green Tab List: https://www.virginiacrop.org/vdot-green-tag-program.html

| Table C-SSM-10-5 Characteristics of Legumes Appropriate for Erosion Control | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Name (Botanical Name) | Life Cycle | Season | pH Range | Germi-nation Time (days) | Optimum Germi-nation Temp-erature (˚ F) | Winter Hardiness | Drought Tolerance | Fertility | Soil Drainage Tolerance | Seeding Rate (lbs/acre) PLS* | Maintenance Requirements | Remarks | Suggested Varieties for Virginia |
| Flatpea (*Lathyrus silvestrus*) | P | C | 5.0 - 7.0 | 14 - 28 | 65 - 75 | G | G | L | PD | 10-15 | Needs lime and high phosphorus. Good shade tolerance. | Tolerates acidic and wetter soils better than other legumes. | Lathco |
| Birdsfoot trefoil (*Lotus corniculatus*) | P | C | 6.0 - 6.5 | 7 | 65 - 70 | G | F | M | SPD | 15-25 | Inoculation is essential. Grows in medium-fertile, slightly acid soils. | Grows better on poorly drained soils than most legumes. Moderate heat tolerance. | Audewey Empire Fergus Norcean |

| Table C-SSM-10-5 Characteristics of Legumes Appropriate for Erosion Control | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Common Name (Botanical Name) | Life Cycle | Season | pH Range | Germi-nation Time (days) | Optimum Germi-nation Temp-erature (˚ F) | Winter Hardiness | Drought Tolerance | Fertility | Soil Drainage Tolerance | Seeding Rate (lbs/acre) PLS* | Maintenance Requirements | Remarks | Suggested Varieties for Virginia |
| Annual Lespedezas (*Lespedeza striata, L. stipulacea*) | A | W | 5.8 - 6.2 | 14 | 70 - 85 | F | VG | L | MWD | 20-30 | Will grow on almost any well-drained soil. | Choose Kobe for southeastern VA; needs almost no nitrogen to survive. | Kobe, Korean |
| Red clover (*Trifolium pratense*) | P | C | 6.0 - 6.5 | 7 - 14 | 70 | *G* | F | M | SPD | 15-20 | Needs high levels of phosphorus and potassium. | Acts as a biennial. Can be added to low-maintenance mixes. | Kenstar, Kenland |
| White clover (*Trifolium repens*) | P | C | 6.0 - 6.5 | 10 | 70 | G | P | M | PD | 10-15 | Requires favorable moisture, fertile soils, high pH. | Spreads by soil surface stolons, white flowers. | Common, White Dutch |
| Partridge Pea | A | Warm | 5.5 - 7.0 | 10-14 | 70 | G | G | L | MWD | 10-15 | Good for initial restoration; can reseed; tolerates sandy soils | Native; high pollinator value | Lark, Riley Comanche |

**Key:**

A = Annual

P = Perennial

C = Cool-Season Plant

W = Warm-Season Plant

G = Good

F = Fair

P = Poor

VP = Very Poor

H = High

M = Medium

L = Low

SPD = Somewhat Poorly Drained

MPD = Moderately Poorly Drained

PD = Poorly Drained

VPD = Very Poorly Drained

Note: All legumes must be inoculated with specific Rhizobia immediately before seeding.

* Seeding rates assuming legumes used in a mixed stand with grasses to achieve > 25% legume cover in final perennial stand.

| Table C-SSM-10-6 Suggested and Example Site-Specific Seeding Mixtures for Appalachian/Mountain Area | | | |
|---|---|---|---|
| **Site Condition** | **Seed Mix** | | **Application Rate (pounds per acre)** |
| Minimum-Care Lawn Commercial or Residential | Turf-Type Tall Fescue | 90-100% | 150 – 200 |
| | Improved Perennial Ryegrass* | 0-10% | |
| | Kentucky Bluegrass | 0-10% | |
| High-Maintenance Lawn | Bluegrass – minimum of three to five varieties from VCIA list for use in Virginia | | 125 |
| | Improved VCIA Turf-Type Tall Fescue | | 150 – 200 |
| General Slope (3H:1V or less) | Tall Fescue**** | | 50 – 75 |
| | Red Top and/or Hard Fescue | | 10 – 20 |
| | White Clover and/or Birdsfoot Trefoil*** | | 10 – 20 |
| | Seasonal Nurse Crop ** | | 30 – 40 |
| Low-Maintenance Slope (> 3:1) or Inaccessible Area*** | Tall Fescue**** | | 50 – 75 |
| | Red Top or Hard Fescue | | 10 – 20 |
| | Annual Lespedeza | | 10 – 15 |
| | White Clover and/or Birdsfoot Trefoil*** | | 10 – 20 |
| | Seasonal Nurse/Cover Crop** | | 30 – 40 |

* Perennial ryegrass will germinate faster and at lower soil temperatures than fescue, thereby providing cover and erosion resistance for seedbed.

** Use seasonal nurse crop in accordance with seeding dates as stated below:

March 1 through May 15 – annual/cereal rye

May 16 through August 15 – foxtail/German millet

August 16 through February 28 – annual/cereal rye

*** All legume seed must be properly inoculated. Legumes recommended unless periodic N fertilization maintenance intended.

Flatpea at 20 lbs/acre may be utilized where warranted. All legume seed must be properly inoculated. Weeping lovegrass may also be included in any slope or low-maintenance mixture during warmer seeding periods; add 10 to 20 lbs/acre in mixes.

**** Increase seeding rate if Kentucky 31 is used rather than VCIA/VDOT improved varieties.

Note: Seed mixes are suggested and subject to modification based on site-specific conditions by an agronomist or other qualified revegetation professionals. All seed rates expressed as PLS (Pure Live Seed; see Table C-SSM-10-9).

| Table C-SSM-10-7 Site-Specific Seeding Mixtures for Piedmont Area | | | |
|---|---|---|---|
| **Site Condition** | **Seed Mix** | | **Application Rate (pounds per acre)** |
| Minimum-Care Lawn Commercial or Residential | Turf-Type Tall Fescue | 95-100% | 150 – 200 |
| | Improved Perennial Ryegrass | 0-5% | |
| | Kentucky Bluegrass | 0-5% | |
| High-Maintenance Lawn | Improved (VCIA) Turf-Type Tall Fescue | 100% | 150 – 200 |
| General Slope (3H:1V or | Tall Fescue*** | | 50 – 75 |

| Table C-SSM-10-7 Site-Specific Seeding Mixtures for Piedmont Area | | |
|---|---|---|
| **Site Condition** | **Seed Mix** | **Application Rate (pounds per acre)** |
| less) | Red Top or Red/Hard Fescue | 10 – 20 |
| | White Clover and/or Birdsfoot Trefoil** | 10 – 20 |
| | Seasonal Nurse Crop* | 30 – 40 |
| Low-Maintenance Slope (> 3:1) or Inaccessible Area*** | Tall Fescue | 50 – 75 |
| | Red Top and/or Hard Fescue | 5 – 10 |
| | White Clover and/or Birdsfoot Trefoil** | 15 – 20 |
| | Annual Lespedeza** | 10 – 15 |
| | Seasonal Nurse/Cover Crop | 20-30 |

* Use seasonal nurse crop in accordance with seeding dates as stated below: February 16 through April annual rye

February 16 through April – annual/cereal rye

May 1 through August 15 – foxtail/German millet

August 16 through February 15 – annual/cereal rye

** Use legume seed that is properly inoculated with specified Rhizobia. Legumes recommended unless periodic N fertilization is intended. Weeping lovegrass may be added to any slope or low-maintenance mix during warmer seeding periods; add 10 to 20 lbs/acre in mixes.

*** Increase seeding rate if KY-31 is used rather than VCIA/VDOT improved varieties.

Bermudagrass can be added to substitute for Tall or Hard Fescue in the Low Maintenance mixes for the Southern Piedmont, particularly on sandy soils or hot (S and W) facing slopes. May through October, use hulled seed. All other seeding periods, use un-hulled seed.

Note: Seed mixes are suggested and subject to modification based on site-specific conditions by an agronomist or other qualified revegetation professionals. All seed rates expressed as PLS (Pure Live Seed; see Table C-SSM-10-9).

| Table C-SSM-10-8 Site-Specific Seeding Mixtures for Coastal Plain Area | | |
|---|---|---|
| **Site Condition** | **Seed Mix** | **Application Rate (pounds per acre)** |
| Minimum-Care Lawn Commercial or Residential | Kentucky 31* or VCIA approved Turf-Type Tall Fescue | 150 – 200 |
| | or Common Bermudagrass | 75 |
| High-Maintenance Lawn | Kentucky 31 or VCIA approved Turf-Type Tall Fescue | 150 – 200 |
| | Hybrid Bermudagrass (seed) ** | 40 (unhulled) |
| | Hybrid Bermudagrass (by other vegetative establishment method refer to Bermudagrass & Zoysiagrass Establishment [C-SSM-07]) | 30 (hulled) |
| General Slope (3H:1V or less) | Tall Fescue and/or Hard Fescue | 50 – 75 |
| | Red Top Grass | 5 – 10 |
| | Annual Lespedeza and/or White Clover*** | 10 – 20 |
| | Seasonal Nurse Crop **** | 30 – 40 |
| Low-Maintenance Slope | Tall Fescue and/or Red/Hard Fescue | 75 – 100 |

| Table C-SSM-10-8 Site-Specific Seeding Mixtures for Coastal Plain Area | | |
|---|---|---|
| **Site Condition** | **Seed Mix** | **Application Rate (pounds per acre)** |
| (Steeper than 3H:1V) | Common Bermudagrass ** | 0 – 15 |
| | Redtop Grass | 5 – 10 |
| | Annual Lespedeza and/or White Clover*** | 10 – 20 |
| | Seasonal Nurse Crop **** | 30 – 40 |

* Increase seed rate if only KY-31 is used.

** May through October, use hulled seed. All other seeding periods, use unhulled see. Weeping lovegrass may be added to any slope or low-maintenance mix during warmer seeding periods; add 10 - 20 pounds per acre in mixes.

*** Use legume seed that is properly inoculated with specified Rhizobia. Legumes recommended unless periodic N fertilization is intended. Weeping lovegrass may be added to any slope or low-maintenance mix during warmer seeding periods; add 10 to 20 lbs/acre in mixes.

***** Use seasonal nurse crop in accordance with seeding dates as stated below:

March 15 through August, foxtail/German millet

September, October through November 15 annual/cereal rye

November 16 through March 15, annual/cereal rye

Note: Seed mixes are suggested and subject to modification based on site-specific conditions by an agronomist or other qualified revegetation professionals. All seed rates expressed as PLS (Pure Live Seed; see Table C-SSM-10-9).

| Table C-SSM-10-9 Examples of Seed Purity Expectations for PLS Calculations | | |
|---|---|---|
| **Seed Type** | **Minimum Seed Purity (%)** | **Minimum Germination (%)** |
| **Legumes** | | |
| Lespedeza, Korean | 97 | 85** |
| **Grasses** | | |
| Bluegrass, Kentucky | 97 | 85 |
| Fescue, tall (Improved, Turf-Type Cultivars) | 98 | 85 |
| Fescue, tall (Ky-31) | 97 | 85 |
| Fescue, red | 98 | 85 |
| Redtop | 94 | 80 |
| | | |
| Perennial ryegrass | 98 | 90 |
| **Perennials** | | |
| Weeping lovegrass | 98 | 87 |
| **Annuals** | | |
| Annual ryegrass | 97 | 90 |

| Table C-SSM-10-9 Examples of Seed Purity Expectations for PLS Calculations | | |
|---|---|---|
| **Seed Type** | **Minimum Seed Purity (%)** | **Minimum Germination (%)** |
| German millet | 98 | 85 |
| Oats | 98 | 80 |
| Cereal rye | 98 | 85 |

* Do not accept seed containing prohibited or restricted noxious weeds. Do not use seed containing more than 0.5 percent weed seed. To calculate percent pure, live seed, multiply germination times purity and divide by 100. Use seed certified by VCIA and/or recommended by VDOT Green Tag program.

Example: VCIA/VDOT Green Tag Tall Fescue with a germination of 85% and a purity of 98%:

100 lbs of VCIA certified seed would contain 98 lbs of pure tall fescue seed.

The same 100 lbs of VCIA certified seed would contain 98 x 0.85 = 83.3 lbs on a Pure Live Seed (PLS) basis.

If the prescribed rate for field application is 75 lbs/per acre, this would need to be applied at 90 lbs/acre.

** Includes "hard seed" that is presumed to germinate within one growing season.

| Table C-SSM-10-10 Ground Agricultural Limestone* (lbs./1,000 $ft^2$) needed to Correct pH Level of Acid Soils to 6.5 | | | |
|---|---|---|---|
| **Existing pH** | **Soil Texture** | | |
| | **Sandy Loam** | **Loam** | **Clay Loam** |
| 6.2 | 20 | 35 | 40 |
| 6.0 | 40 | 55 | 70 |
| 5.8 | 55 | 65 | 85 |
| 5.6 | 70 | 80 | 105 |
| 5.4 | 90 | 100 | 125 |
| 5.2 | 105 | 120 | 140 |
| 5.0 | 120 | 140 | 160 |
| 4.8 | 125 | 180 | 205 |
| 4.6 | 155 | 210 | 230 |
| 4.0 | 200 | 250 | 300 |

* Apply lime in accordance with the results of a soil test, such as may be obtained through the soil testing laboratory at Virginia Tech or through a reputable commercial laboratory.

## 8.0 References

VDEQ. 1992. Virginia Erosion and Sediment Control Handbook. Third ed. Available online at: https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/handbooks.

Virginia Department of Conservation and Recreation (DCR). 2022. Virginia Invasive Plant Species List. https://www.dcr.virginia.gov/natural-heritage/invsppdflist (accessed August 16, 2023).

## 9.0 Appendix A Plant Information Sheets

**Plant Information Sheets**

Contents:

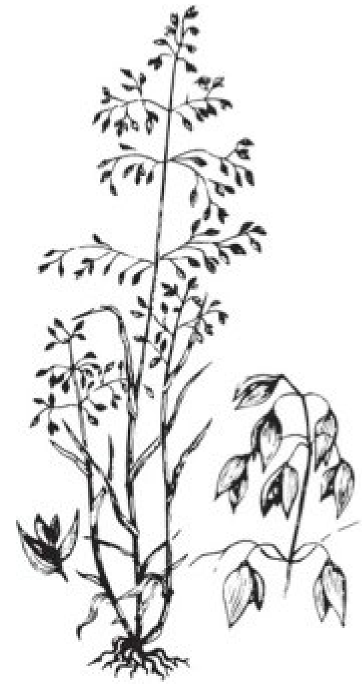


**Annual Grasses and Grains**

Small grains are cool-season annual grasses primarily grown for animal feed and human consumption. In Virginia, the grains used for soil stabilization are primarily rye and oats. Foxtail millet, which is sometimes considered a small grain, is becoming a very popular and successful planting for soil stabilization.

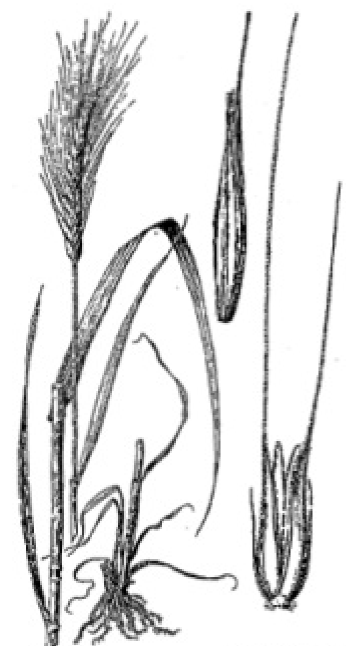
## Oats (*Avena sativa*)

A cool-season annual grass primarily grown for animal feed and human consumption but also used for soil stabilization. Oats are seeded in early spring in the western part of the state (winter oats may be sown in the Coastal Plain). Seeding rates are three bushels (100 lbs) per acre bare ground or 2.5 lbs per 1,000 $ft^2$.



## Rye (*Secale cereale*)

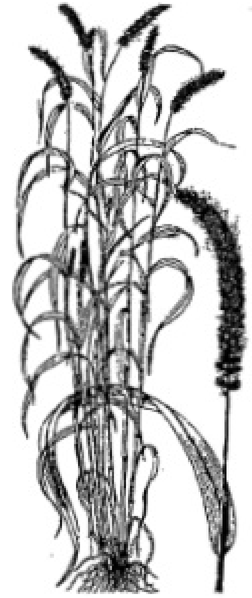
Often referred to as winter rye because of its winter hardiness, rye is the most common small grain used for soil stabilization. It is also the most productive grain on dry, infertile, acid, or sandy soils. It may be seeded in the fall for winter ground cover. By maturing early, it offers less competition during late spring, a critical time in the establishment of perennial species. Rye grain germinates quickly and is tolerant of poor soils. Including rye grain in fall-seeded mixtures is almost always advantageous, but it is particularly helpful on difficult and erodible soils, erodible slopes, or when seeding is late. Rates up to 100 lbs for bare ground. Overly thick stands of rye grain will suppress the growth of perennial seedlings. Approximately 50 lbs per acre is the maximum for this purpose and, where lush growth is expected, that rate should either be cut in half or rye grain should be eliminated from the mixture.



Rye (Secale cereale)

## Foxtail millet (*Setaria italica*)

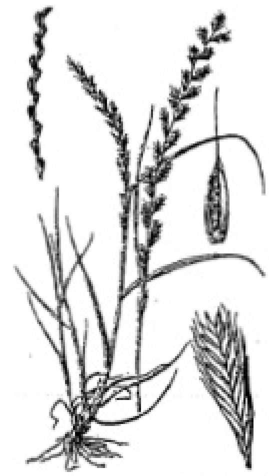
A warm-season annual grass that may be used for temporary cover. German millet (variety commonly used in Virginia) germinates quickly and goes to seed quickly. These features make it an excellent companion grass for summer seedlings. It dies at first frost. Seeding rates are up to 50 lbs per acre for temporary cover. Use 10 to 20 lbs per acre in mixes.



Foxtail Millet (*Setaria italica*)

**Annual rye (*Lolium multiflorum*)**

A cool-season annual grass used for temporary cover or as a nurse grass to allow for germination of permanent stands. Most used in mixes for erosion control. Performs well throughout the state in neutral to slightly acid soils. Rates up to 100 lbs per acre for temporary cover. Use 10 to 20 lbs per acre in mixes



Annual Rye (*Lolium multiflorum*)

**Perennials**

| **Tall fescue (*Festuca arundinacea*)** | |
|---|---|
| Uses | Pasture; hay; recreation areas; lawns; and stabilization of waterways, banks, slopes, cuts, fills, and spoils. It is the most widely used grass at this time for stabilizing large, disturbed areas. |
| Description | A robust, cool-season, long-lived, deep-rooted bunchy grass that may have short rhizomes (underground stems). Kentucky 31 is the best-known variety. New varieties of tall fescue are becoming available for lawn and other fine turf uses, and several offer definite improvements. However, their higher cost over the standard (Ky 31) is seldom justified when used for stabilization and erosion control. Tall fescue tolerates a wide range of seeding dates; however, except at high mountain elevations, it is most dependable when planted in fall. |
| Adaptation | Adapts well to both high- and low-maintenance uses throughout Virginia. Adapted to a wide range of climatic conditions. Optimum pH range is 6.0 to 7.0; will tolerate from 3.0 to 8.0. Will grow on shallow and claypan soils if they are moist. Growth is limited more by moisture than by temperature extremes, but it will tolerate drought, infertile soils, and moderate shade. |
| Establishment | Requires a firm seedbed. Hydroseeding is successful. Seeding rates vary from 100 lbs per acre for erosion control to 250 lbs per acre for lawns. Plant in early spring or from the middle of August through September. Legumes may not thrive in fescue stands due to the aggressive growth habits of this grass. Mowing is desirable on critical areas at least once every 2 years; lack of periodic mowing will encourage clumping of grass. |
| Sources | Readily available as seed and sod. |

*Tall Fescue (Festuca arundinacea)*

| Kentucky bluegrass (*Poa pratense*) | | |
|---|---|---|
| Uses | Pasture, turf for lawns, athletic fields, golf courses, and playgrounds. Also used to stabilize waterways, slopes, cuts, and fills. Choice food for grouse, turkeys, deer, and rabbits. |  Kentucky Bluegrass (Poa pratense) |
| Description | Long-lived, cool-season perennial grass that forms a dense sod. Becomes dormant in the heat of summer because its growing season is spring and fall. | |
| Adaptation | Best adapted to well-drained, fertile soils of limestone origin and the climate of northern and western Virginia. Optimum pH range is 6.0 to 7.0. Bluegrasses are better suited to high-maintenance situations in the transition zone.<br>Essentially dormant during dry or hot weather; however, bluegrass will normally survive severe drought. | |
| Establishment | Requires a firm, weed-free seedbed, and adequate fertilization (liberal phosphorus) and lime are important. Can be used with tall fescues at low rates. Minimum mowing height is 1.5 inches. Critical erosion areas may be mowed only once per year, if desired. This grass is usually seeded with a mixture of other grasses or legumes. Use several varieties of bluegrass together to ensure good stand survival. Bare ground rates are 120 lbs per acre. Overseed 1 to 1.5 lbs per 1,000 $ft^2$. | |
| Sources | Readily available as seed and sod. | |

| **Perennial ryegrass (*Lolium perrenne*)** | |
|---|---|
| Uses | Erosion control, soil improvement, lawns, pasture, and hay; newer varieties are excellent for high-traffic areas. |
| Description | Perennial ryegrasses are an excellent selection where rapid establishment is desired. Cool-season grass. Ryegrasses cross-pollinate freely, so “common ryegrass” may be a mixture of annual and perennial species. Certified seed of perennial ryegrass varieties is produced: Blaser, Palmer, Goalie, Fiesta II, Ranger, Regal, and Pennfine may be used in Virginia. |
| Adaptation | Throughout Virginia. Grows best on dark, rich soils in mild climates. Newer varieties have good drought tolerance but may require irrigation if under drought stress or heavy traffic. Will tolerate wet soils with good surface drainage. |
| Establishment | A firm, mellow surface over compact subsoils will provide good results. Seed in fall or spring. Perennial ryegrass may also be seeded in mid-August to early September. For turf, use a rate of 5 to 8 lbs per 1,000 $ft^2$. If seeded alone; lesser amounts are suitable in mixtures depending on the characteristics of the companion species.<br>Generally, not seeded alone except on athletic fields subject to intensive use.<br>Perennial ryegrass does best when used with bluegrass as 20 percent or less of the mixture. Ryegrasses germinate rapidly, which makes them particularly suited to disturbed-area stabilization and temporary seeding. Ryegrasses will tend to dominate stands in mixtures if the percentage is too high. |
| Sources | Readily available commercially. Take care to buy seed appropriate to the needs of the project. |

Perennial Ryegrass (Lolium perrenne)

| **Fine fescues (red fescue, hard fescue, Chewings fescue)** | |
|---|---|
| Uses | Excellent for shady, low-maintenance areas and north-facing slopes. May be used to stabilize waterways, slopes, banks, cuts, fills, and as a cover crop in orchards. |
| Description | Red fescue is a cool-season perennial that occurs in two forms: bunch type and creeping. Creeping red fescue forms a tight sod. The leaves of red fescue are narrow and wiry. Hard fescues are slow growing with excellent shade tolerance. |
| Adaptation | Shade-tolerant and somewhat drought-resistant once established. Grows well in sandy and acidic soils. Optimum pH range is 4.5 to 6.0. Prefers well-drained soils but requires adequate moisture for establishment. In areas of high temperature and humidity (such as southeastern Virginia), some fine fescues may turn brown or deteriorate during the summer. Newer varieties of hard fescue are more drought tolerant. |
| Establishment | Rarely seeded in pure stands. Seedbed preparation and fertility adjustments are usually dictated by the other grasses in the mixture. Red fescues may comprise 25 to 60 percent by weight of a seeding mixture. In shaded areas, red fescue may be the key grass in the mixture. Do not mow consistently below 1.5 inches. |
| Sources | Readily available commercially. New hard fescues may be in short supply. |

*Red Fescue (Festuca rubra)*

| Bermudagrass (*Cynodon dactylion*) | | |
|---|---|---|
| Uses | Soil and water conservation, pasture, hay, silage, lawns, both high-maintenance and general-purpose turf, and stabilization of grassed waterways. | <br>Bermudagrass (Cynodon dactylion) |
| Description | A long-lived, warm-season perennial that spreads by stolons and rhizomes (runners and underground stems). Height of stems of common Bermudagrass may be 12 inches.<br>The stems are short-jointed and the leaves flat and spreading. Common Bermudagrass may be established vegetatively with sprigs (sections of stems) or from seeds; however, this grass has the potential to develop into a weed problem because it spreads vigorously. Cold-tolerant hybrids are usually specified.<br>These are traditionally established from sprigs or sod, but seed is now available. | |
| Adaptation | Southern Piedmont and Coastal Plain in Virginia and some southern Appalachian ridges and valleys. Refer to Bermudagrass and Zoysiagrass Establishment (C-SSM-07) for regional adaptations of varieties. Makes its best growth when average daily temperatures are above 75 degrees Fahrenheit. Grows on a wide range of soils from heavy clays to deep sands. Optimum pH is 6.0 to 6.5. It is drought- resistant and salt-tolerant.<br>Tolerates floods of short duration but will not thrive on waterlogged soils; does not persist under heavy shade. For rough areas, the varieties Midland (a forage hybrid) and Coastal are recommended. For fine-turf areas, Tufcote (a fine-leaved turf hybrid), Midiron, Tifway, and Vamont are used in Virginia. | |
| Establishment | By sodding or planting sprigs. Plant sprigs (by hand or machine) when soil is warm in a well-prepared, moist seedbed. Extend one end of the sprig aboveground, and cover the other end with firmly packed soil. | |
| Sources | Readily available as seed, sprigs, and sod. | |

**Miscellaneous Erosion Control Grasses**

| Weeping lovegrass (*Eragrostis curvula*) | |
|---|---|
| Uses | Fast-growing cover for erosion control. In the northeast, weeping lovegrass acts as a summer annual. The normal life of 3 to 5 years may be foreshortened by low winter temperatures. May provide permanent cover on southern exposure. |
| Description | A rapid-growing, warm-season bunchgrass introduced from East Africa. The long, narrow leaves are numerous, very fine, and droop over to the ground, hence the name. Leaf height is rarely above 12 inches. |
| Adaptation | Prefers light-textured, well-drained soil; will thrive on soil of low fertility. Low winter temperatures may deplete stand. |
| Establishment | Easy to establish by seed; germinates rapidly and grows quickly. Lime and fertilizer needs are similar to those of tall fescue and ryegrass.<br>Requires pH of 5.5 or higher. May be planted any time after danger of frost and throughout the summer. Very fine seed, commonly added to erosion control seed mixtures. Use of hydroseeders is successful if the seeding rate is increased to compensate for the lack of a firm seedbed. Normal seeding rates are 5 to 20 lbs per acre in mixes. |
| Sources | Readily available from large seed companies. |

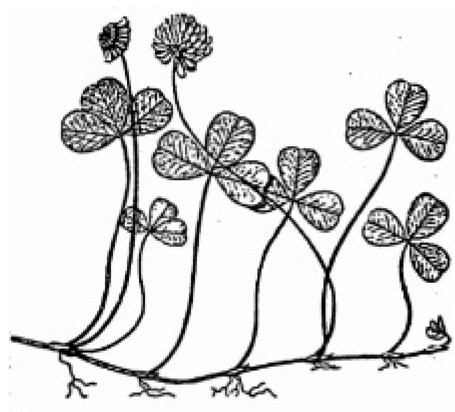
Weeping Lovegrass (*Eragrostis curvula*)

| **Redtop (*Agrostis alba*)** | |
|---|---|
| Uses | Erosion control, pasture, companion grass in turf seedings and stabilizing ditch and channel banks, grassed waterways, and other disturbed areas. |
| Description | A coarse, cool-season perennial grass with rhizomes (underground stems). Grows to 30 to 40 inches. |
| Adaptation | Throughout Virginia; does better in the cool, humid areas. Will grow under a wide variety of soil and moisture conditions. Grows on very acid soils (pH 4.0 to 7.5) and poor, clay soils of low fertility. While drought-resistant, it is also a useful wetland grass. |
| Establishment | Has very small seed and requires a compact seedbed. May be sown in early spring or late summer. Seldom seeded alone except as temporary turf. Adequate fertilization is essential on critical areas to obtain good cover rapidly. Mostly added to mixes, usually 2 to 3 lbs per acre. Redtop will disappear from a stand under frequent low mowing. |
| Sources | Available from commercial sources. |

Redtop (*Agrostis alba*)

| **Flatpea (*Lathyrus sylvestris*)** | | |
|---|---|---|
| Uses | Flatpea is an erosion control plant that provides a thick mat of vegetative cover, fixes nitrogen in the soil, and can be maintained with a minimum of management. It is useful on road banks, dams, borrow area, gravel pits, surface mine spoil, and industrial waste areas. It is an ideal plant for stabilizing logging roads and utility rights-of-way because it will restrict the invasion of many woody species. It also provides good wildlife cover and food. | |
| Description | A cool-season perennial legume. It will climb to a height of 6 to 7 feet if support is available, but the normal height is 2 to 3 feet. | |
| Adaptation | Flatpea is adaptable to a wide variety of soil conditions. It is drought-tolerant; cold-hardy; and does well on low-fertility sites such as sands, gravels, and soils from acidic sandstones. It is not adapted to wet sites, but it will grow on somewhat poorly drained soils. It will tolerate minor shade and a minor degree of flooding. The optimum pH range is from 6.0 to 6.5. The only available variety is Lathco, developed by the USDA Soil Conservation Service. |  Flatpea (Lathyrus sylvestris) |
| Establishment | Use only inoculated seed. Scarify the seedbed if possible. The seed is normally drilled or band seeded, but on rough sites or steep slopes, it can be broadcast and then worked into the soil by light dragging. Where possible, install a light application of mulch, properly anchored, to ensure a good stand. Lime application is essential if the soil pH is below<br><br>5.0. Fertilize according to a soil test or apply 400 lbs per acre of 10-20-10 fertilizer. Work lime and fertilizer into soil when preparing the seedbed. For a primary stand, use a seeding rate of 30 to 40 lbs in a mixture with 8 to 10 lbs of perennial ryegrass or 10 to 15 lbs of tall fescue.<br><br>Flatpea is slow to germinate, so plant grasses to provide quick cover. Early spring seedings in April or May are best; June seedings are less desirable. Grass seedings may be overseeded with flatpea from November through March. Flatpea is usually not winter-hardy if seeded in mid or late summer; therefore, dormant seedings are recommended. Mulch with straw at a minimum rate of 1.5 tons per acre on all critical sites and anchor. Little management is required. Remove woody vegetation if the site is invaded. Mowing is acceptable once the stand is established. Mow after full bloom at a 6-inch minimum height. | |

| | |
|---|---|
| Sources | Lathco is commercially available. |

| **White clover (*Trifolium repens*)** | | |
|---|---|---|
| Uses | Common white clover is used mostly for pastures. Ladino clover, a giant white clover, is also used for hay and silage in mixtures with a grass. The thick growing, spreading characteristics of the common type make it ideal for erosion control. |  White Clover (Trifolium repens) |
| Description | A cool-season perennial legume. The common type has a prostrate type of growth, while the Ladino is more upright. Both spread by stolons (horizontal branches along ground) and by roots at the nodes. Representative common varieties used in Virginia are Tillman, common, and white Dutch. Ladino is the only cultivar for the large type. | |
| Adaptation | Thrives in cool climates and on moist, rich soils with full sun. Will not tolerate extremes of cold or drought. Where soil moisture is not adequate, Ladino is short-lived. Optimum soil pH is 6.5, but it will grow in a range of 5.0 to 7.5. Common white clover volunteers readily in bluegrass mixtures where moderate to high fertility is maintained. Stands are persistent. | |
| Establishment | Ladino clover requires inoculation, fertilizing, and liming for successful growth. Phosphorus and potash are the key fertilizer elements required. Ladino makes a good companion crop with grasses such as orchardgrass, bromegrass, and tall fescue. These grasses will normally crowd out the Ladino after 2 to 3 years. Plant seed (drilled or broadcast) at shallow depths, and a firm seedbed is desirable. | |
| Sources | Available commercially. | |

# C-SSM-11 Mulching

## 1.0 Definition

Mulching is the application of a protective blanket of straw or other plant residues/materials to the soil surface during the establishment of temporary and permanent seeding.

## 2.0 Purpose and Applicability of Best Management Practice

The purposes of mulching are:

1. To prevent erosion by protecting the soil surface from raindrop impact and reducing the velocity of overland water flow.
2. To foster the growth of vegetation by increasing available moisture levels and providing insulation against extreme heat and cold.

Mulches can increase the infiltration rate of the soil, reduce soil moisture loss by evaporation, prevent crusting and sealing of the soil surface, modify soil temperatures, and provide a suitable microclimate for seed germination.


*Source: James Madison University*

Mulching applies in the following conditions:

1. Mulch areas that have been permanently seeded (see Permanent Seeding, BMP C-SSM-10) immediately following seeding.
2. Mulch areas that cannot be seeded because of the season to provide some protection to the soil surface. Use an organic mulch, and then seed the area as soon as weather or seasonal conditions permit. Do not use fiber mulch alone for this practice, as at normal application rates, it does not provide adequate protection.
3. Mulch may be used together with plantings of trees, shrubs, or certain ground covers that do not provide adequate soil stabilization by themselves.
4. Use mulch in conjunction with temporary seeding operations as specified in Temporary Seeding (BMP C-SSM-09).

## 3.0 Planning and Considerations

Mulches are applied to the soil surface to conserve a desirable soil property or to promote plant growth. A surface mulch is one of the most effective means of controlling runoff and erosion on disturbed land.

Organic mulch materials, such as straw, wood chips, bark, and fiber mulch, have been found to be the most effective.

Do not use chemical soil stabilizers or soil binders alone for mulch. These materials are useful to bind organic mulches together to prevent displacement.

Multiple manufactured Soil Stabilization Blankets and Matting (BMP C-SSM-05) have been developed for erosion control in recent years. Some of these products can be used as mulches, particularly in critical areas such as waterways. Soil stabilization blankets may be used to hold other mulches to the soil surface.

The choice of materials for mulching will be based on the type of soil to be protected, site conditions, season, and economics. It is especially important to mulch liberally in midsummer, before winter, and on cut slopes and southern slope exposures.

*Source: Iowa DNR*

| Table C-SSM-11-1 Design Considerations for Organic Mulches | |
|---|---|
| **Mulch** | **Notes on Proper Use** |
| Straw | Straw is most used in conjunction with seeding. Use straw that comes from wheat or oats (free of troublesome weed seeds) and spread by hand or machine. Anchor down straw by an acceptable method, as the straw can be windblown. |
| Hay | Hay may be used in lieu of straw where volunteer germination will not present a problem and may be spread by hand or machine. Anchor or tack down hay that can be windblown. |
| Corn Stalks | Shred corn stalks into 4- to 6-inch lengths. Stalks decompose slowly and are resistant to displacement. |
| Wood Chips | Wood chips are suitable for areas that will not be closely mowed and around ornamental plantings. Place wood chips at 2 to 7 inches of depth. Chips decompose slowly and do not require tacking. Treat wood chips with 12 pounds of nitrogen per ton to prevent nutrient deficiency in plants; however, wood chips can be a very inexpensive mulch if obtained from trees cleared on the site. |
| Bark Chips, Shredded Bark | Bark chips and shredded bark are by-products of timber processing used in landscaped plantings. Bark is also a suitable mulch for areas planted with grasses and not closely mowed. Bark may be applied by hand or mechanically and is not usually toxic to grasses or legumes; additional nitrogen fertilizer is not required. Place bark at a rate of 35 cubic yards per acre. |

| Table C-SSM-11-1 Design Considerations for Organic Mulches | |
|---|---|
| **Mulch** | **Notes on Proper Use** |
| Fiber Mulch | Fiber mulch is used in hydroseeding operations and applied as part of the slurry. It creates the best seed-soil contact when applied atop (as a separate operation) newly seeded areas. These fibers do not require tacking, although tacking agents or binders are sometimes used in conjunction with the application of fiber mulch. This form of mulch does not sufficiently protect highly erodible soils. Additionally, fiber mulch is not adequate when used during the dry summer months or when used for late fall mulch cover. Use straw mulch during these periods. Fiber mulch may be used to tack (anchor) straw mulch. This treatment is well suited for steep slopes, critical areas, and areas susceptible to displacement. Apply fiber at a maximum of rate 2,000 pounds per acre. |
| Other Organic Materials | There are other organic materials that make excellent mulches but are only available locally or seasonally. Creative use of these materials can reduce costs. |
| Chemical Mulches and Soil Binders | A wide range of synthetic, spray-on materials is marketed to stabilize and protect the soil surface. These include emulsions or dispersions of vinyl compounds, rubber, or other substances mixed with water and applied to the soil. These materials may be used alone in some cases as temporary stabilizers or in conjunction with fiber mulches or straw.<br><br>When used alone, chemical mulches are not capable of insulating the soil or retaining soil moisture like organic mulches and do not have good characteristics for an aid in seeding establishment. This soil protection is also easily damaged by traffic. Application of these mulches is usually more expensive than organic mulching, and the mulches decompose in 60 to 90 days.<br><br>Check labels on chemical mulches and binders for environmental concerns. Take precautions to avoid damage to fish, wildlife, and water resources. |

| Table C-SSM-11-1 Design Considerations for Organic Mulches | |
|---|---|
| **Mulch** | **Notes on Proper Use** |
| Netting, Blankets, and Mats | Netting is very effective at holding mulch in place on waterways and slopes before grass can be established.<br><br>Field experience has shown that plastic netting, when used alone, does not retain soil moisture or modify soil temperature. In some cases, netting may stabilize the soil surface while grasses are establishing but is primarily used in grassed waterways and on slopes to hold straw or similar mulch in place.<br><br>Jute mesh and other soil stabilization blankets are good choices for mulching on difficult slopes and in minor drainage swales. Most of the soil stabilization mattings (used to create a permanent matrix for root growth within the soil) must be mulched to properly stabilize an area. Notably, some manufacturers have recently developed permanent mattings that include self-contained, temporary mulching materials; however, these measures will have to meet the requirements noted in Soil Stabilization Blankets and Matting (BMP C-SSM-05) before they can be recommended for use on steep slopes and in channel flow situations.<br><br>The most critical aspect of installing blankets and mats is obtaining firm, continuous contact between the material and the soil. Without such contact, the material may fail and allow erosion to occur. It is important to use an adequate number of staples and make sure the material is installed properly to maximize soil protection. These products are discussed in more detail in Soil Stabilization Blankets and Matting (BMP C-SSM-05). |

## 4.0 Stormwater Performance Summary

### 4.1 MS-1: Stabilization

Permanent or temporary soil stabilization should be applied to denuded areas within 7 days after final grade is reached on any portion of the site. Temporary soil stabilization should be applied within 7 days to denuded areas that may not be at final grade but will remain dormant for longer than 14 days. Permanent stabilization should be applied to areas to be left dormant for more than 1 year.

**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: Low**

## 5.0 Design Criteria

Be aware of the slope, soil, and water availability in the specific location proposed for the use of mulching. Consult with the design engineer before making any assumptions/modifications to the specifications in the approved plan.

## 6.0 Construction Specifications

| Table C-SSM-11-2 Construction Specifications for Organic Mulches | |
|---|---|
| **Parameter** | **Instructions** |
| Criteria | Organic mulches may be used in any area where mulch is required, subject to the restrictions noted in Table C-SSM-11-5. Organic mulches are effective where they can be tacked securely to the surface of the soil. |
| Materials | Select materials based on site requirements, availability of materials, and availability of labor and equipment. Table C-SSM-11-5 lists the most used organic mulches. Other materials, such as peanut hulls and cotton burs, may be used with the permission of the certified plan reviewer. |
| Prior to Mulching | Before mulching, complete the required grading and install necessary sediment control practices. Apply lime and fertilizer seed and complete surface roughening as needed before mulching except in the following circumstances.<br>Seed is applied as part of a hydroseeder slurry containing wood fiber mulch.<br>A hydroseeder slurry is applied over straw. |
| Application | Spread mulch materials uniformly by hand or machine. When spreading straw mulch by hand, divide the area to be mulched into approximately 1,000-square-foot sections and place 70 to 90 pounds (1.5 to 2 bales) of straw in each section to facilitate uniform distribution. After spreading mulch, ensure no more than 25% of the ground is visible. When using a hydroseeder, confirm the use of a green dye to ensure the seed is spread uniformly across the ground. |

Straw mulch must be anchored immediately after spreading to prevent displacement. Other organic mulches listed in Table C-SSM-11-5 do not require anchoring. Use the following methods of anchoring straw.

| Table C-SSM-11-3 Mulch Anchoring Specifications | |
|---|---|
| **Method** | **Notes on Proper Use** |
| Mulch Anchoring Tool | A tractor-drawn implement designed to punch mulch into the soil surface, often referred to as a Krimper or Krimper tool. This method provides good erosion control with straw. It is limited to use on slopes no steeper than 3H:1V, where equipment can operate safely. Operate machinery along the contour. |
| Fiber Mulch | A very common practice with widespread use today. Apply fiber mulch by means of a hydroseeder at a rate of 500 to 750 pounds per acre atop straw mulch or hay. Fiber mulch has an added benefit of providing additional mulch to the newly seeded area. |
| Mulch Nettings | Lightweight plastic, cotton, or paper nets may be stapled over the mulch according to manufacturer's recommendations. |

| Table C-SSM-11-3 Mulch Anchoring Specifications | |
|---|---|
| **Method** | **Notes on Proper Use** |
| Peg and Twine | Because it is labor-intensive, this method is feasible only in small areas where other methods cannot be used. Drive 8- to 10-inch wooden pegs 3 inches into the soil surface every 4 feet in all directions. Stakes may be driven before or after straw is spread.<br><br>Secure mulch by stretching twine between pegs in a crisscross-within-a square pattern. Turn twine two or more times around each peg. |
| Vegetation | Rye (grain) may be used to anchor the mulch in fall plantings and German millet in the spring. Broadcast at 15 pounds per acre before applying mulch. |
| Liquid Mulch Binders | Ensure application of liquid mulch binders and tackifiers is heaviest at edges of mulched areas and at crests of ridges and banks to prevent displacement. Uniformly apply the binder to the remainder of the area. Binders may be applied after mulch is spread or may be sprayed into the mulch as it is being blown onto the soil. Straw and binder together are noted as the most effective method.<br><br>The following types of binders may be used:<br><br>**Synthetic Binders:** Formulated binders or organically formulated products may be used as recommended by the manufacturer to anchor mulch.<br><br>**Asphalt:** Any type of asphalt thin enough to be blown from spray equipment is satisfactory. Use rapid-curing (RC-70, RC-250, RC-800), medium-curing (MC-250, MC- 800), and emulsified asphalt (SS-1, CSS-1, CMS-2, MS-2, RS-1, RS-2, CRS-1, and CRS-2).<br>Apply asphalt at 0.1 gallon per square yard (10 gal./1000 sq. ft. or 430 gal./acre). Do not use heavier applications, as it may cause the straw to “perch” over rills. All asphalt designations are from the Asphalt Institute Specifications. In traffic areas, uncured asphalt can be picked up on shoes and cause damage to the indoors of buildings/houses. Use RS or CRS types to minimize any potential risk.<br><br>*Note: This method is not used as commonly as it once was. The development of hydraulic seeding equipment has encouraged the industry to turn to synthetic or organically based binders and tackifiers. When this method is used, environmental concerns should be addressed to ensure that petroleum-based products do not enter water supplies. Avoid applications into waterways or channels. |

| Table C-SSM-11-4 Chemical Mulch Specifications | |
|---|---|
| **Mulch Type** | **Notes on Proper Use** |
| Chemical Mulches | Chemical mulches* may be used alone only in the following situations: Where no other mulching material is available.<br><br>In conjunction with temporary seeding when mulch is not required for that practice.<br>From March 15 to May 1 and August 15 to September 30, provided they are used on areas with slopes no steeper than 4H:1V that have been roughened in accordance with Surface Roughening (C-SSM-03). If rill erosion occurs, another mulch material will be applied immediately.<br><br>*Note: Chemical mulches may be used to bind other mulches or with fiber mulch in a hydroseeded slurry at any time. Manufacturer's recommendations for application of chemical mulches will be followed. |

| Table C-SSM-11-5 Organic Mulch Materials and Application Rates | | | |
|---|---|---|---|
| **Mulches** | **Rates** | | **Notes** |
| | **Per Acre** | **Per 1,000 ft²** | |
| Straw or Hay | 1.5 to 2 tons | 70 to 90 lbs. | Free from weeds and coarse matter. Must be anchored. Spread with mulch blower or by hand. Use a minimum of 2 tons per acre for winter cover. |
| Fiber Mulch | 1,500 lbs. | 35 lbs. | Do not use as mulch for winter cover or during hot, dry periods. Apply as slurry. When fiber mulch is the only available mulch during periods when straw should be used, apply at a minimum rate of 2000 lbs./acre or 45 lbs./1,000 $ft^2$. |
| Corn Stalks | 4 to 6 tons | 185 to 275 lbs. | Cut or shredded in 4- to 6-inch lengths. Air-dried. Do not use in fine turf areas. Apply with mulch blower or by hand. |
| Wood Chips | 4 to 6 tons | 185 to 275 lbs. | Free of coarse matter. Air-dried. Treat with 12 lbs. nitrogen per ton. Do not use in fine turf areas. Apply with mulch blower, chip handler, or by hand. |
| Bark Chips or Shredded Bark | 50 to 70 cy | 1 to 2 cy | Free of coarse matter. Air-dried. Do not use in fine turf areas. Apply with mulch blower, chip handler, or by hand. |
| Source: Va. DSWC | | | |

## 7.0 Operations and Maintenance Considerations

Inspect all mulches and soil coverings periodically and after rainstorm events to check for erosion. Where erosion is observed in mulched areas, apply additional mulch. Inspect nets and mats after rainstorms for dislocation or failure. If washouts or breakage occur, reinstall netting or matting as necessary after repairing damage to the slope or ditch. Inspect mulches until grasses are firmly established.

Where mulch is used in conjunction with ornamental plantings, inspect periodically throughout the year (approximately every 3 months) to determine if mulch is maintaining coverage of the soil surface; repair as needed.

## 8.0 References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# CHAPTER 8 DESIGN SPECIFICATIONS FOR POST-CONSTRUCTION BMPS

**Contents:**

# 8.1 Introduction to the New Virginia Post-Construction Stormwater Best Management Practices

The application of post-construction stormwater best management practices (BMPs) has continued to advance since the previous publications of the Virginia Department of Environmental Quality (VDEQ) handbooks. This chapter provides an overview of the various types of post-construction stormwater BMPs that may be constructed during site development with the intent of maintaining hydrologic balance and meeting water quality requirements within the watershed after development.

# 8.2 Significant Updates

Several significant updates to post-construction stormwater BMPs have been introduced with this new Handbook. The updates include not only additional guidance and BMPs for the designer, but an updated framework, numbering, and nomenclature used to integrate the construction and post-construction BMPs into one guidance framework, as introduced and implement in Chapter 7.

## 8.2.1 Post-Construction Stormwater BMP Framework

The specifications framework for post-construction stormwater BMPs has been developed as an integrated framework with the construction BMPs described in Chapter 7 and is described below:

- **Definition** – The clear and distinct description of the BMP.
- **Purpose and Applicability of Best Management Practice** – This section describes the purpose of the BMP and the general conditions under which the BMP should be considered for specification. This section can provide guidance in the selection of the appropriate BMP for the project; this section is not intended to be directing in nature.
- **Planning and Considerations** – This section provides guidance for consideration in the selection of BMPs as it relates to potential environmental and community impacts and infers how the BMP may interact with the surrounding environment. This is where the designer may find “rules of thumb” or other standards of practice related to the BMP. The purpose of this section is to provide guidance in the selection of the appropriate BMP for the project; this section is not intended to be directing in nature.
- **Stormwater Performance Summary** – This section of the specification provides guidance to the designer in selection of the appropriate BMPs to comply with the runoff reduction and phosphorus removal requirements of the Virginia Stormwater Management Regulation. This section also provides a rating for nitrogen reduction removal efficiency of the BMP, although not required at the site design level. This section typically outlines varying degrees of runoff reduction and treatment efficiency (design levels) and the BMP design guidelines to achieve the established performance criteria.
- **Design Criteria** – This section provides the design criteria that must be followed to properly implement the BMP. For most practices, designers may choose to go with a traditional baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient and runoff reduction. These two levels have specific design requirements and receive different removal performance credits.
- **Construction Specifications** – This section provides detailed installation, materials, and assembly directions for the construction of the BMP. Construction details are also included in this section.
- **Operations and Maintenance Considerations** – This section provides detailed guidance on the operations and maintenance required to ensure adequate performance of the BMP.

### 8.2.2 Post-Construction Stormwater BMP Numbering and Nomenclature

The post-construction stormwater BMPs identified within this chapter feature a leading ‘P’ in the nomenclature to designate the BMP as a “Post-Construction Stormwater BMP.”

The nomenclature following the “P” identifies the subcategory of post-construction BMP:

- P-BAS – Basins;
- P-CNV – Conveyance;
- P-FIL – Filtration and Infiltration; and
- P-SUP – Support Components.

## 8.3 Overview of Best Management Practices

The following are summary overviews of the post-construction stormwater BMPs specified for use in Virginia. Complete standards and specifications for these practices are provided within this chapter.

The post-construction stormwater BMPs are numbered and categorized as follows:

### 8.3.1 Basins – P-BAS

These are post-construction stormwater BMPs that are typically designed to detain or impound runoff. These practices typically provide little to no infiltration. These BMPs provide treatment through settling, runoff reduction and biologic uptake. The BMPs within this category include:

- P-BAS-01 Constructed Wetlands;
- P-BAS-02 Wet Pond;
- P-BAS-03 Extended Detention Pond; and
- P-BAS-04 Rainwater Harvesting.

### 8.3.2 Conveyance – P-CNV

These post-construction BMPs are typically used in applications that receive a sustained concentrated flow of

runoff or cross significant changes in grade. These BMPs provide filtration, infiltration and settling within the conveyance system. The BMPs within this category include:

- P-CNV-01 Grass Channels;
- P-CNV-02 Dry Swales;
- P-CNV-03 Wet Swales; and
- P-CNV-04 Regenerative Stormwater Conveyance.

### 8.3.3 Filtration and Infiltration – P-FIL

These BMPs are typically installed to filter runoff through a natural or engineered medium. Filtering practices provide no infiltration. However, some filtering practices such as Bioretention could be designed with infiltration. The BMPs within this category are:

- P-FIL-01 Rooftop/Impervious Surface Disconnection;

- P-FIL-02 Vegetated Roof;
- P-FIL-03 Permeable Pavement;
- P-FIL-04 Infiltration Practices;
- P-FIL-05 Bioretention;
- P-FIL-06 Filtering Practices;
- P-FIL-07 Sheet Flow to Vegetated Filter Strip/Conserved Open Space;
- P-FIL-08 Soil Compost Amendment; and
- P-FIL-09 Tree Planting.

### 8.3.4 Support Components – P- SUP

A new feature to the Handbook is the addition of support components. These components provide more generalized information that can be used across multiple BMPs (i.e., pre-treatment). Information contained within is to be used in combination with other BMPs described in this Handbook. These support components are outlined as follows:

- P-SUP-01 Earthen Embankment;
- P-SUP-02 Principal Spillway;
- P-SUP-03 Vegetated Emergency Spillway;
- P-SUP-06 Pretreatment; and
- P-SUP-07 Quantity-Only Approach to BMPs.

## 8.4 Overview of Manufactured Treatment Devices

Stormwater treatment can be provided by public domain practices, proprietary products, or "manufactured treatment devices" (MTDs). MTDs are engineered structural treatment devices that are commercially available to remove pollutants of interest from runoff.* VDEQ categorizes these MTDs as:

- Hydrodynamic devices;
- Filtering devices; and
- Biofilter devices.

The VDEQ credits the level of treatment provided by MTDs based on the evaluation results described in Section 8.4.4. This process considers performance testing data provided by recognized testing and verification programs as well as independent research and testing efforts designed to capture the performance of MTDs. The VDEQ grants a total phosphorus (TP) removal credit based on the MTD category and submission. The TP removal efficiency values or ranges by MTD category are:

- Hydrodynamic devices = 20% TP removal efficiency; and
- Filtering and biofilter devices = 40%, 50%, or greater than 50% TP removal efficiency.

Sizing of MTDs is based on the hydraulic loading rate (HLR) of the MTD as well as the effective treatment area (ETA) of the model of MTD being used. The HLR of an MTD is defined as a flowrate per unit of ETA, with the most common specific unit being gallons per minute per square foot (gpm/sq ft).* The maximum treatment flowrate (MTFR) is the highest flowrate that can be conveyed through an MTD to achieve the verified performance-based claims for pollutant removal*. The MTFR is determined by multiplying the HLR of a MTD by the ETA of the MTD. The HLR is constant for any given MTD so MTFR will vary linearly with unit size.

To design an MTD, the designer must determine the influent discharge for the MTD and select the model of the MTD that has an MTFR equal to or greater than the influent discharge. Details on how this is accomplished are outlined in Section 8.4.4.3

** These terms are consistent with terminology defined by ASTM E64 on Stormwater Control Measures*

## 8.4.1 Hydrodynamic Devices – MTD-H

### 8.4.1.1 General Overview

Hydrodynamic MTDs are flow-through structures equipped with a settling or separation unit to remove sediments and other pollutants that are adsorbed to sediment particles, hydrocarbons, and floatable gross solids.

Hydrodynamic MTDs most commonly take the form of hydrodynamic separator (HDS) systems. These MTDs are widely deployed as stormwater treatment BMPs in stand-alone applications and pre-treatment MTDs in a treatment train. HDS systems target the removal of high specific gravity suspended solids (such as sand, grit, and degraded asphalt), free-floating oil, grease, trash, and debris.

These HDS systems are typically vertically oriented cylinders (manholes) or multi-chambered rectangular vaults containing a permanent water pool in the treatment chamber. The HDS systems may use special components (such as baffles, weirs, and screens) to direct the flow path, attenuate water velocity, and enhance the settling of particulates and the capture of oil and other floatables. Often HDS system MTDs use internal bypass features to prevent or minimize resuspension and washout of previously captured pollutants during extreme events which result in flows greater than the MTFR.

The primary treatment mechanisms used in HDS systems are gravity separation and spill capture. High specific gravity particulates settle by gravity to the sump of the MTD, and low specific gravity oil, trash, and debris float to the surface and are trapped. Common design features for HDS systems include floatable storage for the MTD to capture and retain an oil or fuel spill of substantial volume until maintenance can recover the spilled hydrocarbons.

Maintenance of HDS systems is typically performed with a vacuum truck to evacuate captured sediment and floatables from the unit. Maintenance is usually performed from the surface without confined space entry. Depending on pollutant loadings delivered to HDS systems, maintenance frequency can typically range from once per year to every 3 to 5 years.

The primary advantages of HDS systems include the treatment and removal of sand and grit at relatively high surface loading rates, the capture of floatable pollutants, the capture of oil and fuel spills, and relatively simple and low cost maintenance. Hydrodynamic separator systems are typically installed underground, which can further reduce the effective footprint. Internal bypass features common to HDS systems can also reduce the total system footprint because additional manholes and diversion structures are typically not required for external bypassing of very high flowrates during the most intense storms. HDS systems can effectively provide pre-treatment for other downstream post-construction BMPs and extend the maintenance interval for these downstream measures.

### 8.4.1.2 Hydrodynamic Devices in Virginia

The VDEQ currently approves the hydrodynamic MTDs listed in Table 8-1 to meet the TP water quality requirements of the Virginia Erosion and Stormwater Management Regulation. All approved hydrodynamic MTDs are credited with 20 percent TP removal efficiency. The approval does not reflect a VDEQ endorsement of the MTD, and VDEQ does not assist with MTD selection. The assigned event mean concentration (EMC) percent TP removal efficiency may be manually added into the Virginia Runoff Reduction Method (VRRM) spreadsheets to demonstrate water quality compliance. Further information on hydrodynamic MTDs is available on the VDEQ website at https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/bmp-clearinghouse/practice-16-hydrodynamic-devices.

**Table 8-1 Hydrodynamic MTDs Approved by VDEQ**

| MTD Name | BMP # | Hydraulic Loading Rate |
|---|---|---|
| Aqua-Swirl | MTD-H-01 | 33.4 gpm/ft$^2$ |
| Xcelerator | MTD-H-02 | 52.5 gpm/ft$^2$ |
| Barracuda Max Hydrodynamic Separator | MTD-H-03 | 54.2 gpm/ft$^2$ |
| Downstream Defender | MTD-H-04 | 40.0 gpm/ft$^2$ |
| First Defense Optimum | MTD-H-05 | 64.5 gpm/ft$^2$ |
| Continuous Deflective Separator (CDS) | MTD-H-06 | 33.2 gpm/ft$^2$ |
| Debris Separating Baffle Box (DSSB) | MTD-H-07 | 39.5 gpm/ft$^2$ |
| Cascade Separator Hydrodynamic System (HDS) | MTD-H-08 | 64.3 gpm/ft$^2$ |
| SciCloneX HDS | MTD-H-09 | 64.9 gpm/ft$^2$ |
| Dual Vortex Separator (DVS) | MTD-H-10 | 35.7 gpm/ft$^2$ |
| Nutrient Separating Baffle Box (NSBB) | MTD-H-11 | 34.9 gpm/ft$^2$ |
| HydroStorm Hydrodynamic Separator | MTD-H-12 | 31.4 gpm/ft$^2$ |
| HydroDome Stormwater Separator | MTD-H-13 | 54.0 gpm/ft$^2$ |
| SiteSaver | MTD-H-14 | 23.1 gpm/ft$^2$ |
| StormSettler | MTD-H-15 | 50.2 gpm/ft$^2$ |

gpm/ft$^2$ = gallon per minute per square foot

## 8.4.2 Filtering Devices – MTD-F

### 8.4.2.1 General Overview

Filtering by MTDs are becoming increasingly common for treating urban stormwater runoff. Filter treatment by MTDs is provided by trapping or straining pollutants and providing a potential platform for microbial breakdown of pollutants. Filtering MTDs are commonly used as stand-alone practices or in treatment train configurations. While performance varies by media type and gradation, filters typically target the treatment of finer sediments, and some media also effectively target dissolved pollutants such as metals and phosphorus.

Manufactured filtration systems are usually housed within rectangular vaults or round manhole structures. Many of these MTDs incorporate sumps or chambers to encourage sedimentation within the structure to reduce loading on the filtration media. Manufactured filtering treatment devices often use a customized filtration medium or porous membrane gradation to remove stormwater pollutants. Common media include expanded perlite, zeolite, sand, and other specialized media to target soluble contaminants through chemical processes. Media are generally housed in removable cartridges or compartments within a concrete vault or manhole structure. Flow enters the system and passes through the media, where solids are physically filtered from the flow stream and soluble pollutants attach to specialized media.

The performance of filtration MTDs is highly dependent on the gradation, depth, type of media, hydraulic loading rate, and pollutant characteristics. Media filters for stormwater treatment can remove fine silt particles and soluble metals and nutrients. Finer gradations of media can remove more pollutants but must operate at a lower hydraulic loading rate to avoid premature clogging and excessive maintenance. Many media filters can treat higher flows than those for which they are commonly designed for short durations. Still, longevity should be considered when designing media filters to avoid frequent maintenance requirements. Filtering MTDs tend to require a larger footprint than other flow-through treatment practices because of the need to maintain lower hydraulic loading rates to ensure both performance and longevity.

### 8.4.2.2 Filtering Devices in Virginia

The VDEQ currently approves the manufactured filtering treatment devices listed in Table 8-2 to meet the TP water quality requirements of the Virginia Erosion and Stormwater Management Regulation. The approval does not reflect a VDEQ endorsement of the MTD, and VDEQ does not assist with MTD selection. The assigned EMC percent TP removal efficiency may be manually added into the VRRM spreadsheets to demonstrate water quality compliance. Further information on filtering devices in Virginia is available at https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/bmp-clearinghouse/practice-17-filtering-devices.

**Table 8-2 Filtering MTDs Approved by VDEQ**

| MTD Name | BMP # | Hydraulic Loading Rate | Approved TP Removal Efficiency | Basis for VDEQ Approval |
|---|---|---|---|---|
| Aqua-Filter | MTD-F-01 | *7.93 gpm/ft²* | 40% | NJDEP |
| BayFilter using Enhanced Media Cartridges (EMC) | MTD-F-02 | 0.50 gpm/ft² * 0.33 gpm/ft² ** | 64% | TAPE TP GULD |
| StormTech Isolator Row Plus | MTD-F-03 | *4.13 gpm/ft²* | 40% | NJCAT |

| Table 8-2 Filtering MTDs Approved by VDEQ | | | | |
|---|---|---|---|---|
| **MTD Name** | **BMP #** | **Hydraulic Loading Rate** | **Approved TP Removal Efficiency** | **Basis for VDEQ Approval** |
| HydroFilter | MTD-F-04 | 2.0 gpm/ft$^2$ | 40% | NJDEP |
| HydroChain Vortex Filter (HCVF) | MTD-F-05 | 8.24 gpm/ft$^2$ | 40% | NJDEP |
| Jellyfish Filter | MTD-F-06 | 0.21 gpm/ft$^2$ | 65% | TAPE TP GULD |
| Kraken Filter | MTD-F-07 | 0.04353 gpm/ft$^2$ | 64.2% | TAPE TP GULD |
| StormFilter Phosphorb ZPG | MTD-F-08 | 1.67 gpm/ft$^2$ + 1.00 gpm/ft$^2$ ++ | 65% (Psorb) 40% (ZPG) | 50% (Psorb) TAPE TP GULD 40% (ZPG) TAPE Basic GULD |
| PerkFilter | MTD-F-09 | 1.50 gpm/ft$^2$ | 62.4% | TAPE TP GULD |
| StormKleener Filter Cartridge System | MTD-F-10 | 2.97 gpm/ft$^2$ | 40% | NJDEP |
| StormKeeper Sediment Strip | MTD-F-11 | *4.00 gpm/ft$^2$* | 40% | NJCAT |
| Up-Flo Filter Using Filter Ribbons | MTD-F-12 | 0.80 gpm/ft$^2$ | 50% | TAPE TP GULD |
| Up-Flo Filter Extended Maintenance Cartridge (EMC) | MTD-F-13 | 0.96 gpm/ft$^2$ | 40% | NJDEP |

Note: HLRs are based on a flowrate per treatment surface area, except for those listed in italics, which are based on a design element such as a chamber.

*For BayFilter models 545 and 522, **For BayFilter model 530; +For Phosphosorb, ++For ZPG

NJDEP = New Jersey Department of Environmental Protection

TAPE TP GULD = Washington State's Technology Assessment Protocol – Ecology (TAPE) Total Phosphorus General Use Level Designation

NJCAT = New Jersey Corporation for Advanced Technology

## 8.4.3 Biofilter Devices – MTD-B

### 8.4.3.1 General Overview

Manufactured biofilter treatment devices treat stormwater runoff through filtration by soil media or vegetation. These MTDs use the same treatment processes and mechanisms as filtering MTDs and have the added capacity for enhanced treatment of pollutants such as nutrients and metals because they integrate biological components or elements into the device.

An MTD that uses a biofiltration media can be configured such that the biological component is at surface level in the form of a tree box, planter box, or similar product type. To contrast, a biofilter MTD can locate the biofiltration media in a subsurface context by being incorporated into a vault or similar encasement.

### 8.4.3.2 Biofilter Devices in Virginia

The VDEQ currently approves the manufactured biofilter treatment devices listed in Table 8-3 to meet the TP water quality requirements of the Virginia Erosion and Stormwater Management Regulation. The approval does not reflect a VDEQ endorsement of the MTD, and VDEQ does not assist with MTD selection. The assigned EMC percent TP removal efficiency may be manually added into the VRRM spreadsheets to demonstrate water quality compliance.

**Table 8-3 Biofiltering MTDs Approved by VDEQ**

| MTD Name | BMP # | Hydraulic Loading Rate* | Approved TP Removal Efficiency | The Basis for VDEQ approval |
|---|---|---|---|---|
| Aqua-Ponic | MTD-B-01 | 7.00 gpm/ft$^2$ | 40% | NJDEP |
| Biopod | MTD-B-02 | 1.60 gpm/ft$^2$ | 64% | TAPE TP GULD |
| EcoPure Biofilter | MTD-B-03 | 1.00 gpm/ft$^2$ | 65% | TAPE TP GULD |
| FocalPoint High-Performance Media Biofiltration System | MTD-B-04 | 1.60 gpm/ft$^2$ | 60% | NJDEP, Other |
| Filterra HC Biofiltration | MTD-B-05 | 3.12 gpm/ft$^2$ | 40% | NJDEP |
| Filterra Biofiltration | MTD-B-06 | 1.00 gpm/ft$^2$ | 65% | TAPE TP GULD |
| Filterra Bioscape Biofiltration | MTD-B-07 | 1.00 gpm/ft$^2$ | 65% | TAPE TP GULD |
| Modular Wetlands Biofiltration | MTD-B-08 | 1.00 gpm/ft$^2$ | 58% | TAPE TP GULD |
| StormGarden | MTD-B-09 | 1.45 gpm/ft$^2$ | 50% | TAPE TP GULD |
| StormTree Biofiltration Practice | MTD-B-10 | 1.25 gpm/ft$^2$ | 62% | TAPE TP GULD |
| StormScape Filter | MTD-B-11 | 1.46 gpm/ft$^2$ | 40% | NJDEP |

*Note: HLRs are based on a flowrate per treatment surface area.

NJDEP = New Jersey Department of Environmental Protection

TAPE TP GULD = Washington State's Technology Assessment Protocol – Ecology (TAPE) Total Phosphorus General Use Level Designation

## 8.4.4 MTD Approval Process

Laws passed in the Virginia General Assembly specify the requirements VDEQ follows to enable the evaluation and approval of MTDs. The process has evolved over the last decade due to changes in the applicable laws.

The process outlined in this section reflects the current MTD evaluation and approval information.

### 8.4.4.1 MTD Evaluation Process

Chapter 32 of the 2022 Acts of Assembly (HB1224) provides for the certification and use of a proprietary BMP only if another state, regional, or national program has verified its nutrient or sediment removal effectiveness and all of such program's established test protocol requirements were met or exceeded. (Codified at § 62.1-44.15:28 12 of the Code of Virginia (Effective July 1, 2024)). The VDEQ is using the following procedural requirements to implement the law:

- Complete the Proprietary BMP Registration Statement (Word).
- Submit the completed registration statement and supporting documents to VDEQ's Rebeccah Rochet (Rebeccah.Rochet@deq.virginia.gov).
- The VDEQ will review submissions and assign the applicable percent TP removal efficiency if approved. After the percent removal has been assigned, this value will be added to the Virginia Stormwater BMP Clearinghouse, and the MTD may be used to meet the water quality design requirements.

The MTDs approved by VDEQ are listed by the following categories:

- Approved Hydrodynamic Devices (BMP MTD-H-XX);
- Approved Filtering Devices (BMP MTD-F-XX);
- Approved Biofiltering Devices (BMP MTD-B-XX); or
- Prior-approved Devices: Prior-approved Hydrodynamics and Prior-approved Filters — Proprietary BMPs on the prior-approved lists may only be used to meet the TP water quality requirements of the Virginia Erosion and Stormwater Management Regulation for stormwater management plans submitted before January 1, 2022.

### 8.4.4.2 VDEQ Evaluations

VDEQ has approved the MTDs listed in this document in accordance with § 62.1-44.15:28 of the Code of Virginia and 9VAC25-870-65 D of the Virginia Erosion and Stormwater Management Regulation.

For each approved MTD, the following information is provided:

- VDEQ approval letter;
- Web link to view specifications and other product information;
- Vendor contact information; and
- Information reviewed by VDEQ.

### 8.4.4.3 Sizing Information

To obtain the approved pollution removal efficiency for the MTD being used, the MTD must be sized appropriately. The MTD vendor and design professional are responsible for adequately sizing a specific MTD for a project.

The VDEQ recommends that designers and reviewers contact the MTD vendor for specific information regarding the MTD type and size needed for each project.

To determine the MTD size needed for a project:

- Calculate the runoff volume to be treated by the MTD (TvBMP). The calculated TvBMP can be obtained from the VRRM spreadsheets.
- Calculate the peak discharge of the obtained treatment volume (qpTv). See Appendix A.
- Work with the MTD vendor to ensure that the qpTv is less than or equal to the MTFR of the MTD (qpTv ≤ MTFR).
  - As previously described, there are often multiple models associated with an MTD that scale by size. Specifically, the ETAs vary among models of the same MTD type.
  - The MTFR for a specified MTD model is determined by multiplying the HLR of the MTD by the ETA associated with the model to be used.
  - If the MTFR for the model analyzed is greater than the qpTv, the model selected is adequate for use. If the MTFR for the model analyzed is below the qpTv, the designer selects models with larger ETAs and repeats the analysis until a model is found that has an MTFR equal to or larger than the qpTv .
  - If no models of the MTD being analyzed can provide an MTFR equal to or larger than the qpTv, the designer should identify a different MTD with a higher HLR or select a different BMP.

# 8.5 Standards and Specifications for Post-Construction BMPs

Standards and specifications for post-construction BMPs are presented below.

## List of BMPs

Select the title of the best management practice you want to view.

P-BAS-01 Constructed Wetlands

P-BAS-02 Wet Pond

P-BAS-03 Extended Detention Pond

P-BAS-04 Rainwater Harvesting

P-CNV-01 Grass Channels

P-CNV-02 Dry Swales

P-CNV-03 Wet Swales

P-CNV-04 Regenerative Stormwater Conveyance

P-FIL-01 Rooftop/Impervious Surface Disconnection

P-FIL-02 Vegetated Roof

P-FIL-03 Permeable Pavement

P-FIL-04 Infiltration Practices

P-FIL-05 Bioretention

P-FIL-06 Filtering Practices

P-FIL-07 Sheet Flow to Vegetated Filter Strip/Conserved Open Space

P-FIL-08 Soil Compost Amendment

P-FIL-09 Tree Planting

P-SUP-01 Earthen Embankment

P-SUP-02 Principal Spillway

P-SUP-03 Vegetated Emergency Spillway

P-SUP-06 Pretreatment

P-SUP-07 Quantity-Only Approach to BMPs

P-SUP-08 Permanent Level Spreader

# P-BAS-01 Constructed Wetlands

***Figure P-BAS-01-1 Constructed Wetland Sketch***


## 1.0 Definition

Constructed wetlands, sometimes called stormwater wetlands, are shallow basins that mimic the functions of natural wetlands and use physical, chemical, and biological processes to treat stormwater.

Three basic design variations are presented for constructed wetlands (see Section 5):

1. Constructed wetland basin (Level 1 design);
2. Constructed multi-cell wetland (Level 2 design); and
3. Constructed multi-cell pond/wetland combination (Level 2 design).

## 2.0 Purpose and Applicability of Best Management Practice

Constructed wetlands are designed to capture and treat runoff from the design storm. They provide a long residence time, which allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity. Constructed wetlands can also help to meet channel and flood protection requirements by using detention storage above the permanent pool to reduce peak flows and reducing peak flows from the 10-year design storm for flood protection requirements.

Constructed wetlands are typically the final element in the roof-to-stream pollutant removal sequence and provide no volume reduction credit. A constructed wetland is typically considered for use if there is remaining pollutant removal or channel protection and flood protection volume to manage after all other upland runoff reduction options have been considered and properly credited.

## 3.0 Planning and Considerations

The designer of constructed wetlands needs to consider the following:

1. The desired plant community (emergent wetland [Level 1 design] or mixed wetland [Level 2 design]; consists of a combination of either emergent wetland and forest or emergent wetland and pond);
2. The contributing hydrology (groundwater, surface runoff or dry weather flow); and
3. The landscape position (linear or basin).

In addition to the conditions identified above, designers need to consider the feasibility/limitations (Table P-BAS-01-1), offset guidance (Table P-BAS-01-2), and community and environmental concerns (Table P-BAS-01-3). Many of these design components will be influenced by the type of constructed wetland being considered.

Designers should note that a constructed wetland is typically the final element in the roof-to-stream pollutant removal sequence and provides no volume reduction credit and should therefore be considered *only* if there is remaining pollutant removal or Channel Protection and Flood Protection Volume to manage after all other upland runoff reduction options have been considered and properly credited.

Constructed wetlands are designed based on three major factors: (1) the desired plant community (an emergent wetland – Level 1 design, a mixed wetland – emergent and forest, or an emergent/pond combination – Level 2 design); (2) the contributing hydrology (groundwater, surface runoff, or dry weather flow); and (3) the landscape position (linear or basin).

To simplify design, three basic design variations are presented for constructed wetlands:

1. Constructed wetland basin – Level 1 design;
2. Constructed multi-cell wetland – Level 2 design; and
3. Constructed multi-cell pond/wetland combination – Level 2 design (see Table P-BAS-01-5).

A Constructed Wetland Basin (Level 1 design) consists of a single cell (including a forebay) with a uniform water depth. A portion of the treatment volume (Tv) can be in the form of extended detention (ED) above the wetland pool (refer to P-BAS-03 for the ED design criteria). In addition, channel protection detention ponding (1-year energy balance) is allowed above the wetland pool. However, the storage depth for both the Tv and channel protection above the pool is limited to 12 inches (the Tv ED and 1-year storm detention are inclusive – not additive).

Multi-cell wetland system (Level 2 design) does not include any Tv storage above the wetland cell pools – the entire Tv volume is provided in the permanent pool of the wetland (Section 6.2). The critical design factor, therefore, is the depth of temporary ponding allowed above the wetland cell pools to pass the Tv or larger design storms: maximum of 8 inches during the Tv (1-inch) event and a maximum of 12 inches during the 1-year event.

The pond/wetland combination design is intended to create a wet pond cell either in parallel or in series with constructed wetland cells. The constructed wetland cell is designed similar to the multi-cell wetland – no ED or detention storage is allowed above the wetland cell permanent pool. The wet pond cell can be designed comparable to the Level 2 wet pond with 50 percent of the wet pond cell Tv in the form of the permanent pool and 50 percent of the wet pond cell Tv in 24-hour ED. The combined design is intended to convey small storms through the wetland cells while diverting (or overflowing with minimal ponding depth) the larger storm runoff into the wet pond cell.

A preferred design is illustrated on Figure P-BAS-01-2 with the wetland cells independent of the detention ponding, allowing for a greater temporary ponding depth in the pond component while keeping the temporary storage depth to a maximum (12 inches) in the wetland.

When constructed in series upstream of the wetland cells, the wet pond cell potentially has three functions:

1. Pre-treatment to capture and retain heavy sediment loads or other pollutants (such as trash, oils and grease);
2. Provisions for an extended supply of flow to support wetland conditions between storms; and
3. Storage volume for larger storms (e.g., the channel protection and flood protection design storms).

**3.1 Feasibility/Limitations**

| Table P-BAS-01-1 Feasibility Criteria | |
|---|---|
| **Parameter** | **Discussion** |
| Space Requirements | Constructed wetlands normally require a footprint that takes up about 3 to 5 percent of the contributing drainage area. |
| Depth to Water Table and Bedrock | The depth to the groundwater table is not a major constraint for constructed wetlands because a high water table can help maintain wetland conditions. |
| Adequate Water Balance | The proposed wetland must have enough water supplied from groundwater, runoff, and/or baseflow so that the wetland micropools will not go completely dry after a 30-day summer drought. A simple water balance calculation must be performed using Equation *P-BAS-01-1*. |
| Soils | Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. If soils are permeable or karst geology is a concern (see Appendix E), it may be necessary to use an impermeable liner. Highly permeable soils make it difficult to maintain a constructed wetland pool. Soil explorations should be conducted at proposed stormwater wetland sites to identify soil infiltration and the presence of karst topography.<br>Underlying soils of hydrologic soil group (HSG) C or D should be adequate to maintain a permanent pool. Most group A soils and some group B soils will require a liner in order to maintain the wetland pool. |
| Contributing Drainage Area (CDA) | If the only source of wetland hydrology is stormwater runoff, then a minimum of 10 acres of drainage area is required to maintain adequate water elevations. Smaller drainage areas of 5 to 10 acres are acceptable if the bottom of the wetland intercepts the groundwater table (ARC 2016). |

| Table P-BAS-01-1 Feasibility Criteria | |
|---|---|
| **Parameter** | **Discussion** |
| Available Hydraulic Head | Minimum of 2 to 4 feet |
| Steep Slopes | A modification of the constructed wetland for steep slopes is the alternative stormwater practice P-CNV-04 Regenerative Conveyance System (RCS). The RCS can be used to convey stormwater down steep grades through a series of step pools. |
| Karst | Stormwater wetlands are not recommended in or near karst terrain. An alternative practice or combination of practices should be employed at the site. |
| Tailwater Conditions | The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the constructed wetland. Design tailwater condition elevation will be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a high tide elevation evaluation will accompany the tailwater condition evaluation (CWP 2020). |
| Trout Streams | The use of constructed wetlands in watersheds containing trout streams is generally not recommended due to the potential for stream warming. |
| Use of or Discharges to Natural Wetlands | A stormwater wetland should never be constructed within an existing natural wetland unless it is part of a broader effort to restore a degraded urban wetland and is approved by the local, state, and/or federal wetland regulatory authority. In general, stormwater wetlands may not be located within jurisdictional waters, including wetlands, without obtaining a Section 404 permit from the appropriate local, state, and/or federal regulatory agency. In addition, designer should investigate the status of adjacent wetlands to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland (see Wright et al. 2006 for guidance on minimizing stormwater discharges to existing wetlands). |
| Regulatory Status | Constructed wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands as long as the owner continues to ensure proper maintenance and function of the BMP. Designers should check with their local wetland regulatory authority to confirm jurisdiction. |
| Perennial Streams | Locating a constructed wetland along or within a perennial stream is strongly discouraged and will require both Section 401 and Section 404 permits from the state or federal regulatory authority. |

| Table P-BAS-01-2 Constructed Wetland Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and other such structures | 25 feet horizontal | Closer offsets may be considered on a case-by-case basis where impermeable liners are specified by the designer. |
| Property Lines | 10 feet horizontal | |

| Table P-BAS-01-2 Constructed Wetland Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Septic System Drain Fields | 50 feet horizontal | |
| Private water wells | 100 feet horizontal | |

* Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the toe of the embankment on the downstream side and the design high water on the upstream side.

| Table P-BAS-01-3 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Discussion** |
| Existing Wetlands | Constructed wetlands should never be constructed within existing natural wetlands, nor should they inundate or otherwise change the hydroperiods of existing wetlands. |
| Existing Forests | Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction.<br>Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Wright et al. 2007). |
| Coastal Plain | Consider the use of bubbler aeration and proper fish stocking to maintain nutrient cycling and healthy oxygen levels in stormwater wetlands located in these areas (ARC 2016). |
| Safety Risk | Constructed wetlands are generally considered to be safer than other pond options because they have few deep pools. Maximum side slopes and unfenced headwalls, however, can still impose some safety risks. Gentle side slopes and vegetated safety benches graded near the water line of any water feature should be provided to avoid potentially dangerous drop-offs, especially where constructed wetlands are located near residential areas. |
| Mosquito Risk | Stormwater wetlands should be designed with non-forebay deep pools that retain some water (ARC 2016). |
| Stream Warming Risk | Constructed wetlands carry a moderate risk of causing stream warming. If a constructed wetland will discharge to temperature-sensitive waters, the designer should consider using the wooded wetland design to shade the water, and any extended detention storage should be released in less than 12 hours. |

## 4.0 Stormwater Performance Summary

There are two levels of design for constructed wetlands. Level 1 is the basic design, and Level 2 is a more enhanced design used to provide a higher level of stormwater function. The overall stormwater functions of constructed wetlands are summarized in Table P-BAS-01-4.

| Table P-BAS-01-4 Summary of Stormwater Functions Provided by Constructed Wetlands | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Volume Reduction (RR) | 0% | 0% |
| Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process | 50% | 75% |
| TP Mass Load Removal | 50% | 75% |
| Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process | 25% | 55% |
| TN Mass Load Removal | 25% | 55% |
| Channel Protection | Yes. Up to 1 foot of detention storage volume can be provided above the normal pool. | |
| Flood Mitigation | Yes. Flood control storage can be provided above the normal pool. | |

1. Change in event mean concentration (EMC) through the practice.

Sources: CWP and CSN 2008; CWP 2007

## 5.0 Design Criteria

There are three constructed wetlands variants: (1) constructed wetland basin, (2) multi-cell wetland system, and (3) pond/wetland combination. A brief description of each variant follows, and the design table (Table P-BAS-01-5) and subsequent text provide more specific requirements:

- A Constructed Wetland Basin (Level 1 design) consists of a single cell, a basin that includes the forebay, and a micropool outlet. Figure P-BAS-01-2 and Figure P-BAS-01-3 illustrate examples of the constructed wetland basin.
- The Multi-Cell Wetland system (Level 2 design) is composed of a series of linked cells of varying depths. Figure P-BAS-01-4 shows a cross section of a multi-cell wetland.
- The Pond/Wetland Combination design (Level 2 design) is intended to create a wet pond cell either in parallel or in series with constructed wetland cells. The combined design is intended to convey small storms through the wetland cells while diverting (or overflowing with minimal ponding depth) larger storm runoff into the wet pond cell. Figure P-BAS-01-5 illustrates the pond/wetland combination variant.

The two levels of design for constructed wetlands are detailed in Table P-BAS-01-5.

| Table P-BAS-01-5 Constructed Wetland Design Variations | | |
|---|---|---|
| **Design Element** | **Level 1 Design (RR:0; TP:50; TN:25)** | **Level 2 Design (RR:0; TP:75; TN:55)** |
| Sizing: Permanent Pool Volume and Forebay | TvBMP = [(Rv)(A)] / 12 + the volume remaining from any upstream BMPs | TvBMP = [1.5(Rv)(A)] / 12 + the volume remaining from any upstream BMPs |
| Sizing: Treatment Volume Storage | Entire water volume below the normal pool or ED for 50% of Tv (24 hr)[3] or detention storage (up to 12 inches) above the wetland pool for channel protection (1-year storm event) | • Multi-cell Wetland: Entire water volume below the normal pool of each cell; maximum 8 inches of height over the cell during the Tv (1- inch) event; limited water surface fluctuations allowed during the 1- inch and 1-year storm events.<br>• Pond/Wetland Combination**:** ED for 50% of Tv (24 hr)[3] per cell |
| Sizing: Water Balance Testing | Water balance calculations required (see Eq. P-BAS- 01-1) | Water balance calculations required (see Eq. P-BAS- 01-1) |
| Pre-treatment1 | Sediment forebay required (but does not count as a cell) | Sediment forebay required and can count as a cell. |
| Internal Design Geometry: Cell | Single cell (with a forebay and micropool outlet)[1,2] | Multiple cells or a multi-cell pond/wetland combination[1,2] |
| Internal Design Geometry: Depth | Uniform wetland depth;[2] allowable mean wetland depth is > 1 foot; see Table P-BAS-01-6 | Diverse microtopography with varying depths[2]; allowable mean wetland depth ≤ 1 foot; see Table P-BAS-01-6 |
| Internal Design Geometry: Micro-Topographic Features | Not required. | Incorporate at least two internal design features |
| Internal Design Geometry: Side Slopes | 5H:1V | 5H:1V |
| Internal Design Geometry: Flow Path | Length/Width ratio *OR* Flow path = 2:1 or more.<br>Length of shortest flow path/overall length = 0.5 or more[3] | Length/Width ratio *OR* Flow path = 3:1 or more.<br>Length of shortest flow path/overall length = 0.8 or more[4] |
| Geotechnical Testing | Soil borings needed in footprint of the proposed embankment, outlet structure, and in at least two locations in the treatment area. | Soil borings needed in footprint of the proposed embankment, outlet structure, and in at least two locations in the treatment area. |
| Conveyance and Overflow | See Section 5.4. | See Section 5.4. |
| Landscaping Plan | Required; see Appendix G Plant Selection; Emergent wetland design | Required; see Appendix G Plant Selection<br>• Multi-cell Wetland: Emergent and upland wetland design<br>• Pond/Wetland Combination: Pond and emergent wetland design |

| Table P-BAS-01-5 Constructed Wetland Design Variations | | |
|---|---|---|
| **Design Element** | **Level 1 Design (RR:0; TP:50; TN:25)** | **Level 2 Design (RR:0; TP:75; TN:55)** |

**Notes:**

RV = runoff volume (in), A = area (ac)

1. Refer to P-SUP-06 Support Component: Pre-treatment
2. Internal Tv storage volume geometry – refer to Conveyance and Overflow section
3. Extended Detention may be provided to meet a maximum of 50% of the Treatment Volume; Refer to P-BAS-03 for ED design
4. In the case of multiple inlets, the flow path is measured from the dominant inlets (that comprise 80% or more of the total pond inflow)

***Figure P-BAS-01-2 Constructed Wetland with Forested Peninsulas***

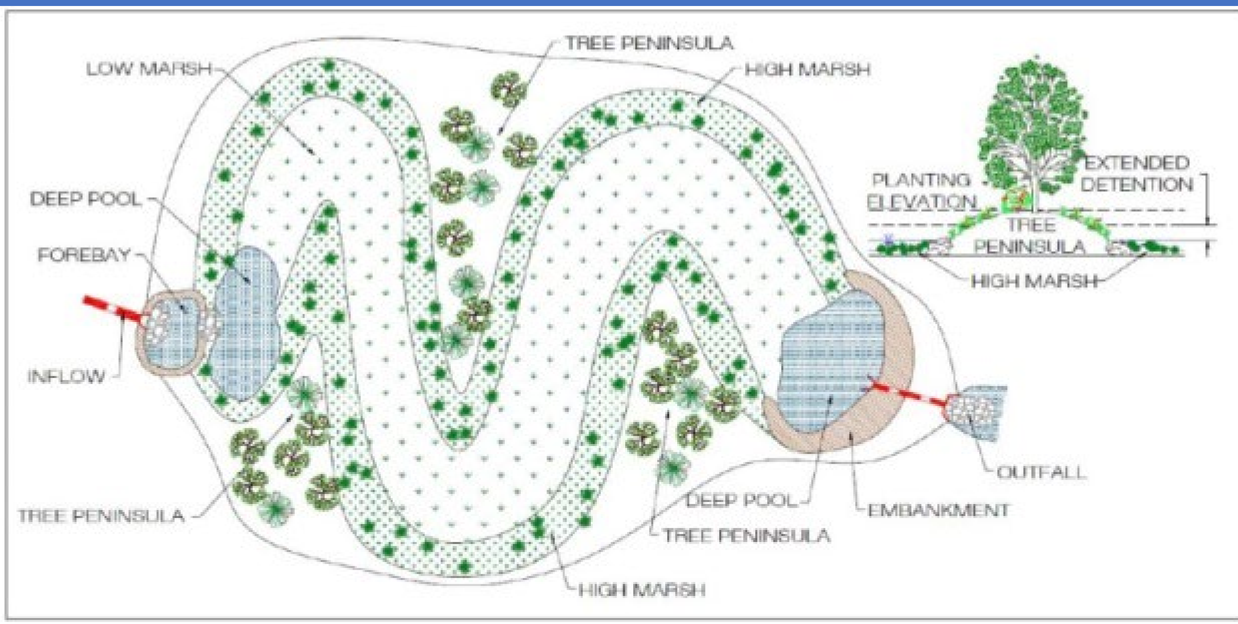


**Figure P-BAS-01-3 Constructed Wetland Level 1 Plan and Cross Section**

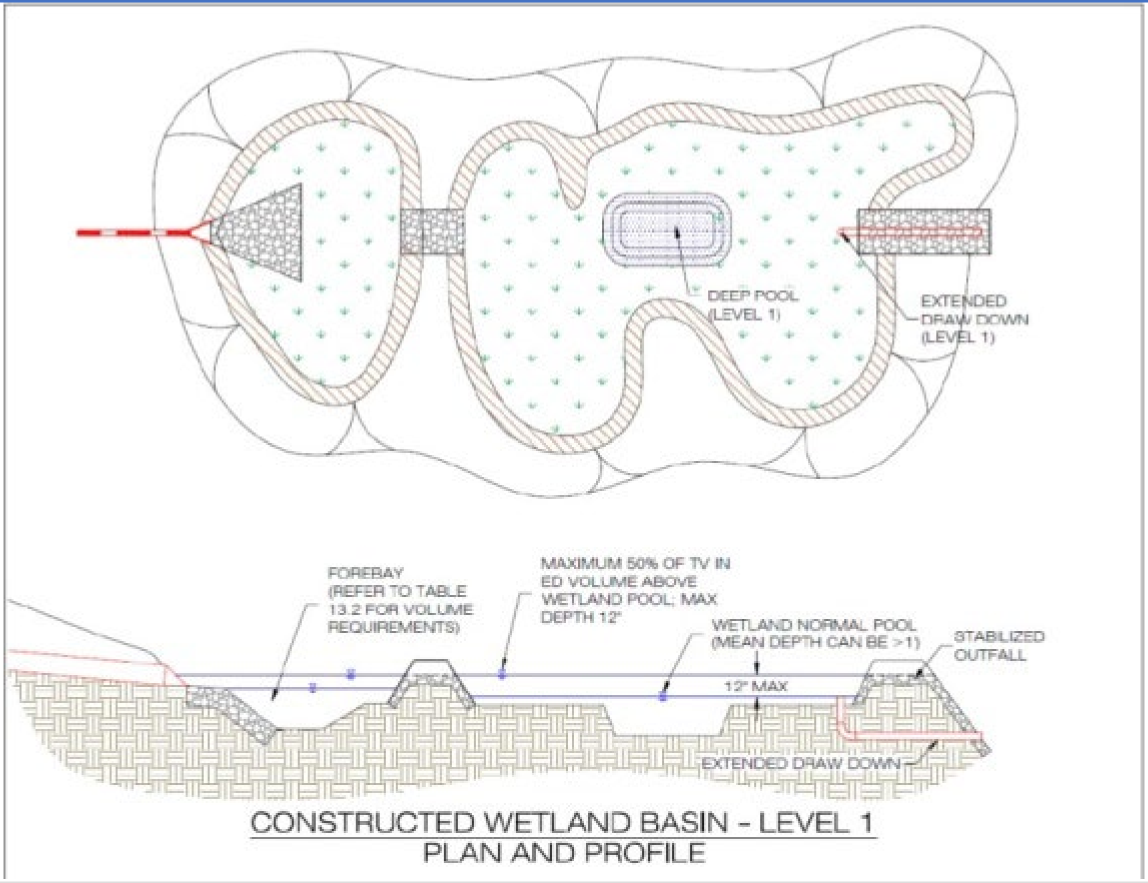



**Figure P-BAS-01-4 Constructed Wetland Level 2 Plan and Cross Section**

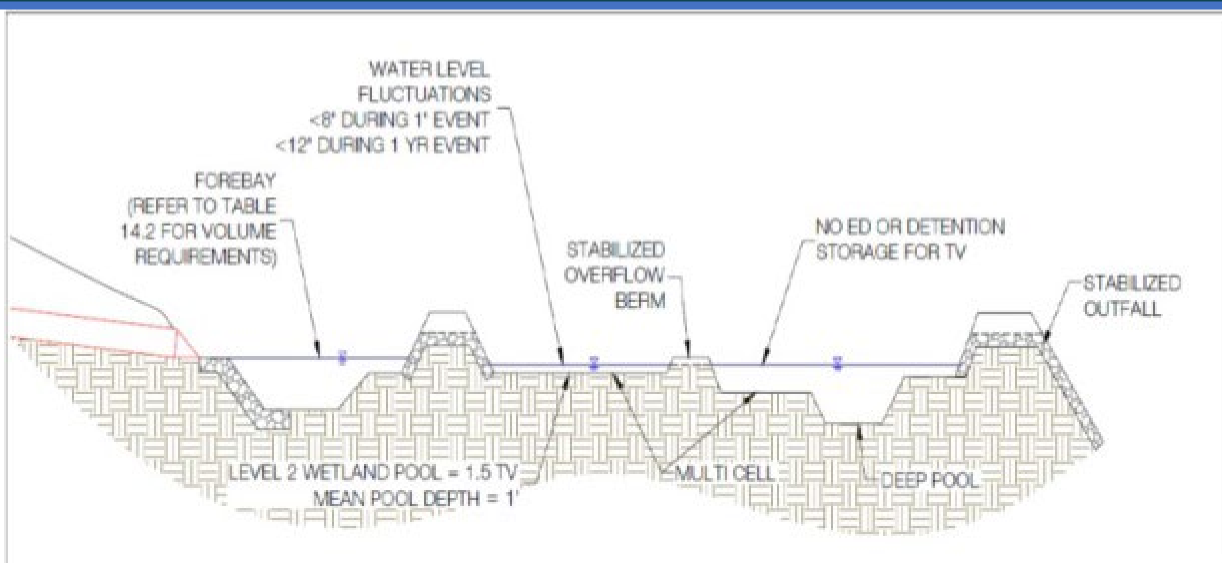
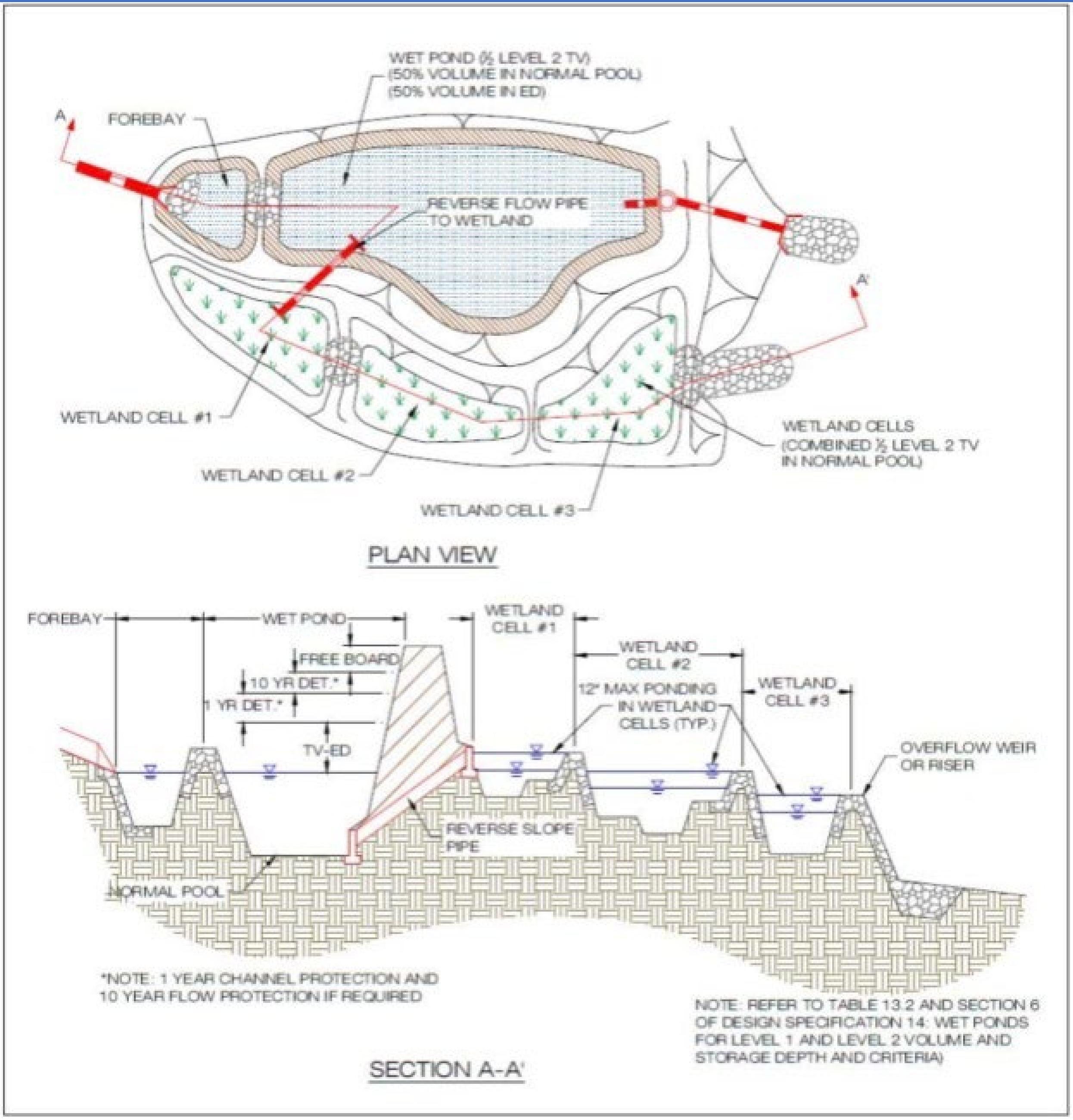


**Figure P-BAS-01-5 Constructed Wetland Level 2 Combination Wet Pond and Wetland Plan and Section**




### 5.1 Sizing of Constructed Wetlands

Designers should use the BMP design treatment volume (TvBMP; defined as the treatment volume based on the contributing drainage area to the practice plus any volume remaining from upstream runoff reduction practices) to size the permanent pool volume and forebay(s). To qualify for the higher nutrient reduction rates associated with the Level 2 design, constructed wetlands must be designed with a Tv that is 50 percent greater than the Tv for the Level 1 design (i.e., 1.50[Rv][A]). Research has shown that larger constructed wetlands with longer residence times enhance nutrient removal rates.

If additional detention storage is proposed beyond the wet pond cell for channel protection and/or flood control, then the size of the facility will expand in surface area and/or embankment elevation. If the constructed wetland is part of a treatment train, designers should use the adjusted curve number reflective of the volume reduction provided by the upstream practices to calculate the developed condition peak flow rates (including the energy balance) to determine detention requirements.

### 5.1.1 Treatment Storage Volume

- In a Constructed Wetland Basin (Level 1 design), a portion of the Tv can be in the form of ED above the wetland pool (refer to Design Specification 15: ED Ponds for the ED design criteria). In addition, channel protection detention ponding is allowed above the wetland pool. However, the storage depth for both the Tv and channel protection above the pool is limited to 12 inches (the Tv extended detention and 1-year storm detention are inclusive – not additive). The storage depth is managed by the combination of surface area and outlet structure: increasing the surface area of the storage volume and using a long-crested weir structure capable of passing large flows at relatively low hydraulic head. An upstream diversion structure is recommended to bypass storms larger than the design storm.
- Multi-Cell Wetland system (Level 2 design) does not include any Tv storage above the wetland cell pools – the entire Tv volume is provided in the permanent pool of the wetland. Similarly, the multi-cell wetland Level 2 design does not accommodate channel protection (detention) storage above the wetland cell. The critical design factor, therefore, is the depth of temporary ponding allowed above the wetland cell pools to pass the Tv or larger design storms: maximum of 8 inches during the Tv (1-inch) event, and a maximum of 12 inches during the 1-year event. The storage depth can be managed using a long weir structure capable of passing large flows at relatively low hydraulic head. An upstream diversion structure is recommended to bypass storms larger than the design storm.
- With the Pond/Wetland Combination design (Level 2 design), no ED or detention storage is allowed above the wetland cell permanent pool. The wet pond cell can be designed with 50 percent of the wet pond cell Tv in the form of the permanent pool and 50 percent of the wet pond cell Tv in 24-hour ED. An upstream diversion structure is recommended to bypass storms larger than the design storm.

### 5.1.2 Water Balance Testing

A water balance calculation is recommended to document that sufficient inflows to the pond exist to compensate for combined infiltration and evapotranspiration losses during a 30-day summer drought without creating unacceptable drawdowns. While it is preferred to avoid an arbitrary minimum drainage area requirement for the system, especially if the hydrology for the constructed wetland is supplied by groundwater or dry weather flow inputs, it may be necessary to calculate a water balance for the wetland and/or pond/wetland combination to ensure the deep pools will not go completely dry during a 30-day summer drought (Equation P-BAS-01-1, Hunt et al. 2007).

Specific water balance computation to determine the wet pond cell minimum pool depth can be computed - refer to Stormwater Design Specification P-BAS-02: Wet Pond.

*Equation P-BAS-01-1. The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland*

$$DP = RFm * EF * WS/WL - ET - INF - RES$$

Where:

DP = Depth of pool (inches)

RF*m* = Monthly rainfall during drought (inches)

EF = Fraction of rainfall that enters the stormwater wetland (CDA * RV)

WS/WL = Ratio of contributing drainage area to wetland surface area

ET = Summer evapotranspiration rate (inches; assume 8)

INF = Monthly infiltration loss (assume 7.2 inches)

RES = Reservoir of water for a factor of safety (assume 6 inches)

Using Equation P-BAS-01-1, setting the groundwater and (dry weather) base flow to 0, and assuming a worst-case summer rainfall of 0 inches, the minimum depth of the pool calculates as follows:

Depth of Pool (DP) = 0” (RFm) – 8” (ET) – 7.2” (INF) – 6” (RES) = 21.2 inches

Therefore, unless there is other input, such as base flow or groundwater, the minimum depth of the pool should be at least 22 inches (rather than the 18-inch minimum depth noted in Section 6.6).

Based on the results of the water balance calculation, adjust pond depths as needed, and submit the results to the reviewer to show that the design ensures the deep pools will not go completely dry during a 30-day summer drought.

An alternative PC-based mass balance site-specific water budgeting program is available to the public at https://resourceprotectiongroup.org/wetbud/wetbud-request/. Wetbud is readily adaptable for use in this application, is approved by the U.S. Army Corps of Engineers for created wetland applications, and is freeware for initial downloads.

#### 5.1.3 Pre-treatment

Sediment forebays are considered an integral design feature to maintain the longevity of all stormwater wetlands. A forebay must be located at every major inlet to trap sediment and preserve the capacity of the main wetland treatment cell. The forebay is used to receive runoff from the inflow from a pipe or open channel and distribute it as sheet flow into a successive wetland cell.

Refer to Support Component: Sediment Forebays for forebay design information. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pre-treatment criteria provided in P-SUP-06 Support Component: Pre-treatment.

#### 5.1.4 Internal Design Geometry

The internal design geometry of the BMP is critical to maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Constructed wetland performance is enhanced when the wetland is designed with multiple cells, longer flow paths, and a high ratio of surface area to volume. In general, wetland designs are unique for each site and application. However, whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. Multiple geometric ratios and limiting depths for the design of a stormwater wetland can be observed for adequate pollutant removal, ease of maintenance, and improved safety.

##### 5.1.4.1 Cells

Cells can be formed by sand berms (anchored by rock at each end), backfilled coir fiber logs, or forested peninsulas (extending as wedges across 95 percent of the wetland width).

- A Level 1 design consists of a single cell with a uniform water depth. In the Level 1 design, the forebay and micropool outlet (which are required) do not count as cells.
- A Level 2 design stormwater wetland should be divided into at least four cells of different elevations: the forebay, at least two additional cells, and a micropool outlet. The forebay can be counted as the first cell. The surface elevation of the successive cell is the normal pool elevation. It may contain a forested island or a sand wedge channel to promote flows into the third cell, which is typically 3 to 6 inches lower than the normal pool elevation. The micropool outlet is the last cell and has an outlet structure or weir to serve as the discharge point.

##### 5.1.4.2 Depth

The following design elements are required for stormwater wetlands:

- Level 1 wetland designs may have a mean pool depth greater than 1 foot.
- Level 2 wetland cells must have a mean pool depth less than or equal to 1 foot. The variable pool depths promote open water areas and adjacent areas of dense and diverse vegetative cover.

The stormwater wetland should be designed with the recommended proportion of "depth zones." The two design levels can have depth zone allocated based on the percentage of the stormwater wetland surface area. Recommended allocations are provided in Table P-BAS-01-6. The three basic depth zones are:

- Deep Ponds -- Approximately 25 percent of the wetland Tv should be provided in at least three deeper pools – located at the inlet (forebay), within the cell, and outlet (micropool) of the wetland. Refer to sizing based on water balance (above) for additional guidance on the minimum depth of the deep pools. This zone supports little emergent wetland vegetation but may support submerged or floating vegetation.
- Low Marsh/Transition Zone -- The low marsh zone (6 to 18 inches below the normal pool elevation) serves as a short transition zone from the deeper pools to the high marsh zone. In general, this transition zone should have a maximum slope of 5H:1V (or preferably flatter) from the deep pool to the high marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone. This zone is suitable for the growth of several emergent wetland plant species.
- High Marsh -- This zone is the shallowest zone and will support a greater density and diversity of wetland species than the low/transition marsh zone and the deep ponds. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.

Research and experience have shown that the internal design geometry and depth zones are critical to maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flow paths, and a high ratio of surface area to volume.

Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. The following design elements are required for stormwater wetlands:

**Table P-BAS-01-6 Approximate Target Volumes of Level 1 and 2 Information for Various Wetland Zones[1]**

| Wetland Zone | Criteria | Level 1 Design | Level 2 Design |
|---|---|---|---|
| Deep Pools | Depth | 18" to 72" | 18" to 48" |
| | % of Total Tv Volume | ≈25% | ≈25% |
| Low Marsh | Depth | 6" to 18" | N/A |
| | % of Tv Total Volume | 10% | N/A |
| High Marsh | Depth | 6" to 0" | -6" to +6" |
| | % of Tv Total Volume | Min. ≈15% | ≈70% |
| Extended Detention | Depth | 0"+ | N/A |
| | % of Total Volume | Max. ≈50% | N/A |

1. (ARC 2016)

### 5.1.4.3 Micro-Topographic Features

Level 2 stormwater wetlands must have internal structures to create a variable micro-topography. Designers will need to incorporate at least two of the following internal design features to meet the micro-topography requirements for Level 2 designs:

- Tree peninsulas, high marsh wedges, or rock filter cells configured perpendicular to the flow path;
- Tree islands above the normal pool elevation and maximum extended detention zone formed by coir fiber logs;
- Inverted root wads or large woody debris;
- Gravel diaphragm layers within high marsh zones; and
- Internal weirs and/or baffles made of cobble and backfilled with sand, gabion baskets, or stabilized earthen berms.

#### 5.1.4.4 Side Slopes

Side slopes for the wetland should generally exhibit gradients of 5H:1V. Such mild slopes promote better establishment and growth of the wetland vegetation. They also contribute to easier maintenance and a more natural appearance.

Flow Path. In terms of the flow path, there are two design objectives:

- The overall flow path through the wetland can be represented as the length-to-width ratio OR the flow path ratio (see the Introduction to the New Virginia Stormwater Design Specifications for diagrams and equation). These ratios must be at least 2:1 for Level 1 designs and 3:1 for Level 2 designs.
- The shortest flow path represents the distance from the closest inlet to the outlet (see the Introduction to the New Virginia Stormwater Design Specifications). The ratio of the shortest flow path to the overall length must be at least 0.5 for Level 1 designs and 0.8 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors –inlets may not be able to meet these ratios. However, the drainage area served by these “closer” inlets should constitute no more than 20 percent of the total contributing drainage area.

### 5.2 Geotechnical Testing

Soil borings need to be installed within the footprint of the proposed embankment, in the vicinity of the proposed outlet structure, and in at least two locations within the planned wetland treatment area. Soil boring data are needed to: (1) determine the physical characteristics of the excavated material to evaluate its adequacy as structural fill or other use; (2) determine the need and appropriate design depth of the embankment cut-off trench; (3) provide data for the designs of outlet works (e.g., bearing capacity and buoyancy); (4) determine the depth to groundwater and bedrock and; (5) evaluate potential infiltration losses (and the potential need for a liner).

Guidance on soil explorations in general is provided in Appendix C . Additional guidance on geotechnical criteria for impoundment facilities is provided in P-SUP-01 Support Component: Earthen Embankments.

### 5.3 Pre-treatment Forebay

Sediment forebays are considered integral to maintaining the longevity of all stormwater wetlands. A forebay must be located at every major inlet to trap sediment and preserve the capacity of the main wetland treatment cell. Refer to P-SUP-02 Support Component: Pretreatment for forebay design information.

Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pre-treatment criteria documented in P-SUP-02 Support Component: Pre-treatment.

### 5.4 Conveyance and Overflow

Table P-BAS-01-7 identifies and provides guidance for designing conveyance and overflow components of the constructed wetland BMP.

| Table P-BAS-01-7 Conveyance and Overflow Design | |
|---|---|
| **Component** | **Discussion** |
| Internal Slope | The slope profile within individual wetland cells should generally be flat from inlet to outlet (adjusting for micro-topography). The recommended maximum elevation drop between wetland cells should be 1 foot or less. |
| Principal Spillway | The principal spillway will be designed with acceptable anti-flotation, anti- vortex, anti-seep collar, and trash rack devices. Trash racks must be installed at the intake of the outlet structure and be designed to avoid acting as the hydraulic control for the outlet system. While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used given their greater operational flexibility to adjust water levels following construction (see Hunt et al. 2007). Also, a weir can be designed to accommodate passage of the larger storm flows at relatively low ponding depths. The spillway must generally be accessible from dry land. Refer to P-SUP-02 Support Component: Principal Spillways for design criteria. |
| Emergency Spillway | Constructed wetland must be constructed with overflow capacity to safely pass the 100-year design storm event without overtopping the embankment and causing structural damage to the facility through either the primary spillway (with 2 feet of freeboard to the settled top of embankment) or a vegetated or armored emergency spillway (with at least 1 foot of freeboard to the settled top of embankment). Refer to P-SUP-03 Support Component: Emergency Spillways for design criteria. |
| On-line Design | Because most constructed wetlands are on-line facilities, they need to be designed to safely pass the maximum design storm (e.g., the 10-year and 100-year design storms). While the ponding depths for the more frequent Tv storm (1 inch of rainfall) and channel protection storm (1-year event) are limited in order to avoid adverse impacts to the planting pallet, the overflow for the less frequent 10- and 100-year storms should likewise be carefully designed to minimize the depth of ponding. A maximum depth of 4 feet over the wetland pool is recommended. |
| Adequate Outfall Protection | The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged during the emergency spillway design event, whichever is greater). The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance with care taken to minimize tree clearing along the downstream channel. Outlet protection or energy dissipation should be provided consistent with the C-ECM-15 Outlet Protection. |

| Table P-BAS-01-7 Conveyance and Overflow Design | |
|---|---|
| **Component** | **Discussion** |
| Inlet Protection. | Inlet areas should be stabilized to ensure non-erosive conditions during storm events up to the overbank flood event (i.e., the 10-year storm event). Outlet protection or energy dissipation should be provided consistent with the C-ECM-15 Outlet Protection. Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation. Inlet pipes should not be fully submerged at normal pool elevations. Where the inlet pipe needs to be submerged, the following criterion needs to be met.<br>▪ Pipe velocities support minimum velocities for sediment flushing per Virginia Department of Transportation (VDOT) Drainage Manual requirements.<br>A hydraulic grade line analysis considering the tailwater effects of the normal pool elevation will be completed that shows the adequacy of the upstream storm system during the 10-year storm. |
| Dam Safety Permits | ED ponds with high embankments or high storage volumes may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.). Refer to P-SUP-01 Support Component: Earthen Embankments for additional information. |

### 5.5 Wetland Landscaping Plan

A wetland landscaping plan is required for all stormwater wetland designs and should be jointly developed by the engineer and a wetlands expert or experienced landscape architect.

The landscaping plan should outline a detailed schedule for the care, maintenance, and possible reinforcement of vegetation in the wetland and its buffer for up to 10 years after the original planting because many plants will adapt to the hydrology. Some areas may require thinning or additional plantings. More details on preparing a wetland landscaping plan are provided in the Appendix G: Plant Selection.

For additional guidance on planting trees and shrubs in wetland buffers, consult the following:

- Cappiella et al. 2006; and
- DCR's Riparian Buffer Modification & Mitigation Guidance Manual available online at: http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/ripbuffmanual.shtml

### 5.6 Maintenance Reduction Features

The following design criteria will help to avoid significant maintenance problems pertaining to constructed wetlands:

#### 5.6.1.1 Maintenance Access

Good access is needed so crews can remove sediments, make repairs, and preserve wetland treatment capacity.

- Maintenance access must be provided to the forebay, safety benches, and outlet riser area.
- Risers should be located in embankments to ensure easy access.

- Access roads must: (1) be constructed of load-bearing materials, (2) have a minimum width of 12 feet, and (3) possess a maximum profile grade of 15 percent.
- Turnaround areas may also be needed depending on the size and configuration of the wetland.

#### 5.6.1.2 Clogging Reduction

If the low-flow orifice clogs, it can result in a rapid change in wetland water elevations that can potentially kill wetland vegetation. Therefore, designers should carefully design the flow control structure to minimize clogging. Refer to P-SUP-02 Stormwater Support Component: Principal Spillways.

## 6.0 Construction Specifications

### 6.1 Constructed Wetland Material Specifications

The basic material specifications for constructed wetlands are outlined in Table P-BAS- 01-8.

**Table P-BAS- 01-8 Constructed Wetlands Materials Specifications**

| Component | Specification |
|---|---|
| Grass and Landscaping | C-SSM-10 Permanent Seeding and Appendix G: PlantSelection |
| Outlet Orifices and Spillway | P-SUP-02 Support Component: Principal Spillways |
| Inlet and Outlet Protection | C-ECM-15 Outlet Protection and C-ECM-13 Rip Rap |
| Pre-treatment | P-SUP-06 Support Component: Pre-treatment |
| Erosion Control Blankets | C-SSM-05 Soil Stabilization Blankets and Matting. Constructed wetlands should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the banks. |
| Embankments | P-SUP-01 Support Component: Earthen Embankments |
| Emergency Spillways | P-SUP-03 Support Component: Vegetated Emergency Spillway |

### 6.2 Construction Sequence

The construction sequence for stormwater wetlands depends on site condition, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing an on-line wetland facility and establishing vigorous plant cover.

#### 6.2.1 Stage 1 Construction Sequence: Wetland Facility Construction

***Step 1: Stabilize Drainage Area.*** Stormwater wetlands should only be constructed after the contributing drainage area to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be dewatered, dredged, and re-graded to design dimensions after the original site construction is complete.

***Step 2: Assemble Construction Materials*** onsite, make sure they meet design specifications, and prepare any staging areas.

***Step 3: Install Erosion and Sediment (E&S) Controls*** prior to construction including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction are to be planted with turf grass, native plant materials, or other approved methods of soil stabilization. Grass sod is preferred over seed to reduce seed colonization of the wetland. During construction, the wetland must be separated from the contributing drainage area so that no sediment flows into the wetland areas. In some cases, a phased or staged E&S Control Plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

***Step 4: Clear and Strip*** the project area to the desired sub-grade.

***Step 5: Excavate the Core Trench for the Embankment and Install the Outlet Works***. Ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al. 2007).

***Step 6: Construct the Embankment and any Internal Berms*** in 8- to 12-inch lifts or as directed by geotechnical recommendations, and compact as required with appropriate equipment.

***Step 7: Construct the Emergency Spillway*** in cut or structurally stabilized soils.

***Step 8: Excavate/Grade*** until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally accomplished by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be undertaken to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

***Step 9: Install Micro-Topographic Features and Soil Amendments*** within wetland area. Because most stormwater wetlands are excavated to deep sub-soils, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add sand, compost, topsoil, or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor survival and future wetland coverage are likely if soil amendments are not added (Bowers 1992). The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped as directed in the design specifications, but it should not be overly compacted. After the planting soil is placed, it should be saturated and allowed to settle for several weeks prior to installation of plant materials.

***Step 10: Stabilize Exposed Soils*** with temporary or permanent seed mixtures appropriate for a wetland environment. All wetland features above the normal pool elevation should be temporarily stabilized by hydro-seeding or seeding over straw. Sod may be used to prevent seeding from washing into the wetland.

### 6.2.2 Stage 2 Construction Sequence: Establishing the Wetland Vegetation

***Step 11: Finalize the Wetland Landscaping Plan.*** At this stage, the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan after the stormwater wetland has been constructed. Several weeks of standing time is needed so that the designer can more precisely predict the following:

- Where the inundation zones are in and around the wetland; and
- Whether the final grade and wetland micro-topography will persist over time.

This allows the designer to select appropriate plant species and additional soil amendments based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland.

***Step 12: Open Up the Wetland Connection.*** Once the final grades are attained, the pond and/or contributing drainage area connection should be opened to allow the wetland cell to fill up to the normal pool elevation.

Gradually inundate the wetland to avoid erosion of unplanted features. Inundation must occur in stages so that deep pool and high marsh plant materials can be placed effectively and safely. Wetland planting areas should be at least partially inundated during planting to promote plant survivability.

***Step 13: Measure and Stake Planting Depths*** at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. At this time, it may be necessary to modify the plan to reflect altered depths or a change in the availability of wetland plant stock. Surveyed planting zones should be marked on the as-built or design plan, and their locations should also be identified in the field using stakes or flags.

***Step 14: Propagate the Stormwater Wetland.*** Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. *Initial Planting of Container-Grown Wetland Plant Stock.* The transplanting window extends from early April to mid-June. Planting after these dates is unreliable because emergent wetland plants need a full growing season to build the root reserves needed to survive the winter. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. *Broadcasting Wetland Seed Mixes.* The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of switchgrass or wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation. Seed can be spread by hand-broadcasting or hydroseeding depending on the size of the wetland cell.
3. *Allowing "Volunteer" Wetland Plants to Establish on Their Own.* The remaining areas of the stormwater wetland will eventually (within 3 to 5 years) be colonized by volunteer species from upstream or the forest buffer.

***Step 15: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation.*** This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a crisscross pattern over the surface area of the wetland and above the level of the emergent plants.

***Step 16: Plant the Wetland Fringe and Buffer Area.*** This zone generally extends from 1 to 3 feet above the normal pool elevation (from the shoreline fringe to about half of the maximum water surface elevation for the 2- year storm). Consequently, plants in this zone are infrequently inundated (5 to 10 times per year) and must be able to tolerate both wet and dry periods.

### 6.3 Construction Inspection

Construction inspections are critical to ensure that stormwater wetlands are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the wetland construction process:

- Pre-construction meeting;
- Initial site preparation (including installation of project E&S controls);
- Excavation/Grading (e.g., interim/final elevations);
- Wetland installation (e.g., micro-topography, soil amendments, and staking of planting zones);
- Planting phase (with an experienced landscape architect or wetland expert); and
- Final inspection (develop a punch list for facility acceptance).

Upon final inspection and acceptance, the global positioning system (GPS) coordinates should be logged for all constructed wetlands and submitted for entry into the local BMP maintenance tracking database.

A construction-phase inspection checklist for constructed wetlands is included at the end of this specification.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulations (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the RSC BMP, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- Restrictive covenants or other mechanisms enforceable by the VESMP Authority should be in place to help ensure that stormwater wetlands are maintained as well as to pass the knowledge along to any subsequent property owners.
- Access to stormwater wetlands should be covered by a drainage easement to allow access by the VESMP Authority to conduct inspections and perform maintenance when necessary.
- All stormwater wetlands should include a long-term Maintenance Agreements consistent with the provisions of the Virginia Erosion and Stormwater Management Regulation and should include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The Maintenance Agreement should also include contact information for owners to obtain local or state assistance to solve common nuisance problems such as mosquito control, geese, invasive plants, vegetative management, and beaver removal.

### 7.2 First Year Maintenance Operations

Successful establishment of constructed wetland areas requires that the following tasks be undertaken in the first 2 years:

**Table P-BAS- 01-9 First Two-Year Maintenance Tasks**

| Task | Discussion |
| --- | --- |
| Initial Inspections | During the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 0.5 inch of rainfall. |
| Spot Reseeding | Inspectors should look for bare or eroding areas in the contributing drainage area or around the wetland buffer and make sure they are immediately stabilized with grass cover. |
| Watering | Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every 3 days for the first month and then weekly during the first growing season (April through October), depending on rainfall. |

| Table P-BAS- 01-9 First Two-Year Maintenance Tasks | |
|---|---|
| **Task** | **Discussion** |
| Reinforcement Plantings | Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain unvegetated and some species will not survive. Poor survival can result from many unforeseen factors such as predation, poor quality plant stock, water level changes, and drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty, extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive. |

### 7.3 Maintenance Inspections

Maintenance of constructed wetlands should be driven by annual inspections that evaluate the condition and performance of the wetland including the following:

- Measure sediment accumulation levels in forebays and micropools.
- Monitor the growth and survival of emergent wetlands and tree/shrub species. Record the species and approximate coverage and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the wetland for material damage, erosion, or undercutting.
- Inspect upstream and downstream banks for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.
- Inspect the wetland outfall channel for erosion, undercutting, rip-rap displacement, woody growth, and other issues.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, and other issues.
- Inspect the condition of all trash racks, reverse-sloped pipes, and flashboard risers for evidence of clogging, leakage, debris accumulation, and other issues.
- Inspect maintenance access to ensure it is free of woody vegetation and check to see whether valves, manholes, and locks can be opened or operated.
- Inspect internal and external side slopes of the wetland for evidence of sparse vegetative cover, erosion, or slumping and make needed repairs immediately.
- Schedule cleanups at least once a year to remove trash, debris, and floatables.

Inspection results will trigger specific maintenance tasks. Example maintenance inspection checklists for constructed wetlands are included in Chapter 10 of the Virginia Stormwater Management Handbook.

### 7.4 Non-Routine Maintenance

Managing vegetation is an important ongoing maintenance task at every constructed wetland and for each inundation zone. Following the design criteria discussed previously should result in a reduced need for regular mowing of the embankment and access roads. Vegetation within the wetland, however, will require some annual maintenance.

| Table P-BAS- 01-10 Annual Maintenance Items | |
|---|---|
| **Task** | **Discussion** |
| Control Invasive Species | Designers should expect significant changes in wetland species composition over time. Inspections should carefully track changes in wetland plant species distribution over time. Invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of undesirable invasive species (e.g., cattails and Phragmites) should commence when their coverage exceeds more than 15 percent of a wetland cell area. Although the application of herbicides is not recommended, some types (e.g., glyphosate) have been used to control cattails with some success. Extended periods of dewatering may also work, as early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland. |
| Thinning and Harvesting of Woody Growth | Thinning or harvesting of excess forest growth may be periodically needed to guide the forested wetland into a more mature state. Vegetation may need to be harvested periodically if the constructed wetland becomes overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Woody species on or near the embankment and maintenance access areas should be removed every 2 years. |
| Sediment Removal | Frequent sediment removal from the forebay is essential to maintaining the function and performance of a constructed wetland. For planning purposes, maintenance plans should anticipate cleanouts approximately every 5 to 7 years or when inspections indicate that 50 percent of the forebay sediment storage capacity has been filled. (Absent an upstream eroding channel or other source of sediment, the frequency of sediment removal should decrease as the drainage area stabilizes.) The designer should also check to see whether removed sediments can be spoiled onsite or must be hauled away. Sediments excavated from constructed wetlands are not usually considered toxic or hazardous. They can be safely disposed of by either land application or landfilling. |

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# P-BAS-02 Wet Pond

## 1.0 Definition

A wet pond is a stormwater facility constructed through filling and/or excavation that provides both permanent and temporary storage of stormwater runoff. It has an outlet structure that creates a permanent pool and detains and attenuates runoff inflows and promotes the settlement of pollutants.

## 2.0 Purpose and Applicability of Best Management Practice

Wet ponds are widely applicable for most land uses and are best suited for larger drainage areas. It is important to stress that wet ponds are not intended to serve as stand-alone stormwater practices due to their poor runoff volume reduction capability. Designers should always maximize the use of upland runoff reduction practices, such as rooftop disconnections, small-scale infiltration, rainwater harvesting, bioretention, grass channels, and dry swales, that reduce runoff volume at its source (rather than merely treating runoff at the terminus of the storm drain system). Upland runoff reduction practices can satisfy some or all the water quality requirements at many sites, which can help to reduce the footprint and volume of wet ponds.

Wet ponds consist of a combination of permanent pools, micro-pools, or shallow marsh that promotes a better environment for gravitational settling, biological uptake, and microbial activity (CWP 2020). Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, wet ponds have a residence time that ranges from many days to several weeks depending on the volume of the permanent pool, which allows pollutant removal mechanisms to operate. Wet ponds can also include extended detention (ED) of a portion of the treatment volume (Tv) above the permanent pool or a multiple-cell design to improve performance and meet the Level 2 performance goals defined in Section 4.0 of this specification.

Wet ponds can also help to meet channel protection requirements by using detention storage above the permanent pool and ED storage volumes to reduce peak flows from the 1-year design storm using the energy balance method described in the Virginia Stormwater Management Program (VSMP) regulations (9VAC25-870).

Designers should note that a wet pond is typically the final element in the roof-to-stream pollutant removal sequence and provides no volume reduction credit. Therefore, it should be considered only if there is remaining pollutant removal or channel protection volume to manage after all other upland runoff reduction options have been considered and properly credited. Wet ponds may be allowed in certain coastal plain situations where the water table is within 3 feet of the ground surface.

Where a wet pond is proposed as an aesthetic amenity, the design parameters contained here represent good engineering design to maintain a healthy pond. The treatment volume requirements for water quality and detention requirements for channel protection may be met more economically through the upstream runoff reduction practices; however, the basic wet pond features related to aesthetics (pool volume and geometry) and safety (e.g., aquatic and safety benches, side slopes, maintenance) remain as important neighborhood or site design features. Wet ponds can be employed in several different design configurations, as illustrated on Figure P-BAS-02-1 and Figure P-BAS-02-2 below:

Wet pond with 100 percent of the permanent pool in a single cell (Level 1 design);

- Pond/Wetland combination (see BMP P-BAS-01 Constructed Wetlands for additional guidance on the
- design of the wetland element); and

- Wet ED and/or multi-cell wet pond meeting additional requirements for pond geometry, landscaping, and other parameters (note that ED may comprise no more than 50 percent of the total Level 2 Tv).

**Figure P-BAS-02-1 Wet Pond Design Schematics**

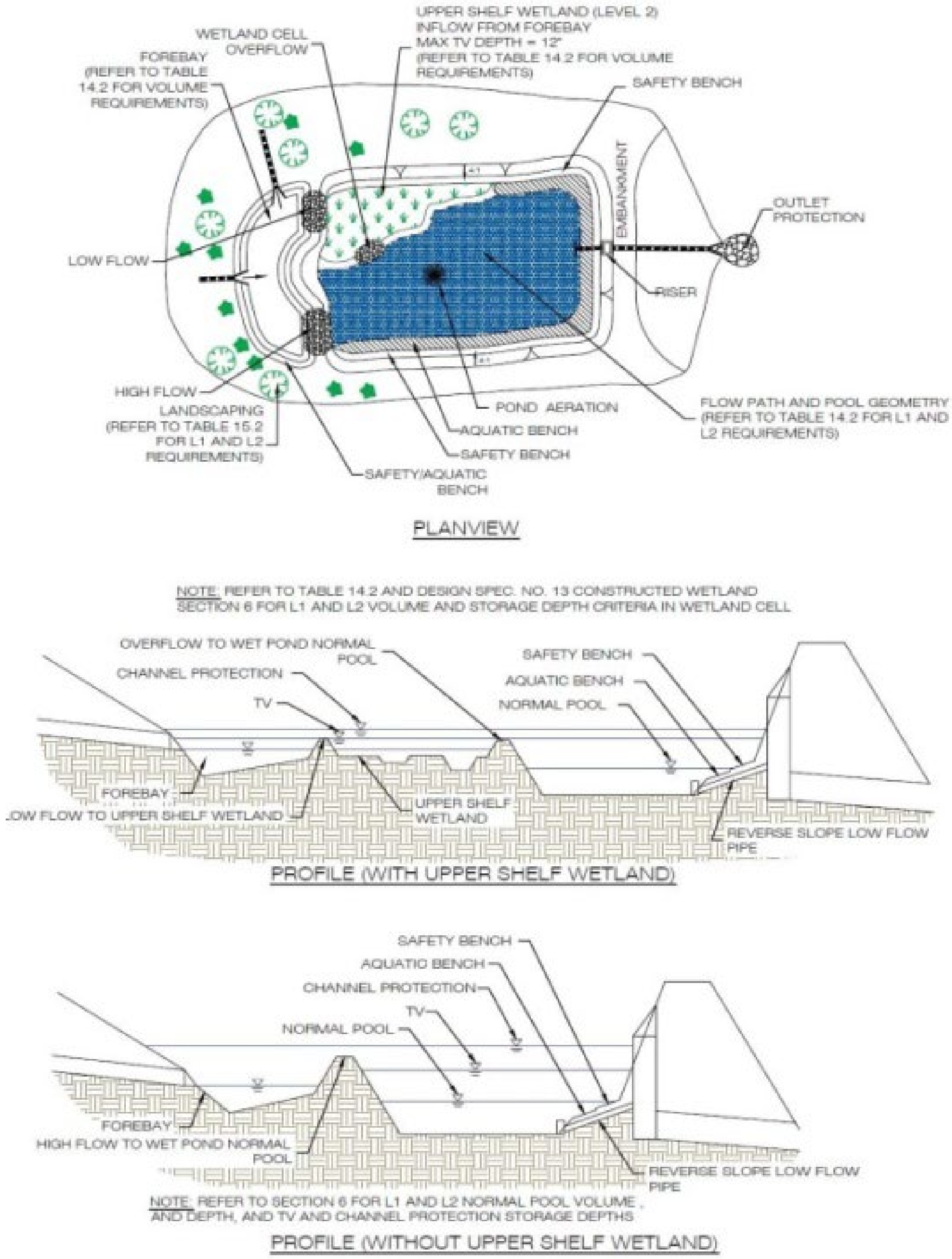
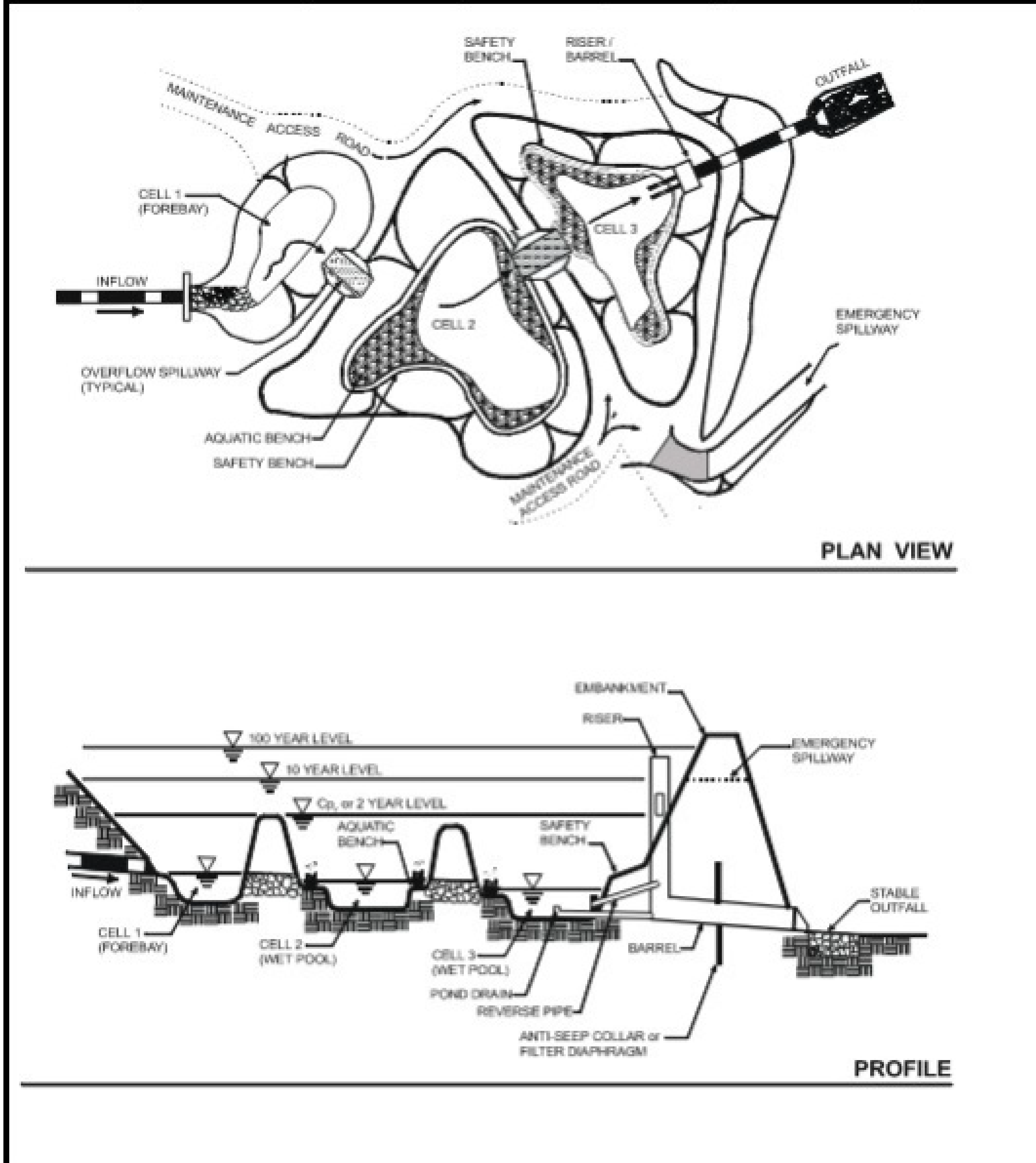


**Figure P-BAS-02-2 Multi-Pond System**

| P-4 | **Figure 3.4** Example of Multiple Pond System | P-4 |
|---|---|---|




Multiple pond systems provide $WQ_v$ storage in two or more cells that create longer pollutant removal pathways.

(from Performance Criteria for Urban BMP Design MD Spec)

## 3.0 Planning and Considerations

The feasibility criteria identified in Table P-BAS-02-1 should be evaluated when designing a wet pond.

| Table P-BAS-02-1 Wet Pond Feasibility Criteria | |
|---|---|
| **Component** | **Criteria** |
| Space Required | The surface area of a wet pond will normally be at least 1 to 3 percent of its contributing drainage area depending on the impervious cover, pond geometry, depth and other characteristics. |
| Contributing Drainage Area (CDA) | A contributing drainage area of 10 acres (25 acres or more is preferred) is typically recommended for wet ponds to maintain a healthy permanent pool. Wet ponds can still function with drainage areas less than 10 acres, but designers should be aware that these "pocket" ponds will be prone to clogging, experience extreme fluctuations in seasonal water levels, and be susceptible to creating nuisance conditions. Wet ponds must have enough water supplied from groundwater, runoff, or baseflow so that wet pools will not draw down by more than 2 feet after a 30-day summer drought. A water balance should be calculated to assess wet pond drawdown. |
| Pocket Ponds | Rather than mandating an arbitrary minimum drainage area, it is recommended instead that these pocket ponds meet the minimum design geometry requirements for all ponds (i.e., a sediment forebay cell, aquatic benches, maximum side slopes no steeper than 5H: 1V, and a length-to-width ratio of 2:1 for Level 1 designs or 3:1 for Level 2 designs). Designers should strictly adhere to the same design requirements that apply to other wet ponds. This should greatly reduce the number of small nuisance ponds with inadequate designs and insufficient functions (i.e., by reducing or eliminating essential pond design elements) forced into sites that are too small. |
| Depth-to-Water Table and Bedrock | The depth to the groundwater table can be a design concern for wet ponds. If the water table is close to the surface, it may make excavation difficult and expensive. Groundwater can also reduce the pollutant removal rates of wet ponds and reduce storage volumes. |
| Soils | Highly permeable soil makes it difficult to maintain a constant water level for the permanent pool in many parts of Virginia. Therefore, it is important to directly address fluctuating water levels in the design. Soil infiltration tests need to be conducted at proposed pond sites to determine the need for a pond liner or other method that addresses water level fluctuation. The underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool.<br><br>Most group A soils and some group B soils will require a liner. Geotechnical tests should be conducted to determine the infiltration rates and other subsurface properties of the soils beneath the proposed pond. Geotechnical explorations must also be conducted at the proposed pond embankment to properly design the embankment cut-off trench and fill material if present. See Support Component: P-SUP-01 Earthen Embankment for more information on geotechnical testing. |

| Table P-BAS-02-1 Wet Pond Feasibility Criteria | |
|---|---|
| **Component** | **Criteria** |
| Tailwater Conditions: | The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the wet pond. Design tailwater condition elevation will be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a high tide elevation evaluation will accompany the tailwater condition evaluation. |
| Tidal Impacts | The outlet elevation of a wet pond providing detention storage should be located above the tidal mean high-water elevation to limit tidal backflow into the pond (CWP 2020). Backflow prevention check valves can be installed to limit tidal backflow into wet ponds, but hydraulic impacts from the valve must be accounted for within pond routing calculations. |
| Hot Spots | In hot spot areas with high potential for stormwater runoff, a geotechnical investigation of the underlying soils is recommended. Identifying the soils beneath a pond helps to determine the best method to prevent groundwater contamination from hot spot runoff. Maintaining separation between the bottom of the pond and water table is important for preventing contamination. Common recommendations in these areas include liners and pre-treatment into ponds to treat runoff from hot spots prior to entering the pond (ARC 2016). |
| Liners | A geotechnical investigation is required to determine the need for a pond liner. Liners are often required in areas with a high water table to prevent contamination, at hot spots to prevent infiltration of pollutants, and in karst areas and on soils with high rates of infiltration to maintain the permanent pool elevation. |
| Karst | Wet ponds are not recommended in karst terrain. An alternative practice or combination of practices should be employed at the site. Refer to Appendix E for guidance on wet pond design in karst areas. |
| Trout Streams | The use of wet ponds in watersheds containing trout streams is strongly discouraged because the discharge can cause the streams to warm, which negatively impacts the trout population. |
| Use of or Discharges to Natural Wetlands | It can be tempting to construct a wet pond within an existing natural wetland, but wet ponds cannot be located within jurisdictional waters, including wetlands, without obtaining a Section 404 permit from the appropriate state and federal regulatory agencies. |
| Perennial Streams | Locating wet ponds on perennial streams is also strongly discouraged and will require both Section 401 and Section 404 permits from the appropriate state and/or federal regulatory agencies. |
| Steep Terrain | The use of wet ponds is highly constrained at development sites with steep terrain. Some adjustment can be made by terracing pond cells in a linear manner, using a 1- to 2-foot armored elevation drop between individual cells. Terracing may work well on longitudinal slopes with gradients up to approximately 10 percent. |

| Table P-BAS-02-1 Wet Pond Feasibility Criteria | |
|---|---|
| **Component** | **Criteria** |
| Cold Climate and Winter Performance | Pond performance decreases when snowmelt runoff delivers high pollutant loads. Ponds can also freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing pond performance. Salt loadings are higher in cold climates due to winter road maintenance. The following design adjustments are recommended for wet ponds installed in higher elevations and colder climates:<br>• Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC 2005).<br>• Plant salt-tolerant vegetation in pond benches.<br>• Do not submerge inlet pipes and provide a minimum 1 percent pipe slope to discourage ice formation.<br>• Locate low-flow orifices so they withdraw at least 6 inches below the typical ice layer.<br>• Place trash racks at a shallow angle to prevent ice formation.<br>• Oversize riser and weir structures to avoid ice formation and pipe freezing.<br>• If winter road sanding is prevalent in the contributing drainage area, increase the forebay size to accommodate additional sediment loading. |
| Linear Highway Sites | Wet ponds are poorly suited to treat runoff within open channels located in the highway right-of way unless storage is available in a cloverleaf interchange or in an expanded right-of-way. Guidance for pond construction in these areas is provided in Virgina Department of Transportation's (VDOT's) annual stormwater management specifications, as reviewed, and approved annually by Virginia Department of Conservation and Recreation (DCR) and Profile Sheet SR-5 in Schueler et al. (2007). |
| Linear Utility Sites | Wet ponds are poorly suited to treat runoff within utility rights-of-way or easements due to their size and would typically require acquisition of additional land adjacent to the utility corridor. |

| Table P-BAS- 02-2 Wet Pond Minimum Setbacks | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and other such structures. | 25 feet horizontal | Closer offsets may be considered on a case-by-case basis where impermeable liners are specified by the designer. |
| Property lines | 20 feet horizontal | |
| Septic system drain fields | 100 feet horizontal | Setbacks from septic system drain fields at the discretion of the licensed professional. |
| Private water wells | 100 feet horizontal | Setbacks from water wells at the discretion of the licensed professional. |

| Table P-BAS- 02-2 Wet Pond Minimum Setbacks | | |
|---|---|---|
| Feature | Offset* | Notes |
| * Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the toe of the embankment on the downstream side and the design high water on the upstream side. Sufficient space must be provided around the wet pond to allow maintenance access. | | |

### 3.1 Regional and Special Case Design Adaptations

#### 3.1.1 Karst Terrain

The presence of karst complicates both land development and stormwater design. Designers should always conduct geotechnical investigations in karst terrain to assess this risk during the project planning stage. Because of the risk of sinkhole formation, groundwater contamination, and frequent facility failures, use of wet ponds is highly restricted in karst regions. At a minimum, designers must specify the following:

- minimum of 6 feet of unconsolidated soil material exists between the bottom of the basin and the top of the karst layer.
- Maximum temporary or permanent water elevations within the basin do not exceed 6 feet.
- Annual maintenance inspections must be conducted to detect sinkhole formation. Sinkholes that develop should be reported immediately after they have been observed and should be repaired, abandoned, adapted, or observed over time following the guidance prescribed by the appropriate local or state groundwater protection authority.
- A liner is installed that meets the requirements outlined in Table P-BAS- 02-3 Wet Pond Feasibility Criteria.

| Table P-BAS- 02-3 Wet Pond Feasibility Criteria. Required Groundwater Protection Liners for Ponds in Karst Terrain | |
|---|---|
| Situation | Criteria |
| Pond *not* excavated to bedrock | 24 inches of soil with a maximum hydraulic conductivity of 1 x 10-5 cm/sec. |
| Pond excavated to bedrock | 24 inches of clay[1] with a maximum hydraulic conductivity of 1 x 10-6 cm/sec. |
| Pond excavated to bedrock within a wellhead protection area, in a recharge area for a domestic well or spring, or in a known faulted or folded area | Synthetic liner with a minimum thickness of 60 mil. |

1. Clay properties as follow:

   Plasticity Index of Clay = Not less than 15% (ASTM D-423/424) Liquid Limit of Clay = Not less than 30% (ASTM D-2216)

   Clay Particles Passing = Not less than 30% (ASTM D-422)

   Clay Compaction = 95% of standard proctor density (ASTM D-2216)

   Source: WVDEP 2006 and DCR 1999

#### 3.1.2 Coastal Plain

The flat terrain, low hydraulic head, and high-water table of many coastal plain sites can constrain the application of wet ponds. Excavating ponds below the water table creates what are known as dugout ponds, in which the Tv is displaced by groundwater, reducing the pond's mixing and treatment efficiency and creating nuisance conditions. Other difficulties with implementing wet ponds in this region are the flat terrain, which makes pond drains more difficult to implement. Also, rainfall intensities are 10 to 20 percent greater for the same design storm event in areas closer to the coast. This leads to median event concentrations of nutrients that are 15 to 25 percent higher in the coastal plain region than in other regions of Virginia.

Wet ponds are considered an "acceptable" stormwater practice for use in the coastal plain where the water table is close to the land surface or intersects the normal pool elevation. However, wet ponds are discouraged where groundwater input to the pond is brackish or is hydraulically connected to tidal waters. Ponds should not intersect the water table when it is brackish and there are other nutrient sources in the contributing drainage area. Wet pond permanent pools providing detention storage and outlet elevations must be above the mean high water tidal elevation. The use of backflow prevention check valves to limit tidal backflow into ponds can be considered for wet ponds discharging into tidally influenced outfalls (CWP 2020). Constructed wetlands are the preferred method in these situations and should be considered throughout the coastal plains. However, when designing wet ponds in coastal plain settings, the following are important design considerations:

- Adjustments to the Nutrient Removal Credit: Multiple research findings indicate that the criteria in this design specification for wet ponds cannot achieve the same level of nutrient removal that can be achieved in the rest of Virginia (based on current design, detention times, the influence of groundwater, and other factors). Therefore, slightly lower nutrient removal rates are assigned to coastal plain wet ponds to reflect real-world performance data for phosphorus and nitrogen removal. Specifically, Level 1 and 2 total removal rates for total phosphorus (TP) are reduced to 45 and 65 percent, respectively, and Level 1 and 2 total nitrogen (TN) removal rates are reduced to 20 and 30 percent, respectively. These slightly lower removal rates are supported by pond research and the detention time relationships (see CSN Technical Bulletin No. 2, 2009).
- Pollutants of Concern: In coastal plain watersheds, the key pollutants of concern are nitrogen, bacteria, and metals (not phosphorous). Nutrient concentrations in this region following a storm event are summarized in Table P-BAS-02-4.

**Table P-BAS-02-4 Comparison of Nutrient Storm Event Mean Concentrations in the Virginia Piedmont versus Coastal Plain (N = 753 storm events)**

| Nutrients | Coastal Plain (mg/L) | Piedmont (mg/L) |
|---|---|---|
| Total nitrogen[1] | 2.13 | 1.70 |
| Total phosphorus | 0.27 | 0.22 |

1. The event mean concentration (EMC) for residential TN in coastal plain is 2.96 milligrams per liter (mg/L).
Source: Appendix G of Hirschman et al. 2008.

Where possible, the design and engineering of stormwater practices need to be greatly modified to achieve greater reductions in nitrogen, bacteria, and metals to improve coastal water quality.

- Enhancing Pollutant Removal: In coastal plain design, measures should be taken to create adjacent anaerobic and aerobic zones in either the vertical or lateral direction to promote de-nitrification in runoff. To enhance bacteria removal, designers should also create high light conditions to promote ultraviolet (UV) exposure in areas of standing water and focus on design to prevent re-suspension of bottom sediments in treatment systems. Bacteria concentrations can also be decreased at one of the main sources by planting vegetation other than turf around ponds and wetlands to make access more difficult for geese and other waterfowl.

- Plant Selection: For pondscaping, plant species chosen should reflect the native coastal plain plant community and must be able to survive well in a high-salinity environment. The aquatic bench should be enlarged to 20 feet wide and be planted with dense wetland vegetation to increase pollutant removal and restrict access for geese and other waterfowl (CWP 2009). Additionally, coyote or swan decoys can be installed to deter geese around wet ponds.
- Shape: A linear design approach, which spreads treatment along the entire length of the drainage path from the rooftop to tidal waters, maximizes the use of in-line treatment in the swale and ditch system. This can be combined with the shallower ponds in the region to improve pollutant removal.
- Aeration: Aeration must be used, and the use of bubbler aeration instead of fountains should be considered along with the proper fish stocking to maintain nutrient cycling and healthy oxygen levels in wet ponds located in these coastal areas (CWP 2009).

### 3.1.3 Community & Environmental Concerns

Wet ponds can generate the following community and environmental concerns that need to be addressed during design.

**Table P-BAS-02-5 Wet Pond Community & Environmental Concerns**

| Concern | Discussion |
| --- | --- |
| Aesthetic Issues | Many residents feel that wet ponds are an attractive landscape feature, promote a greater sense of community, and are an attractive habitat for fish and wildlife.<br><br>Designers should note that these benefits are often diminished where wet ponds are undersized or have small contributing drainage areas. |
| Existing Wetlands | A wet pond should never be constructed within an existing natural wetland. Discharges from a wet pond into an existing natural wetland should be minimized to prevent pollution damage and changes to its hydroperiod. Wet ponds should not be constructed within a significant natural community as defined by DCR or impact an ecological core as identified in the Virginia Natural Landscape Assessment (https://www.dcr.virginia.gov/natural-heritage/vaconvisvnla). |
| Existing Forests | Construction of a wet pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction. Wet ponds should not be constructed within a significant natural community as defined by DCR or impact an ecological core as identified in the Virginia Natural Landscape Assessment (https://www.dcr.virginia.gov/natural-heritage/vaconvisvnla). |

| Table P-BAS-02-5 Wet Pond Community & Environmental Concerns | |
|---|---|
| **Concern** | **Discussion** |
| Stream Warming Risk | Wet ponds can warm streams by 2 to 10 degrees Fahrenheit. To minimize stream warming, landscaping plans for wet ponds should emphasize shading with a combination of emergent vegetation and overstory shading. Additionally, the outlet structure can be modified to withdraw from a deeper point in the permanent pool to reduce temperature impacts (NCDEQ 2020). When a Level 2 design is required (and all upgradient runoff reduction options have been exhausted), designers should use the multiple cells and not the ED option. Stream warming may not be a major problem for degraded urban streams. |
| Safety Risk | Pond safety is an important community concern. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially where wet ponds are located near residential areas. Consult the locality, as appropriate, regarding more stringent safety requirements. |
| Mosquito Risk: | Mosquitoes are not a major problem for larger wet ponds (Santana et al. 1994; Ladd and Frankenburg 2003; Hunt et al. 2005). However, fluctuating water levels in smaller or undersized wet ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC 2005. |
| Geese and Waterfowl: | Wet ponds with extensive managed turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the pollutant removal efficiency for those pollutants. Several design and landscaping features can make wet ponds much less attractive to geese (see Schueler 1992). |
| Harmful Algal Blooms: | Recent research on wet ponds in the coastal plain has shown that some ponds can be hot spots or incubators for algae that generate harmful algal blooms (HABs). The type of HAB may include cyanobacteria, raphidophytes, or dinoflagellates, and the severity appears to be related to environmental conditions and high nutrient inputs. Given the known negative effects of HABs on the health of shellfish, fish, wildlife, and humans, this finding is a cause for concern for coastal stormwater managers. At this time, it is not possible to develop design guidelines to avoid HAB problems in coastal wet ponds. However, as HABs are most pronounced in wet ponds that have brackish groundwater and/or are directly connected to tidal waters (DeLorenzo and Fulton 2009), working to use other BMPs in those situations would likely be beneficial. Implementing specific design guidance and criteria included within this Handbook for wet ponds located in the coastal plain can mitigate these effects. |

## 4.0 Stormwater Performance Summary

There is no runoff volume reduction credit for wet ponds because the runoff reduction pathways of infiltration and extended filtration are generally limited. The wet pond functions as a basin that generally discharges a volume equivalent to the entire inflow runoff volume. While a minimal runoff reduction credit is awarded for Level 2 ED ponds, the soils appropriate for wet ponds limit the ability of the wet pond to achieve any measurable volume reduction.

**Table P-BAS-02-5 Summary of Stormwater Functions Provided by Wet Ponds**

| Stormwater Function | Level 1 Design | Level 2 Design |
|---|---|---|
| Annual Runoff Volume Reduction (RR)[1] | 0% | 0% |
| TP EMC Reduction[2] by BMP Treatment Process | 50% (45%)[3] | 75% (65%)[3] |
| TP Mass Load Removal | 50% (45%)[3] | 75% (65%)[3] |
| TN EMC Reduction[2] by BMP Treatment Process | 30% (20%)[3] | 40% (30%)[3] |
| TN Mass Load Removal | 30% (20%)[3] | 40% (30%)[3] |
| Channel Protection | Yes; detention storage can be provided above the permanent pool. | |
| Flood Mitigation | Yes; flood control storage can be provided above the permanent pool. | |

**Notes:**

1. Runoff Reduction rates for ponds used for year-round irrigation can be determined through a water budget computation.
2. Change in event mean concentration (EMC) through the practice.
3. Number in parentheses is slightly lower EMC removal rate in the Coastal Plain (or any location) if the wet pond is influenced by groundwater. See Section 3 of this design specification and CSN Technical Bulletin No. 2. (2009).

Sources: CWP and CSN 2008, CWP 2007

## 5.0 Design Criteria

The major design goal for wet ponds in Virginia is to maximize nutrient removal. To this end, designers may choose to go with the baseline design (Level 1) or an enhanced design (Level 2) that maximizes nutrient removal. The basic criteria for the two levels of wet pond design are shown in Table P-BAS-02-6. At this point, there is no runoff volume reduction credit for wet ponds. Refer to the Support Component: P-SUP-07 Quantity Only Approach to BMPs for design specifications and criteria on the design of ponds and basins that are not designed for pollutant removal and only provide detention storage needed to meet channel and flood protection requirements.

**Table P-BAS-02-6 Level 1 and 2 Wet Pond Design Guidance**

| Level 1 Design (RR:01; TP: 505; TN:305) | Level 2 Design (RR:01; TP: 755; TN:405) |
|---|---|
| Tv = [(1.0)(Rv)(A)/12] – volume reduced by upstream BMP | Tv = [1.5 (Rv) (A) /12] – volume reduced by upstream BMP |
| Single pond sell (with forebay) | Wet ED2 (24 hr) and/or a multiple-cell design[3] |
| Length/Width ratio of permanent pool = 2:1 or more; Length of shortest flow path/overall length[4] = 0.5 or more | Length/Width ratio of permanent pool = 3:1 or more; Length of shortest flow path/overall length[4] = 0.8 or more |
| No wetlands required | Wetlands more than 10 percent of pond area |

| Table P-BAS-02-6 Level 1 and 2 Wet Pond Design Guidance | |
|---|---|
| **Level 1 Design (RR:01; TP: 505; TN:305)** | **Level 2 Design (RR:01; TP: 755; TN:405)** |
| Safety and aquatic benches | Safety and aquatic benches |
| Pond buffers: 25-foot vegetated turf buffer from maximum water surface elevation 25-foot buffer from principal spillway with no woody vegetation<br><br>15-foot buffer from toe of embankment with no woody vegetation | Pond buffers: (See Figure P-BAS-02-1 below)<br><br>25-foot vegetated buffer with from maximum water surface elevation with trees, shrubs, and herbaceous plants including shoreline landscaping to discourage geese<br><br>25-foot buffer from principal spillway with no woody vegetation<br><br>15-foot buffer from toe of embankment with no woody vegetation |
| No internal pond mechanisms | Aeration (preferably bubblers that extend to or near the bottom or floating islands) |

**Notes:**

1. Runoff volume reduction can be computed for wet ponds designed for water reuse and upland irrigation.
2. Extended detention may be provided to meet a maximum of 50 percent of the Level 2 Tv; Refer to BMP P-BAS- 03 ED Pond.
3. At least three internal cells must be included including the forebay.
4. In the case of multiple inflows, the flow path is measured from the dominant inflows (that comprise 80 percent or more of the total pond inflow).
5. Due to groundwater influence, slightly lower TP and TN removal rates in coastal plain (Section 3) and CSN Technical Bulletin No. 2. (2009)

   Sources: CSN 2009, CWP and CSN 2008, CWP 2007

*Figure P-BAS-02-1 Vegetated buffer surrounding wet pond*

(https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf)

| Table P-BAS-02-7 Coastal Plain Level 1 and 2 Wet Pond Design Guidance | |
|---|---|
| **Level 1 Design (RR:01; TP: 455; TN:205)** | **Level 2 Design (RR:01; TP: 655; TN:305)** |
| Tv = [(1.0)(Rv)(A)/12] – volume reduced by upstream BMP | Tv = [1.5 (Rv) (A) /12] – volume reduced by upstream BMP |
| Single pond cell (with forebay) | Wet ED2 (24 hr) and/or a multiple-cell design[3] |
| Length of shortest flow path/overall length[4] = 1 or more | Length of shortest flow path/overall length[4] = 1.5 or more |
| 20 feet minimum width aquatic benches | Wetlands more than 10 percent of pond area |
| Shoreline landscaping to discourage geese | Trees, shrubs, and herbaceous plants in pond buffers Shoreline landscaping to discourage geese |
| Aeration (preferably bubblers that extend to or near the bottom or floating islands) | |
| Maintenance access to the forebay/riser | |
| Wet pond permanent pools and outlet elevations must be above the mean high water tidal elevation | |

| Table P-BAS-02-7 Coastal Plain Level 1 and 2 Wet Pond Design Guidance | |
|---|---|
| Level 1 Design (RR:01; TP: 455; TN:205) | Level 2 Design (RR:01; TP: 655; TN:305) |

**Notes:**

1. Runoff volume reduction can be computed for wet ponds designed for water reuse and upland irrigation.
2. Extended detention may be provided to meet a maximum of 50 percent of the Level 2 Tv; Refer to BMP P-BAS- 03 ED Pond.
3. At least three internal cells must be included including the forebay.
4. In the case of multiple inflows, the flow path is measured from the dominant inflows (that comprise 80 percent or more of the total pond inflow).
5. Due to groundwater influence, slightly lower TP and TN removal rates in coastal plain (Section 3) and CSN Technical Bulletin No. 2 2009.

Sources: CSN 2009, CWP and CSN 2008, CWP 2007

### 5.1 Overall Sizing

Wet ponds should be designed to capture and treat the remaining Tv for the water quality design storm and additional detention storage for required energy balance, channel protection, and flood protection volumes (if needed) discharged from the upstream runoff reduction practices. Designers can use a site-adjusted Tv or CN to reflect the use of upland runoff reduction practices.

To qualify for the higher nutrient reduction rates associated with the Level 2 design, wet ponds must be designed with a Tv that is 50 percent greater than the Tv for the Level 1 design (i.e., 1.50[Rv][A]).

Research has shown that larger wet ponds with longer residence times enhance algal uptake and nutrient removal rates. Runoff treatment credit may be taken for the following:

Wet Pond – Level 1 design:

- The entire water volume below the normal pool elevation.

Wet ED and/or multi-cell pond – Level 2 design (1.5 Tv):

- The entire water volume below the normal pool elevation (three internal cells)
- Up to 50 percent of the Tv when provided in ED above the permanent pool elevation within one or multiple cells (refer to Extended Detention Pond BMP P-BAS-03 for ED design).

While most wet ponds have little or no runoff volume reduction capability, they can be designed to promote runoff volume reduction through water reuse (e.g., pumping pond water back into the contributing drainage area for use in seasonal landscape irrigation). While this practice is not common, it has been applied to golf course ponds, and accepted computational methods are available (Wanielista and Yousef 1993 and McDaniel and Wanielista 2005). It is recommended that designers be allowed to take credit for annual runoff reduction achieved by pond water reuse if acceptable modeling data are provided for documentation.

Treatment Volume Storage: The total Tv storage may be provided by a combination of the permanent pool, a shallow marsh, and/or extended detention storage. The permanent pool storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area-to-volume ratios, and/or redundant treatment methods (such as a combination of the permanent pool, ED, and a shallow marsh). A berm or simple weir should be used instead of pipes to separate multiple pond cells.

Maximum Extended Detention Levels: The maximum extended detention volume associated with the Tv may not extend more than 12 inches above the wetland cell permanent pool (at least 10 percent of the Level 2 surface area) at its maximum water surface elevation. The maximum ED and channel protection detention levels can be up to 5 feet above the wet pond permanent pool.

Water Balance Testing: A water balance calculation is recommended to document sufficient inflows to the pond to compensate for combined infiltration and evapotranspiration losses during a 30-day summer drought without creating unacceptable drawdowns (Equation below, adapted from Hunt et al. 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

*Water Balance Equation for Acceptable Water Depth in a Wet Pond*

$$DP > ET + INF + RES - MB$$

Where:

DP = Average design depth of the permanent pool (inches)

ET = Summer evapo-transpiration rate (inches) (assume 8 inches)

INF = Monthly infiltration loss (assume 7.2 @ 0.01 inch/hour)

RES = Reservoir of water for a factor of safety (assume 24 inches)

MB = Measured baseflow rate to the pond, if any (convert to inches)

Design factors that will alter this equation are the measurements of seasonal baseflow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the baseflow conditions over time. As part of the Stormwater Master Planning efforts, extensive national research found that liners should only be used when there are HSG A or B soils that will prevent the normal water elevation from being maintained or when there is potential contamination within the groundwater that should be kept out of the stormwater facility.

Translating the baseflow to inches refers to the depth within the pond. Therefore, the following equation can be used to convert the baseflow, measured in cubic feet per second (ft3/s), to pond-inches:

$$\text{Pond inches} = ft^3/s * (2.592E6) * (12''/ft) / \text{SA of Pond } (ft^2)$$

Where:

2.592E6 = Conversion factor: $ft^3/s$ to $ft^3$/month.

SA = surface area of pond in $ft^2$

### 5.2 Internal Design Geometry

Side slopes for the wet pond should generally have a gradient of 4H:1V to 5H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. See profile view figures in Section 2.

Long Flow Path: Wet pond designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time and pond performance. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al. 2009).

a. The overall flow path can be represented as the length-to-width ratio OR the flow path ratio. These ratios must be at least 2L:1W for Level 1 designs and 3L:1W for Level 2 designs. Internal berms, baffles, or vegetated peninsulas can be used to extend flow paths and/or create multiple pond cells.

b. The shortest flow path represents the distance from the closest inlet to the outlet. Ratio of the shortest flow to the overall length must be at least 0.5 for Level 1 designs and 0.8 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these "closer" inlets should constitute no more than 20 percent of the total contributing drainage area.

Stormwater Pond Benches: The perimeters of all pool areas greater than 4 feet deep must be surrounded by two benches as follows:

- A safety bench is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. Except when the stormwater pond side slopes are 5H:1V or flatter, provide a safety bench that generally extends 8 to 15 feet outward from the normal water edge to the toe of the stormwater pond side slope. The maximum slope of the safety bench is 2 percent.
- An aquatic bench is a shallow area just inside the perimeter of the normal pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. Incorporate an aquatic bench that generally extends up to 10 feet inward from the normal shoreline, has an irregular configuration, and extends a maximum depth of 18 inches below the normal pool water surface elevation.

Safety Features:

- The principal spillway opening must be designed and constructed to prevent access by small children.
- End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.
- An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges. Refer to Support Component P-SUP-01 Earthen Embankments and Support Component P-SUP-03 Emergency Spillway for design details.
- Both the safety bench and the aquatic bench should be landscaped with vegetation that hinders or prevents access to the pool.
- Warning signs prohibiting swimming should be posted.
- Local governments and homeowner associations may require fencing of wet ponds at their discretion. Fencing is required at or above the maximum water surface elevation in the rare situations when the pond slope is a vertical wall.

Aeration Fountains:

- The fountain should draw water from fewer than 2 feet below the permanent pool to avoid resuspending solids.
- Separated units (where the nozzle, pump, and intake are connected by tubing) should be used only if they draw water from the surface in the deepest part of the pond.
- The falling water from the fountain should be centered in the pond, away from the shoreline.

### 5.3 Required Geotechnical Testing

Soil borings will be installed within the footprint of the proposed embankment, in the vicinity of the proposed outlet structure, and in at least two locations within the proposed wet pond treatment area. Soil boring data are needed to: (1) determine the physical characteristics of the excavated material to determine its adequacy as structural fill or other use, (2) determine the need and appropriate design depth of the embankment cut-off trench, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine the depth to groundwater and bedrock, and (5) evaluate potential infiltration losses (and the potential need for a liner). Refer to Support Component P-SUP-01 Earthen Embankments for further information on required geotechnical investigations.

### 5.4 Pretreatment Forebay

Sediment forebays are an integral design feature to maintain the longevity of all wet ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. In addition to forebays, there may be a need for grass filter strips or gravel flow spreaders into the forebay. Sediment forebays and other applicable forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with Support Component P-SUP-06 Pre-Treatment.

### 5.5 Conveyance and Overflow

| Table P-BAS-02-8 Conveyance and Overflow Design Considerations | |
|---|---|
| **Component** | **Discussion** |
| Principal Spillway | The principal spillway will be designed with acceptable non-clogging low-flow orifice, anti-flotation, anti-vortex, and trash rack devices. The spillway must generally be accessible from dry land. Trash racks must be installed at the intake of the outlet structure and be designed to avoid acting as the hydraulic control for the outlet system. Refer to Support Component P-SUP-02 Principal Spillways. |
| Emergency Spillway | Wet ponds must be constructed with overflow capacity to pass the 100-year design storm event through either the primary spillway (with 2 feet of freeboard to the settled top of embankment) or a vegetated or armored emergency spillway (with at least 1 foot of freeboard to the settled top of embankment). Refer to Support Component P-SUP-01 Emergency Spillways. |
| Pond Drain | Wet ponds should be equipped with a drainpipe that can completely or partially drain the permanent pool. Where a low-level drain is not feasible (such as in an excavated pond or a pond in the coastal plain where a low-level outlet is not available), a pump wet well should be provided to accommodate a temporary pump intake when needed to drain the pond.<br>• The drainpipe should have an upturned elbow or protected intake within the pond to prevent sediment deposition and a diameter capable of draining the pond within 24 hours.<br>• The pond drain must be equipped with an adjustable valve located within the riser where it will not be normally inundated and can be operated in a safe manner. |
| Adequate Outfall Protection | The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged during the emergency spillway design event, whichever is greater). The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance.<br>Outlet protection should be provided consistent with state or local guidance.<br>Outlet protection or energy dissipation should be provided consistent with BMP C-ECM-15 Outlet Protection. |

| Table P-BAS-02-8 Conveyance and Overflow Design Considerations | |
|---|---|
| **Component** | **Discussion** |
| Inlet Protection | Inlet areas should be stabilized to ensure non-erosive conditions during storm events up to the overbank flood event (i.e., the 10-year storm event). Outlet protection or energy dissipation should be provided consistent with BMP C-ECM-15 Outlet Protection. Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation. Inlet pipes should not be fully submerged at normal pool elevations.<br>Where the inlet pipe needs to be submerged, the following criterion needs to be met.<br>• Pipe velocities support minimum velocities for sediment flushing per VDOT Drainage Manual requirements.<br>A hydraulic grade line analysis considering the tailwater effects of the normal pool elevation will be completed that shows the adequacy of the upstream storm system during the 10-year storm. |
| Dam Safety Permits | Wet ponds with high embankments or large drainage areas and impoundments may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.). Refer to Design Specification Support Component P-SUP-01 Earthen Embankments for additional information. |

**5.6 Landscaping and Planting Plan**

A Landscaping Plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the pond and its buffer. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within both the pond and buffer;
- Selection of corresponding plant species;
- A planting plan;
- The sequence for preparing the wetland benches (including soil amendments if needed);
- Sources of native plant material;
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers. However, to the extent possible, the aquatic and safety benches should be planted with dense shoreline vegetation to help establish a safety barrier as well as to discourage resident geese;
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment or within 25 feet from the principal spillway structure;
- A vegetated buffer should be provided that extends at least 25 feet outward from the maximum water surface elevation of the wet pond. Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction;
- The soils in the stormwater buffer area are often severely compacted during construction to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of

thumb, planting holes should be three times deeper and wider than the diameter of the root ball for ball-and-burlap stock and five times deeper and wider for container-grown stock;

- Avoid planting species that require full shade or are prone to wind damage. Extra mulching around the bases of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds; and
- The use of native plants is encouraged. Native plant species can be identified using https://www.dcr.virginia.gov/natural-heritage/document/riparian-nat-plants.pdf and DCR native plant finder https://www.dcr.virginia.gov/natural-heritage/native-plants-finder.

For more guidance on planting trees and shrubs in wet pond buffers, consult the following:

- Cappiella et al. 2006;
- DCR's Riparian Buffer Modification & Mitigation Guidance Manual, available online at:http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/ripbuffmanual.shtml; and
- Support Component P-SUP-05 Landscaping.

### 5.7 Wet Pond Material Specifications

Wet ponds are generally constructed with materials obtained onsite, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), stone for inlet and outlet stabilization, and filter fabric for lining banks or berms.

The basic material specifications for wet ponds are outlined in Table P-BAS-02-9:

**Table P-BAS- 02-9 Wet Pond Materials Specifications**

| Component | Specification |
|---|---|
| Turf Grass and Landscaping | C-SSM-10 Permanent Seeding Support Component |
| Outlet Orifices and Spillway | Support Component P-SUP-02 Principal Spillways |
| Inlet and Outlet Protection | C-ECM-15 Outlet Protection and C-ECM-13 Riprap |
| Pre-treatment | Support Component P-SUP-06 Pre-treatment |
| Erosion Control Blankets | C-SSM-05 Soil Stabilization Blankets and Matting Pond banks should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the banks. |
| Embankments | Support Component P-SUP-01 Earthen Embankments |
| Emergency Spillways | Support Component P-SUP-03 Vegetated Emergency Spillway |

### 5.8 Maintenance Considerations

The following wet pond maintenance issues can be addressed during design to make ongoing maintenance easier:

- Maintenance Access: Functional access is needed so crews can remove sediment, make repairs, and preserve pond treatment capacity.
  - Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
  - The riser should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

- Access roads must: (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 12 feet, and (3) have a profile grade that does not exceed 15 percent. Steeper grades are allowable if appropriate stabilization techniques are used such as a gravel road.
- Account for the type of equipment required to perform the maintenance in access design.
- A maintenance right-of-way or easement must extend to the stormwater pond from a public or private road.

- Liners: When a stormwater pond is located over highly permeable soils or fractured bedrock, a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include the following: (1) a clay liner following the specifications outlined in Table P-BAS-02-10; (2) a 30 mil poly-liner; (3) bentonite; (4) use of chemical additives; or (5) an engineering design as approved on a case-by-case basis by the local review authority. A clay liner should have a minimum thickness of 12 inches, with a minimum 12 inches for each foot the groundwater table to above the normal pool elevation of the pond and have an additional 12-inch layer of compacted soil above it. Clay liners must meet the specifications outlined in Table P-BAS-02-10. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

**Table P-BAS-02-10 Clay Liner Specifications**

| Property | Test Method | Unit | Specification |
|---|---|---|---|
| Permeability | ASTM D-2434 | Cm/sec | 1 x 10-6 |
| Plasticity Index of Clay | ASTM D-423/424 | % | Not less than 15 |
| Liquid Limit of Clay | ASTM D-2216 | % | Not less than 30 |
| Clay Particles Passing | ASTM D-422 | % | Not less than 30 |
| Clay Compaction | ASTM D-2216 | % | 95% of standard proctor density |
| Source: DCR 1999 | | | |

- Pond Aerators: Electric or mechanical aeration is used to place as much oxygen into contact with water as economically practical. That can be accomplished by mixing large quantities of water (both volume and total surface area) with atmospheric oxygen. Aerators can be used continuously, seasonally, or temporarily as needed to maintain minimum oxygen levels. Several different types and scales of aeration devices are available. Most aeration equipment will require electricity at the pond bank.

## 6.0 Construction Specifications

### 6.1 Construction Sequence

The following is a typical construction sequence to properly install a wet pond. The steps may be modified to reflect different wet pond designs; site conditions; and the size, complexity, and configuration of the proposed facility.

Step 1: Use of Wet Pond as an Erosion and Sediment (E&S) Control: A wet pond may serve as a sediment basin during project construction. If so, the volume should be based on the more stringent sizing rule (E&S control requirement vs. water quality treatment requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction wet pond in mind. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a wet pond.

Step 2: Stabilize the Drainage Area: Wet ponds should only be constructed after the contributing drainage area to the pond is completely stabilized. If the proposed pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be dewatered, dredged, and re-graded to design dimensions after the original site construction is complete.

Step 3: Assemble Construction Materials onsite, ensure they meet design specifications, and prepare any staging areas.

Step 4: Install E&S Controls prior to construction including temporary dewatering devices and stormwater diversion practices. All areas surrounding the pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization. See Appendix G for guidance on plant selection.

Step 5: Clear and Strip the project area to the desired sub-grade.

Step 6: Excavate the core trench and install the spillway pipe as applicable.

Step 7: Install the Riser or Outflow Structure and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 8: Construct the Embankment and Any Internal Berms in 8- to 12-inch lifts, or as directed by geotechnical recommendations, and compact as required with appropriate equipment.

Step 9: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the pond.

Step 10: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 11: Install Outlet Protection including inflow points, emergency, and primary outlet apron protection in accordance with approved plans.

Step 12: Stabilize Exposed Soils with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

Step 13: Plant the Pond Buffer Area following the pondscaping plan.

### 6.2 Construction Inspection

Multiple inspections are critical to ensuring that stormwater ponds are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting;
- Initial site preparation (including installation of E&S controls);
- Excavation/Grading (interim and final elevations);
- Installation of the embankment, the riser/primary spillway, and the outlet structure;
- Implementation of the pondscaping plan and vegetative stabilization; and
- Final inspection (develop a punch list for facility acceptance).

Upon final inspection and acceptance, the global positioning system (GPS) coordinates for all wet ponds should be logged for entry into the VSMP Authority's BMP maintenance tracking database.

A construction phase inspection checklist for wet ponds is included in 9.0 Appendix A Sample Construction Inspection Checklist for Wet Ponds.

To facilitate maintenance, contractors should measure the actual constructed pond depth at three areas within the permanent pool (forebay, mid-pond, and at the riser), and they should mark and geo-reference them on an as-built drawing. This simple dataset will enable maintenance inspectors to determine pond sediment deposition rates to schedule sediment cleanouts. Alternatively, a full topographic map of the pond bottom can also ensure the pond volume as-built meets the design volume.

# 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of wet ponds, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- Restrictive covenants or other mechanisms enforceable by the VESMP Authority should be in place to help ensure that wet ponds are maintained as well as to pass the knowledge along to any subsequent property owners.
- Access to wet ponds should be covered by a drainage easement to allow access by the VESMP Authority to conduct inspections and perform maintenance when necessary.
- All wet ponds should include a long-term Maintenance Agreement consistent with the provisions of the Virginia Erosion and Stormwater Management Regulation and should include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The Maintenance Agreement should also include contact information for owners to obtain local or state assistance to solve common nuisance problems such as mosquito control, geese, invasive plants, vegetative management, and beaver removal.

### 7.2 First Year Maintenance Operations

Successful establishment of wet ponds requires that the following tasks be undertaken during the first year following construction.

Initial inspections: For the first 6 months following construction, the site should be inspected after large storm events.

Planting of Aquatic Benches: The aquatic benches should be planted with emergent wetland species, following the planting recommendations contained in Support Component: P-SUP-05 Landscaping and Stormwater BMP P-BAS-01 Constructed Wetlands. Native plant species are always preferred.

Spot Reseeding: Inspectors should look for bare or eroding areas in the contributing drainage area or around the pond buffer and make sure they are immediately stabilized with grass cover.

Watering: Trees planted in the pond buffer may need to be watered during the first growing season. In general, consider watering every 3 days for the first month, and then weekly during the remainder of the first growing season (April through October) depending on rainfall. Lack of maintenance during the initial growing season may lead to costly tree replacement projects.

### 7.3 Maintenance Inspections

Maintenance of a wet pond is driven by annual inspections that evaluate the condition and performance of the pond including the following:

- Measure sediment accumulation levels in the forebay.
- Monitor the growth of wetland plants, trees, and shrubs planted. Record the species and their approximate coverage and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion, or undercutting.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine embankment integrity.
- Check for the presence of trees or woody growth, on the face, top, downstream slope or within 25 feet of the toe of the embankment, or that blocks inflow and orifices that compromises the integrity of the embankment.
- Inspect the pond outfall channel for erosion, undercutting, rip-rap displacement, woody growth, and other issues.
- Inspect the condition of the principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, and other issues.
- Inspect the condition of all trash racks, reverse-sloped pipes, or flashboard risers for evidence of clogging, leakage, debris accumulation, and other issues.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes, and locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately.
- Inspection results will trigger specific maintenance tasks. Example maintenance inspection checklists for wet ponds are included in Chapter 10 of the Virginia Stormwater Management Handbook

### 7.4 Common Ongoing Maintenance Tasks

Maintenance is needed to operate stormwater ponds as designed in the long term. Wet ponds normally carry fewer routine maintenance requirements than other stormwater control measures. Stormwater pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine stormwater pond maintenance, such as mowing and removing debris and trash, is needed several times each year (See Table P-BAS-02-9). Mowing should include removal of woody growth on or below the dam to prevent impacts to the integrity of the dam from their root systems. More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Critical structural features (e.g., embankments and risers) need to be inspected and repaired by a qualified professional (e.g., a geotechnical or structural engineer) who has experience in the construction, inspection, and repair of these features.

The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining upland buffer can be managed as a meadow (mowing every other year) or forest. An invasive vegetation management plan should be included within the maintenance plan. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

| Table P-BAS-02-11 Typical Wet Pond Maintenance Tasks and Frequency | |
|---|---|
| **Maintenance Items** | **Frequency** |
| • Mowing – twice a year<br>• Remove debris and blockages<br>• Repair undercut, eroded, and bare soil areas | Quarterly or after major storms (>1 inch of rainfall) |
| • Mowing, including removal of woody growth | Twice a year |
| • Shoreline cleanup to remove trash, debris and floatables<br>• A full maintenance inspection<br>• Open up the riser to access and test the valves<br>• Repair broken mechanical components if needed | Annually |
| • Pond buffer and aquatic bench reinforcement plantings | One time (during the second year following construction) |
| • Forebay sediment removal | Every 5 to 7 years |
| • Repair pipes, the riser and spillway as needed | From 5 to 25 years |

### 7.5 Sediment Removal

Frequent sediment removal from the forebay is essential to maintaining the function and performance of a wet pond. For planning purposes, maintenance plans should anticipate cleanouts approximately every 5 to 7 years or when inspections indicate that 50 percent of forebay sediment storage capacity has been filled. (Absent an upstream eroding channel or other source of sediment, the frequency of sediment removal should decrease as the drainage area stabilizes.) The designer should also check to see whether removed sediments can be spoiled onsite or must be hauled away. Sediments excavated from wet ponds are not usually considered toxic or hazardous. They can be safely disposed of by either land application or landfilling. Sediment testing may be needed prior to sediment disposal if the wet pond serves a hot spot land use.

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## 9.0 Appendix A Sample Construction Inspection Checklist for Wet Ponds

The following checklist provides a basic outline of the anticipated items for the construction inspection of a wet pond. Inspectors should review the plans carefully and adjust these items and the timing of inspection verification as needed to ensure the intent of the design and the inspection is met. Finally, users of this information may wish to incorporate these items into a VSMP Authority Construction Checklist format consistent with the format used for erosion and sediment control and BMP construction inspections.

**Pre-Construction Meeting**

- ☐ Pre-construction meeting with the contractor designated to install the wet pond has been conducted.
- ☐ Identify the tentative schedule for construction and verify the requirements and schedule for interim inspections and sign-off.
- ☐ Impervious cover has been constructed/installed and the facility contributing drainage area is free of erodible materials and potentially pollutant generating materials/activities
- ☐ All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation and erosion control measures have been removed.
- ☐ Certification of Stabilization Inspection: Inspector certifies that the drainage areas are adequately stabilized to convert the temporary measure into a permanent wet pond.

**Construction of Wet Pond Embankment and Principal Spillway**

- ☐ Stormwater has been diverted around or through the area of the wet pond embankment to a stabilized conveyance; and perimeter erosion control measures to protect the facility during construction have been installed.
- ☐ Construction of key trench, principal spillway, including the riser and barrel, seepage controls, outlet protection, etc., is built in accordance with approved plans.
- ☐ Geotechnical analysis and approval of the core (if required) and embankment material has been provided, and the material has been placed in lifts and compacted in accordance with the approved plans.
- ☐ Certification of Embankment and Principal Spillway Inspection: Inspector certifies that each element of the embankment and principal spillway has been constructed in accordance with the approved plans.

**Excavation of Wet Pond**

| | |
|---|---|
| ☐ | Excavation of the wet pond geometry (including bottom width, side slopes, check dams, weir overflow and outlet protection, etc.) achieves the elevations in accordance with approved plans.. |
| ☐ | Excavation of internal micro-topographic features: deep pool, forebays, etc., is in accordance with approved plans |
| ☐ | Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturers specifications. |
| ☐ | Certification of Excavation Inspection: Inspector certifies that the excavation has achieved all the appropriate grades, grade transitions, and wet pond geometry as shown on the approved plans. |

**Landscaping Plan and Stabilization**

| | |
|---|---|
| ☐ | Exposed soils on pond side slopes above permanent pool elevation are stabilized with specified seed mixtures, stabilization matting, mulch, etc., in accordance with approved plans. |
| ☐ | Appropriate number and spacing of plants are installed and protected on the aquatic bench and pond buffer in accordance with the approved plans. |
| ☐ | All erosion and sediment control practices have been removed. |
| ☐ | Follow-up inspection and as-built survey/certification has been scheduled. |
| ☐ | GPS coordinates have been documented for the wet pond installation. |

# P-BAS-03 Extended Detention Pond

## 1.0 Definition

An extended detention (ED) pond is an earthen structure constructed by either excavation of existing soil or impoundment of a natural depression. An ED pond relies on temporary storage of runoff and hydraulically attenuates post-development runoff peak increases by providing detention and drawdown of stormwater runoff after each rain event.

## 2.0 Purpose and Applicability of Best Management Practice

An ED pond relies on gravitational settling as its primary pollutant removal mechanism. Consequently, ED ponds generally provide fair to good removal of particulate pollutants, but low or negligible removal of soluble pollutants such as nitrate and soluble phosphorus. The use of ED alone generally results in the lowest overall pollutant removal rate of any single stormwater treatment option. Alternatively, an ED component is combined with P-BAS-02 Wet Ponds and P-BAS-01 Constructed Wetlands to maximize pollutant removal rates of those practices.

An ED pond reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the receiving stream. A design maximum peak rate of flow, or peak discharge, is commonly used to meet channel protection or flood control requirements and often only detains flows for a few minutes or hours. However, in some cases, detention designed for channel protection using the “energy balance” method described in the Virginia Stormwater Management Program (VSMP) regulations (4VAC50-60-66) may result in extended drawdown times. Therefore, designers are encouraged to evaluate the channel protection detention drawdown compared to the ED requirements to optimize the design and meet both criteria.

Designers should note that an ED pond is typically the final element in the roof-to-stream pollutant removal sequence and provides a limited volume reduction credit (Level 2 only). Therefore, this best management practice (BMP) should be considered only if there is remaining treatment volume (Tv) or channel and flood protection volume to manage after all other upland runoff reduction practices have been considered and properly credited.

An ED pond can be combined as a design element with other stormwater treatment practices (e.g., wet ponds and constructed wetlands) to enhance their performance and appearance. Similarly, other design variations can be incorporated into the ED pond (e.g., bioretention, infiltration, sand filters) located within the overall footprint but housed in a separate, distinct cell, where the maximum allowable contributing drainage area (CDA) can be addressed. The traditional (and most common) design applications for ED include:

- Micro-pool and dry ED;
- Wet ED pond (covered in P-BAS-02 Wet Ponds); and
- Limited ED above wetlands (covered in P-BAS-01 Constructed Wetlands).

Figure P-BAS-03-1 illustrates ED pond design variations. While ED ponds can provide for channel and flood protection, they will rarely provide adequate runoff volume reduction and pollutant removal to serve as a stand-alone water quality compliance strategy. Therefore, designers should maximize the use of upland runoff reduction practices (e.g., rooftop disconnections, small-scale infiltration, rainwater harvesting, bioretention, grass channels and dry swales) that reduce runoff at its source (rather than merely treating the runoff at the terminus of the storm drain system). Upland runoff reduction practices can be used to satisfy most or all the runoff reduction requirements at most sites. However, an ED pond may still be needed to fulfil any remaining channel and flood protection requirements. Upland runoff reduction practices will greatly reduce the size, footprint, and cost of the downstream ED pond.

### 2.1 Feasibility/Limitations

The feasibility criteria identified in Table P-BAS-03-1 should be evaluated when ED ponds are considered as the final practice in a treatment train. Many of these items will be influenced by the type of ED pond being considered (refer to Design Applications at the end of this section). Table P-BAS-03-2 describes offset guidance for ED pond placement.

**Table P-BAS-03-1 Extended Detention Pond Feasibility Criteria**

| Parameter | Criteria |
|---|---|
| Depth to Water Table and Bedrock | Water table separation of a minimum of 2 feet below the bottom of the basin is needed for dry ED pond. Water table separation for level 2 with micro-pool is not needed. |
| Soils | The permeability of soils is seldom a design constraint for ED ponds. Infiltration through the bottom of the pond is encouraged unless it impairs the integrity of the embankment. Soil explorations should be conducted at the proposed pond embankment to estimate infiltration rates and properly design the embankment cut-off trench.<br>An initial soil exploration and investigation should be conducted to rule out infiltration as a preferred practice and to rule out the presence of karst topography. If karst topography is present, please refer to the Design Criteria section of this spec for additional guidance when designing within karst topography. |

| Table P-BAS-03-1 Extended Detention Pond Feasibility Criteria | |
|---|---|
| **Parameter** | **Criteria** |
| Tailwater Conditions | The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the ED pond. Design tailwater condition elevation will be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a high tide elevation evaluation will accompany the tailwater condition evaluation. |
| Tidal Impacts | The outlet elevation of an ED pond should be located above the tidal mean high water elevation to limit tidal backflow into the pond. |
| Perennial Streams | Locating ED ponds on perennial streams is typically not allowed and would require Section 401 and Section 404 permits from the appropriate state or federal regulatory agencies. |

| Table P-BAS-03-2 ED Pond Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and other such structures. | 25 feet Horizontal | Closer offsets may be considered on a case-by- case basis where impermeable liners are specified by the designer. |
| Property lines | 10 feet horizontal | |
| Septic system drain fields | 35 feet horizontal | |
| Private water wells | 50 feet horizontal | |

* Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the toe of the embankment on the downstream side and the design high water or 100-year water surface elevation (whichever is greater) on the upstream side (DCR 2013).

## 3.0 Planning and Considerations

Table P-BAS- 03-3 highlights environmental and community concerns regarding ED ponds, each of which should be considered when evaluating BMP alternatives.

| Table P-BAS- 03-3 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Justification** |
| Aesthetics | ED ponds tend to accumulate sediment and trash, which residents are likely to perceive as unsightly and creating nuisance conditions. Fluctuating water levels in ED ponds also create a difficult landscaping environment. In general, designers should avoid designs that rely solely on dry ED ponds. |
| Existing Wetlands | ED ponds should never be constructed within existing natural wetlands nor should they inundate or otherwise change the hydroperiods of existing wetlands. |

| Table P-BAS- 03-3 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Justification** |
| Existing Forests | Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction.<br>Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Wright et al. 2007). |
| Stream Warming Risk | ED ponds carry a lower risk of stream warming than other pond options, but they can warm streams if they are not shaded or contain significant surface area in shallow pools. If an ED pond discharges to temperature-sensitive waters, it should be shaded to the maximum extent possible while ensuring no woody vegetation is planted within 15' of the toe of the embankment and 25' of the principal spillway, contain the minimum number of pools to prevent clogging and have a drawdown time of no longer than 24 hours. If a level 2 design with a drawdown time of 36 hours is necessary, the additional detention time may be allowed if sufficient landscaping with an emphasis on shade is provided. |
| Trout Streams | Pond practices have a tendency to raise the water temperatures in receiving streams. Therefore, the use of ED ponds in watersheds containing trout streams is restricted to situations in which upland runoff reduction practices cannot meet the full channel protection volume (CPv) requirement. In these instances, an ED pond should:<br>• Be designed with a maximum 24-hour detention time (to avoid excessive warming of runoff);<br>• Have a minimum outlet micro-pool volume sufficient to prevent clogging;<br>• Be planted with trees so it becomes fully shaded; and<br>• Be located outside of any required stream buffers. |
| Safety Risk | ED ponds are generally considered to be safer than other pond options because they have few deep pools. Maximum side slopes and unfenced headwalls, however, can still create some safety risks. Gentle side slopes and safety benches graded near the water line of any water feature should be provided to avoid potentially dangerous drop-offs, especially where ED ponds are located near residential areas. |
| Mosquito Risk | The fluctuating water levels within ED ponds have potential to create conditions that lead to mosquito breeding. Designers can minimize the risk by combining ED with a wet pond or wetland. |

## 4.0 Stormwater Performance Summary

Table P-BAS- 03-4 provides the credit given by Virginia Department of Environmental Quality (VDEQ) to Level 1 and Level 2 designs of ED ponds.

| Table P-BAS-03-4 Summary of Stormwater Functions Provided by ED Ponds | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Volume Reduction (RR) | 0% | 15% |
| Total Phosphorus (TP) event mean concentration (EMC) Reduction[1] by BMP Treatment Process | 15% | 15% |
| **TP Mass Load Removal** | **15%** | **31%** |
| Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process | 10% | 10% |
| TN Mass Load Removal | 10% | 24% |
| Channel Protection | Yes; storage volume can be provided to accommodate the full CPv | |
| Flood Mitigation | Yes; flood protection storage can be provided beyond the maximum extended detention volume | |

1. Change in EMC through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate.

## 5.0 Design Criteria

As the last component in the treatment train, ED ponds can serve the dual functions of providing the final runoff volume and pollutant load reduction needed on the development site, while also providing the detention storage required to meet the channel and flood protection requirements. Refer to P-SUP-07 Quantity Only Approach to BMPs for design specifications and criteria on the design of ponds and basins that are not designed for pollutant removal and only provide detention storage needed to meet channel and flood protection requirements. Designers may, therefore, select the baseline design (Level 1) or may maximize the volume and pollutant load reduction by incorporating an enhanced design (Level 2). To qualify for the higher nutrient reduction rates associated with the Level 2 design, ED ponds must be designed with a Tv equal to 1.25(Rv)(A) as well as other specific design elements. Table P-BAS-03-5 lists the criteria for the Level 1 and 2 designs. See Section 6 for more detailed design guidelines.

| Table P-BAS-03-5 ED Pond Criteria | |
|---|---|
| **Level 1 Design (RR:0; TP:15; TN:10)** | **Level 2 Design (RR:15; TP:15; TN:10)** |
| Tv = [(1.0) (Rv) (A )] / 12 – the volume reduced by an upstream BMP | Tv = [(1.25) (Rv) (A)] / 12 – the volume reduced by an upstream BMP |
| A minimum of 15 percent of the Tv in the permanent pool (forebay, micro-pool) | A minimum of 40 percent of Tv in the permanent pool (15 percent in forebays and micro-pool, and 25 percent in constructed wetlands) |
| Length/Width ratio OR flow path = 2:1 or more; Length of the shortest flow path/overall length = 0.4 or more | Length/Width ratio OR flow path = 3:1 or more; Length of the shortest flow path/overall length = 0.7 or more. |
| Average Tv Drawdown Time = 24 hours | Average Tv Drawdown Time = 36 hours. |

| Table P-BAS-03-5 ED Pond Criteria | |
|---|---|
| **Level 1 Design (RR:0; TP:15; TN:10)** | **Level 2 Design (RR:15; TP:15; TN:10)** |
| Vertical Tv ED fluctuation may exceed 4 feet. | Maximum vertical Tv ED limit of 4 feet. |
| Turf cover on floor | Trees, shrubs, and herbaceous plants in upper elevations and emergent plants in wet features |
| Forebay and micro-pool | Incudes additional cells or features (e.g., deep pools, wetlands) |
| Liner allowed | Liner not allowed |

**5.1 Overall Sizing**

The ED pond is designed to hold the design Tv within the water volume below the normal pool elevation of any micro-pools and forebays (minimum of 15 percent for ED Level 1; 15 percent of the Tv will be provided in the forebay and 25 percent is provided in the micro-pools for Level 2) as well as the temporary ED storage volume beyond the normal pool. To qualify for the higher nutrient reduction rates associated with the Level 2 design, the ED pond must be designed with a Tv 25 percent greater than the Tv for the Level 1 design (i.e., 1.25[Rv][A]; additional CPv is not required).

Designers should use the BMP design treatment volume (TvBMP; defined as the treatment volume based on the contributing drainage area [TvDA] less any volume reduced by upstream runoff reduction practices) to size and design the wet features and ED volume. If additional detention storage is proposed for channel and/or flood protection, designers should use the adjusted curve number reflective of the volume reduction provided by the upstream practices as well as the ED pond (Level 2) to calculate the developed condition energy balance detention requirements (Refer to Chapter 5 of the Virginia Stormwater Handbook).

**5.2 Treatment Volume Drawdown and Detention Design**

Methods for calculating the required orifice size for achieving the target drawdown of the Tv for the Level 1 (24 hours) and Level 2 (36 hours) design are provided in Appendix A. Similarly, the hydraulic design of the multi-stage riser to meet the channel and flood protection design goals are also included in the same location.

| Table P-BAS- 03-6 Treatment Volume Design | |
|---|---|
| **Parameter** | **Details** |
| Tv (water quality) Storage | The ED pond is designed to hold the design Tv by a combination of the permanent pool (in the form of micro-pools, forebays, and wetland areas) as well as the temporary ED storage volume beyond the normal pool. The permanent pool must hold a minimum of 15 percent of the design Tv for ED Level 1 and 40 percent for Level 2. To qualify for the higher nutrient reduction rates associated with the Level 2 design, the ED pond must be designed with a Tv 25 percent greater than that for the Level 1 design (i.e., 1.25[Rv][A]; additional CPv is not included).<br><br>Constructed wetlands added to achieve a Level 2 design should be connected to the forebays or the micro-pool with a transition zone. Refer to BMP P-BAS-01 Constructed Wetlands for criteria on the appropriate depth, side slopes, and other design features for the wetland pool component. |
| Vertical Extended Detention Limits | The maximum Tv ED water surface elevation may not extend more than 5 feet above the basin floor or normal pool elevation; 4 feet for a Level 2 design. The maximum vertical elevation for ED and channel protection detention over shallow wetlands is 1 foot. The limit is also applicable when an ED is stacked with bioretention or infiltration basins. The bounce effect is not as critical for larger flood protection storms (e.g., the 10-year design storm), and these events can exceed the 5-foot vertical limit if they are managed by a multi-stage outlet structure. |

| Table P-BAS-03-7 Internal Design Geometry | |
|---|---|
| **Component** | **Details** |
| Side Slopes | Side slopes leading to the ED pond should generally have a gradient no steeper than 4H:1V or 3H:1V with safety bench. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. |
| Long Flow Path | ED pond designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time, treatment pathways, and pond performance. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond and (2) the length of the shortest flow path (Hirschman et al. 2009):<br><br>The overall flow path can be represented as the length-to-width ratio OR the flow path ratio (These ratios must be at least 2L:1W for Level 1 designs and 3L:1W for Level 2 designs). Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.<br><br>The shortest flow path represents the distance from the closest inlet to the ED pond outlet. The ratio of the shortest flow to the overall length must be at least 0.4 for Level 1 designs and 0.7 for Level 2 designs. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these “closer” inlets should constitute no more than 20 percent of the total CDA. |

| Table P-BAS-03-7 Internal Design Geometry | |
|---|---|
| **Component** | **Details** |
| Safety Features | Several installation features of impounding structures are intended to provide elements of safety but are not required for engineering design:<br>• A safety bench is a minimum 10-foot-wide bench with a maximum cross slope of 2 percent located immediately above the ED design high water; slopes above the safety bench should be no steeper than 3:1.<br>• An aquatic bench is located on the perimeter of all wet features (forebays, micro- pools, wetland pools) and is graded from a depth of 0 to 18 inches (maximum). The width of the aquatic bench should be 4 to 6 feet for forebays and 6 to 10 feet for micro-pools.<br>• Safety benches and aquatic benches should be landscaped with vegetation that hinders or prevents access to the pool.<br>• The principal spillway opening must be designed and constructed to prevent access by small children.<br>• End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a safety hazard.<br>• An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges and provide a safe and stable discharge of runoff from the ED pond in the event of spillway overflow. Safe and stable discharge minimizes the possibility of erosion and flooding of downstream areas. |

### 5.3 Required Geotechnical Testing

Soil explorations should be conducted within the footprint of the proposed embankment, in the vicinity of the proposed outlet, and in at least two locations within the proposed ED pond treatment area or surrounding area. Soil boring data are needed to: (1) determine the physical characteristics of the excavated material to evaluate its adequacy as structural fill or other use, (2) determine the need and appropriate design depth of the embankment cut-off trench, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine the depth to groundwater and bedrock, and (5) evaluate potential infiltration losses (and the potential need for a liner).

Additional guidance on geotechnical criteria for impoundment facilities is provided in P-SUP-01 Earthen Embankment. Guidance on soil explorations in general is provided in Appendix C. Geotechnical investigation for dry ponds with karst terrain should comply with the survey methods outlined in the Chesapeake Bay Stormwater Network Technical Bulletin No 1, Ver. 2 and guidelines in Appendix E.

### 5.4 Pretreatment Forebay

Sediment forebays are an integral design feature that maintain the longevity of ED ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. Refer to P-SUP-06 Pre-Treatment for design criteria and specifications associated with sediment forebays. Other forms of pre-treatment for sheet flow and concentrated flow for minor inflow points should be designed consistent with pre-treatment criteria documented in P-SUP-06 Pre-Treatment.

In karst terrain, a lined sedimentation forebay may be required.

**5.5 Conveyance and Overflow**

**Table P-BAS-03-8 Conveyance and Overflow Design**

| Component | Details |
|---|---|
| No Pilot Channels | Micro-pool ED ponds will not have a low-flow pilot channel, but instead must be constructed in a manner whereby flows are evenly distributed across the pond bottom to promote the maximum infiltration possible. |
| Internal Slope | The maximum longitudinal slope through the pond must be approximately 0.5 to 1 percent to promote positive flow through the ED pond. |
| Principal Spillway | The principal spillway will be designed with acceptable anti-flotation, anti- vortex, anti-seep collar, and trash rack devices. Trash racks must be installed at the intake of the outlet structure and designed to avoid acting as the hydraulic control for the outlet system. The spillway must generally be accessible from dry land. Refer to P-SUP-02 Principal Spillway for design criteria. |
| Non-Clogging Low Flow Orifice | ED ponds with drainage areas of 10 acres or less, for which small-diameter outlet pipes and orifices are typical, are prone to chronic clogging by organic debris and sediment. Vertical perforated risers wrapped in gravel should be the preferred orifice. Horizontal perforated extensions wrapped in gravel are good for maintaining a dry basin bottom. Conventional trash racks need to have spacings that are half the diameter of the orifice; this is not practical for 3-inch or smaller orifices. Orifices less than 3 inches in diameter should be avoided, unless otherwise approved by the VESMP authority. Refer to P-SUP-02 Principal Spillway for design criteria and information regarding low-flow orifice design. |
| Emergency Spillway | ED ponds must be constructed with overflow capacity to safely pass the 100-year design storm event without overtopping the embankment and causing structural damage to the facility through either the primary spillway (with 2 feet of freeboard to the settled top of embankment) or a vegetated or armored emergency spillway (with at least 1 foot of freeboard to the settled top of embankment). Refer to P-SUP-03 Vegetated Emergency Spillway for design criteria. |

| Table P-BAS-03-8 Conveyance and Overflow Design | |
|---|---|
| **Component** | **Details** |
| Adequate Outfall Protection | The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged during the emergency spillway design event, whichever is greater). The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance with care taken to minimize tree clearing along the downstream channel. Outlet protection or energy dissipation should be provided consistent with BMP C-ECM-15 Outlet Protection. |
| Inlet Protection | Inlet areas should be stabilized to ensure non-erosive conditions during storm events up to the overbank flood event (i.e., the 10-year storm event). Outlet protection or energy dissipation should be provided consistent with BMP C-ECM-15 Outlet Protection. Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation. Inlet pipes should not be fully submerged at normal pool elevations.<br>Where the inlet pipe needs to be submerged, the following criterion needs to be met.<br>• Pipe velocities support minimum velocities for sediment flushing per Virginia Department of Transportation (VDOT) Drainage Manual requirements.<br>A hydraulic grade line analysis considering the tailwater effects of the normal pool elevation will be completed that demonstrates the adequacy of the upstream storm system during the 10-year storm. |
| On-Line ED Ponds | On-line ED ponds must be designed to detain the required Tv and either manage or be capable of safely passing larger storm events conveyed to the pond (e.g., 1- year and 2-year channel protection detention, 10-year flood protection, and/or the 100-year design storm event). Adequate design freeboard between the maximum design water surface elevation and the top of the embankment must be provided in accordance with P-SUP-01 Earthen Embankment. |
| Dam Safety Permits | ED ponds with high embankments or large drainage areas and impoundments may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.). Refer to P-SUP-01 Earthen Embankment for additional information. |

**5.6 Landscaping and Planting Plan**

A landscaping plan must be provided that documents the methods used to establish and maintain vegetative coverage within the ED pond and its buffer. Minimum elements of a plan include the following:

- Delineation of pondscaping zones within both the pond and buffer;
- Selection of corresponding plant species;
- The planting plans;

- The sequence for preparing the wetland bed if one is incorporated with the ED pond (including soil amendments if needed);
- Sources of native plant material;
- The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the stormwater wetland and buffers;
- The planting plan should allow the pond to mature into a native forest in the right places but keep mowable turf along the embankment and all access areas. The wooded wetland concept proposed by Cappiella et al. 2005 may be a good option for many ED ponds;
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment or within 25 feet from the principal or emergency spillway structures;
- A vegetated buffer of native plants that requires minimal maintenance should be provided that extends at least 25 feet outward from the maximum water surface elevation of the ED pond. See Appendix G for guidance on plant selection.
- Permanent structures (e.g., buildings) should not be constructed within the buffer area. Existing trees should be preserved in the buffer area during construction;
- The soils in the stormwater buffer area are often severely compacted during construction. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the rootball for ball-and-burlap stock and five times deeper and wider for container-grown stock; and
- Avoid species that require full shade or are prone to wind damage. Extra mulching around the bases of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

For more guidance on planting trees and shrubs in ED pond buffers, consult Cappiella et al. 2006 and

Appendix G Plant Selection .

**5.7 Maintenance Features**

Good maintenance access is needed so crews can remove sediments from the forebay, alleviate clogging, and repair risers. The following ED pond maintenance activities can be addressed during design in order to make ongoing maintenance easier:

- Adequate maintenance access must extend to the forebay or close to the micro-pool. Any safety benches, riser, and outlet structure can occur and must have sufficient area to allow vehicles to turn around.
- The riser or outfall device should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
- Access roads must: (1) be constructed of materials that can withstand the expected frequency of use; (2) have a minimum width of 8 feet; and (3) have a profile grade that does not exceed 15 percent.
- Steeper grades are allowable if appropriate stabilization techniques, such as gravel or other material, are used.
- A maintenance right-of-way or easement must extend to the ED pond from a public or private road.
- The designer should check to see whether sediments can be spoiled (deposited) onsite or must be hauled away.

**5.8 Additional Design Guidance**

| Table P-BAS-03-9 Additional Design Guidance | |
|---|---|
| **Condition** | **Response** |
| Karst Terrain | The presence of karst complicates both land development in general and stormwater design. Designers should always conduct geotechnical investigations in areas of karst terrain to assess this risk and rule out the presence of karst during the project planning stage. If these studies indicate that less than 3 feet of vertical separation exists between the bottom of the ED pond and the underlying soil- bedrock interface, ED ponds are generally discouraged due to the risk of sinkhole formation and groundwater contamination (see Appendix E). However, an ED pond may be designed with a limited interior infiltration field, with the remainder of the pond lined with 60 mil polyvinyl chloride (PVC) or bentonite geotextile fabric up to the maximum pool elevation and must have an acceptable liner in accordance with the guidance provided in BMP P-SUP-01. "Impermeable" clay ($10^{-6}$ to $10^{-7}$ cm/s ksat) is discouraged as a liner due to potential cracking and fissuring if the clay is allowed to dry out. |
| Coastal Plain Terrain | The lack of sufficient hydraulic head, poorly draining soils, tidal impacts, and the presence of a high-water table at many coastal plain sites significantly constrain the application of ED ponds. Excavating ponds below the water table creates what are known as dugout ponds, in which the water quality volume is displaced by groundwater, reducing the pond's mixing and treatment efficiency and creating nuisance conditions. The potential for backflow of tidal saltwater into ED ponds during tidal elevations that exceed mean high tide could potentially impact plantings within the ED pond. In general, shallow constructed wetlands are a practical alternative to ED ponds in coastal plain settings. |
| Steep Terrain | ED ponds can be used on development sites with slopes up to approximately 15 percent. |
| Hot Spots | ED ponds can accept runoff from stormwater hot spots but need significant separation from groundwater or the inclusion of an impermeable liner when used for this purpose. |

| Table P-BAS-03-9 Additional Design Guidance | |
|---|---|
| **Condition** | **Response** |
| Cold Climate and Winter Performance | Winter conditions can cause freezing problems within inlets, flow splitters, and ED outlet pipes due to ice formation. The following design adjustments are recommended for ED ponds installed in higher elevations and colder climates:<br>• Do not submerge inlet pipes.<br>• Provide a minimum 1 percent slope for inlet pipes to discourage standing water and potential ice formation in upstream pipes.<br>• Place all pipes below the frost line to prevent frost heave and pipe freezing.<br>• Locate low-flow orifices in the micro-pool so they withdraw at least 6 inches below the typical ice layer.<br>• Place trash racks at a shallow angle to prevent ice formation.<br>• If winter road sanding is prevalent in the CDA, increase the forebay size to 25 percent of the total Tv to accommodate additional sediment loadings. |
| Linear Highway Sites | ED ponds are poorly suited to treat runoff within open channels located in the highway right-of-way unless storage is available in a cloverleaf interchange or in an expanded right-of-way. Guidance for pond construction in these areas is provided in VDOT's annual stormwater management specifications as reviewed and approved annually by DCR. Additional guidance is provided in Profile Sheet SR-5 in Schueler et al. 2007. |
| Linear Utility Sites | ED ponds are poorly suited to treat runoff within utility rights-of-way or easements due to their size and would typically require acquisition of additional land adjacent to the utility corridor. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence for Extended Detention Ponds

The following is a typical construction sequence to properly install a dry ED pond. The steps may be modified to reflect different dry ED pond designs; site conditions; and the size, complexity, and configuration of the proposed facility.

***Step 1: Use of ED pond as an erosion and sediment (E&S) control.*** An ED pond may serve as a sediment basin during project construction. If so, the volume should be based on the more stringent sizing rule (E&S control requirement vs. water quality treatment requirement). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction ED pond in mind. The bottom elevation of the ED pond should be lower than the bottom elevation of the temporary sediment basin.

The construction notes should clearly indicate that the facility will be dewatered, dredged, re-graded, and stabilized to design dimensions after the original site construction is complete. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into an ED pond.

***Step 2: Stabilize the drainage area.*** Final grading and construction of ED pond components should only be accomplished after the contributing drainage area to the pond is stabilized.

***Step 3: Assemble construction materials*** onsite, make sure they meet design specifications, and prepare any staging areas.

***Step 4: Install E&S controls*** prior to construction including temporary dewatering devices and stormwater diversion practices. All areas surrounding the ponds that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

***Step 5: Clear and strip*** the project area to the desired sub-grade.

***Step 6: Excavate the core trench and install the spillway pipe.***

***Step 7: Install the riser or outflow structure*** and ensure the top invert of the overflow weir is constructed level at the design elevation.

***Step 8: Construct the embankment and any internal berms*** in 8- to 12-inch lifts, or as directed by geotechnical recommendations, and compact as required with appropriate equipment.

***Step 9: Excavate/Grade*** until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the ED pond.

***Step 10: Construct the emergency spillway*** in cut or structurally stabilized soils.

***Step 11: Install outlet protection*** including emergency and primary outlet apron protection.

***Step 12: Stabilize exposed soils*** with temporary seed mixtures appropriate for the pond buffer. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

***Step 13: Plant the pond buffer area*** following the pondscaping plan (see Section 5).

### 6.2 Construction Inspection

Multiple inspections are critical to ensure that stormwater ponds are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting;
- Initial site preparation (including installation of E&S controls);
- Excavation/Grading (interim and final elevations);
- Installation of the embankment, the riser/primary spillway, and the outlet structure;
- Implementation of the pondscaping plan and vegetative stabilization; and
- Final inspection (develop a punch list for facility acceptance).
- A construction phase inspection checklist for ED ponds can be accessed at the end of this specification.

To facilitate maintenance, the contractor should measure the actual constructed pond depth at three areas within the micro-pool or other water feature and mark and geo-reference them on an as-built drawing. This simple dataset will enable maintenance inspectors to determine pond sediment deposition rates to schedule sediment cleanouts.

Upon final inspection and acceptance, the global positioning system (GPS) coordinates for all ED ponds should be logged for entry into the VSMP Authority’s maintenance tracking database.

### 6.3 Sample Construction Inspection Checklist for Extended Detention Ponds

The following checklist provides a basic outline of the anticipated items for the construction inspection of an ED pond. Inspectors should review the plans carefully and adjust these items and the timing of inspection verification as needed to ensure the intent of the design and the inspection is met. Finally, users of this information may wish to incorporate these items into a VSMP Authority Construction Checklist format consistent with that used for E&S control and BMP construction inspections.

**6.4 Pre-Construction Meeting**

- Pre-construction meeting with the contractor designated to install the ED pond has been conducted.
- The tentative schedule for construction has been identified and the requirements and schedule for interim inspections and sign-off have been verified.
- Subsurface investigation and soils report supports the placement of an ED pond in the proposed location.
- Impervious cover has been constructed/installed and area is free of construction equipment, vehicles, material storage, and all other construction-related equipment.
- All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation, and erosion control measures have been removed.
- **Certification of Stabilization Inspection**: Inspector certifies that the drainage areas are adequately stabilized to convert the sediment pond or trap (if used for sediment control) into a permanent ED pond.

**6.5 Construction of ED Pond Embankment and Principal Spillway**

- Stormwater has been diverted around or through the area of the ED pond embankment to a stabilized conveyance, and perimeter erosion control measures to protect the facility during construction have been installed.
- Materials for construction of the embankment and principal spillway are available and meet the specifications of the approved plans.
- Key trench and principal spillway (including the riser and barrel, anti-seepage controls, outlet protection) are constructed in accordance with approved plans.
- Geotechnical analysis and approval of the core (if required) and embankment material have been provided, and the material has been placed in lifts and compacted in accordance with the approved plans.
- **Certification of Embankment and Principal Spillway Inspection**: Inspector certifies that each element of the embankment and principal spillway has been constructed in accordance with the approved plans.

**6.6 Excavation of ED Pond**

- Excavation of the ED pond geometry (including bottom shape and length: width ratio and side slopes) achieves the elevations in accordance with approved plans.
- Excavation of internal micro-topographic features (e.g., micro-pool outlet, forebays) is in accordance with approved plans.
- Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturers specifications.
- **Certification of Excavation Inspection**: Inspector certifies that the excavation has achieved all the appropriate grades, grade transitions, and ED pond geometry as shown on the approved plans.

**6.7 Landscaping Plan and Stabilization**

- Exposed soils on pond bottom, side slopes, and buffer areas are stabilized with specified seed mixtures, stabilization matting, mulch, or other BMPs in accordance with approved plans.
- Appropriate number and spacing of plants is installed and protected on the aquatic bench and pond buffer in accordance with the approved plans.
- All E&S control practices have been removed.
- Follow-up inspection and as-built survey/certification have been scheduled.
- GPS coordinates have been documented for the ED pond installation.

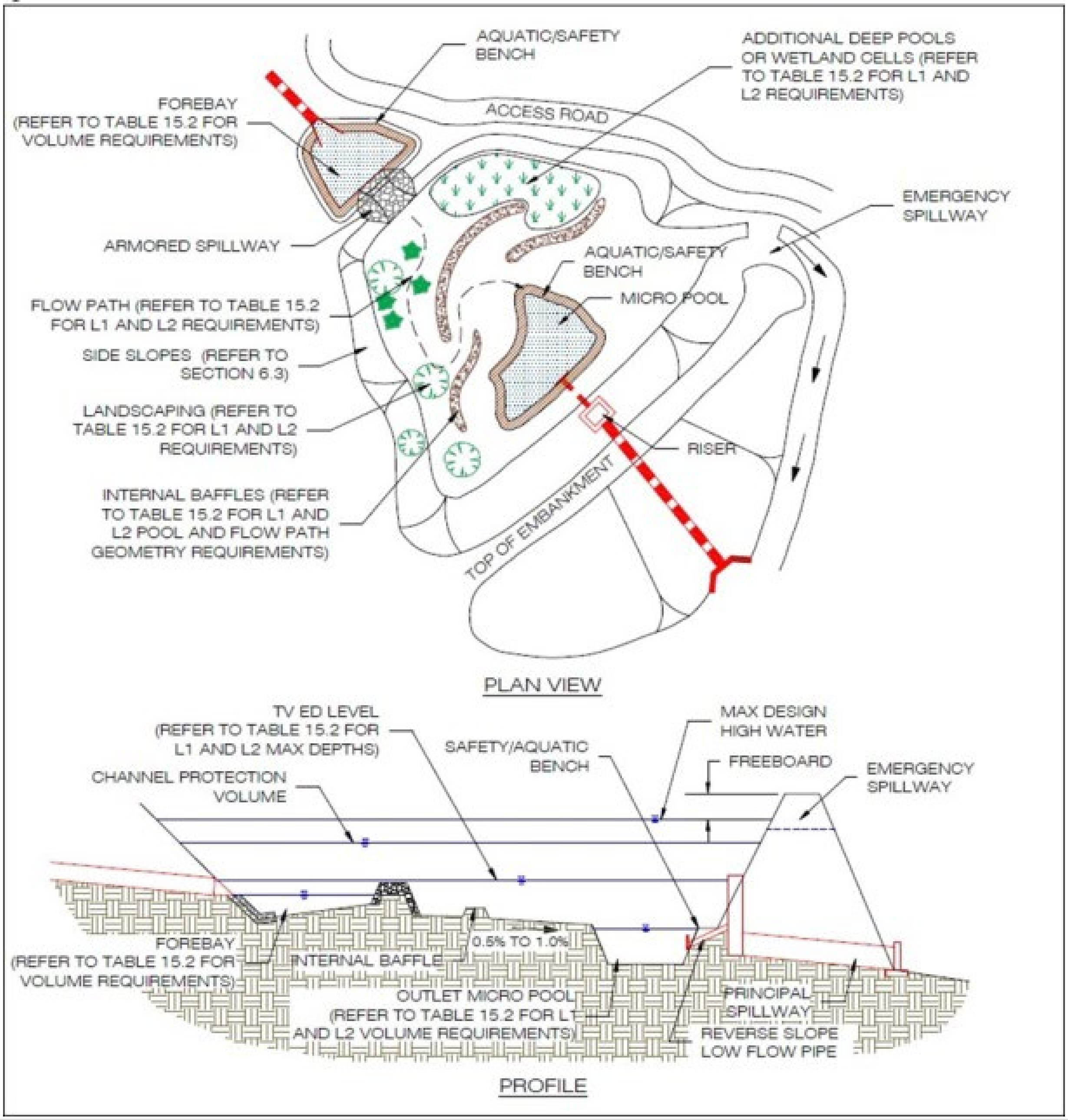
### 6.8 ED Pond Material Specifications

The basic material specifications for ED ponds are identified in Table P-BAS-03-10.

**Table P-BAS-03-10 ED Pond Materials Specifications**

| Component | Specification |
|---|---|
| Grass and Landscaping | BMP C-SSM-10 Permanent Seeding, Appendix G Plant Selection |
| Outlet Orifices and Spillway | P-SUP-02 Principal Spillway |
| Inlet and Outlet Protection | C-ECM-15 Outlet Protection and C-ECM-13 Riprap |
| Pre-Treatment | P-SUP-06 Pre-Treatment |
| Erosion Control Blankets | BMP C-SSM-05 Soil Stabilization Blankets and Matting. ED Ponds should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the banks. |
| Embankments | P-SUP-01 Earthen Embankment |
| Emergency Spillways | P-SUP-03 Vegetated Emergency Spillway |

**Figure P-BAS-03-1 Typical Extended Detention Pond Plan and Profile**




## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of extended detention ponds, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- Restrictive covenants or other mechanisms enforceable by the VESMP Authority should be in place to help ensure that extended detention ponds are maintained as well as to pass the knowledge along to any subsequent property owners.
- Access to extended detention ponds should be covered by a drainage easement to allow access by the VESMP Authority to conduct inspections and perform maintenance when necessary.
- All extended detention ponds should include a long-term Maintenance Agreement consistent with the provisions of the Virginia Erosion and Stormwater Management Regulation and should include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The Maintenance Agreement should also include contact information for owners to obtain local or state assistance to solve common nuisance problems such as mosquito control, geese, invasive plants, vegetative management, and beaver removal.

**7.2 Maintenance Inspections**

Maintenance of ED ponds is driven by annual inspections that evaluate the condition and performance of the pond including the following:

- Measure sediment accumulation levels in forebay.
- Monitor the growth of wetlands, trees, and shrubs planted. Record the species and their approximate coverage and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion or undercutting, and subsidence/sinkhole formation.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, gully erosion, or subsidence/sinkhole formation that may undermine embankment integrity.
- Inspect pond outfall channel for erosion, undercutting, riprap displacement, woody growth, subsidence/sinkhole formation, and other issues.
- Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, subsidence/sinkhole formation, and other issues.
- Inspect condition of all trash racks, reverse sloped pipes, or flashboard risers for evidence of clogging, leakage, debris accumulation, and other issues.
- Inspect maintenance access to ensure it is free of woody vegetation and check to see whether valves, manholes, and locks can be opened and operated.
- Inspect internal and external side slopes of the pond for evidence of sparse vegetative cover, erosion, slumping, or subsidence/sinkhole formation, and make needed repairs immediately.

Based on inspection results, specific maintenance tasks will be triggered. Example maintenance inspection checklists for ED ponds are provided in Appendix H.

For ED ponds constructed in karst areas, inspections should include checking for subsidence features anywhere within the basin, at inlets leading to the basin, and at the basin outfall. Any subsidence/sinkhole discovered is considered a mode of failure and should be repaired using the appropriate sinkhole repair/mitigation BMP.

**7.3 Common Ongoing Maintenance Tasks**

ED ponds are prone to clogging at the ED low-flow orifice. This component of the pond's plumbing should be inspected at least twice a year. The constantly changing water levels in ED ponds make it difficult to mow or manage vegetative growth. The bottoms of ED ponds often become soggy, and water-loving trees such as willows may take over. The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing only periodically to sustain healthy growth) or forest.

The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables that tend to accumulate in the forebay, micro-pool, and on the bottoms of ED ponds.

Frequent sediment removal from the forebay is essential to maintaining the function and performance of an ED pond. For planning purposes, maintenance plans should anticipate cleanouts every 5 to 7 years or when inspections indicate that 50 percent of the forebay capacity has been filled. (Absent an upstream eroding channel or other source of sediment, the frequency of sediment removal should decrease as the drainage area stabilizes.) As noted above, the designer should also check to see whether removed sediments can be spoiled (deposited) onsite or must be hauled away. Sediments excavated from ED ponds are typically not considered toxic or hazardous and can be safely disposed by either land application or landfilling.

## 8.0 References

Center for Watershed Protection. 2020. Southern Lowcountry Design Manual – Stormwater Best Management Practices.

Aecom, Atlanta Regional Commission, Cener for Watershed Protection, Center Forward, Georgia Environmental Protection Division, and Mandel Design. 2016. Georgia Stormwater Management Manual, Volumes 1 & 2.

Blick, Sandra A., Kelly, Fred, and Joseph J. Skupien. 2004. New Jersey stormwater best management practices manual. Retrieved from https://doi.org/doi:10.7282/T3K64GFK Pennsylvania Department of Environmental Protection. 2023. Pennsylvania Post-Construction Stormwater Management (PCSM) Manual. Draft ed.

Virginia Department of Conservation and Recreation (DCR). 2013.Wet Pond. Virginia DCR Stormwater Design Specification No. 14. Version 2.0.

# P-BAS-04 Rainwater Harvesting

## 1.0 Definition

Rainwater harvesting systems function by intercepting, diverting, storing, and releasing rainfall for future use. For the purposes of this design specification, rainwater harvesting includes rainwater that falls on a rooftop that is collected and conveyed into an above- or below-ground storage tank or chamber where it can be used for non-potable water uses, onsite stormwater infiltration, and/or detention. In some instances, rainwater can also be channeled to a pond rather than a storage tank, as long as the pond is sized to meet the cistern sizing requirements and any water quantity design criteria if there are any discharges from the pond anticipated.

**What is Non-Potable Use?**

Non-potable uses may include flushing of toilets and urinals inside buildings, landscape irrigation, exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, fire trucks), fire suppression (sprinkler) systems, supply for chilled water-cooling towers, replenishing and operation of water features and fountains, and laundry if approved by the local authority. Replenishing of pools may be acceptable if special measures are taken as approved by the appropriate regulatory authority (Virginia Department of Health).

This specification focuses on providing a design framework for addressing the treatment volume (Tv) reduction objectives and achieving compliance with the Virginia Stormwater Management Regulations. Depending on the configuration, rainwater harvesting systems may be used to meet various elements of the stormwater management requirements for a site including water quality and quantity requirements.

The basic cistern design configurations described in this specification include:

1. Year-round indoor use with seasonal indoor and/or outdoor uses;
2. Year-round indoor use with seasonal indoor and/or outdoor uses supplemented with a secondary runoff reduction drawdown practice; and
3. Seasonal indoor and/or outdoor uses supplemented with a secondary runoff reduction drawdown practice.

Note: *This specification provides guidance for the design of a cistern that collects roof runoff. The collection and reuse of surface runoff from parking lots or other surfaces is not addressed in this specification (because a much more robust system to ensure the cleanliness of the runoff would be required to not interfere with the mechanical components of the system as well as to ensure the relative cleanliness of the water for the intended use).*

## 2.0 Purpose and Applicability of Best Management Practice

Rainwater harvesting systems can be used in a wide range of settings and configurations. The purpose of rainwater harvesting from a stormwater management perspective is to maximize runoff volume reduction and nutrient removal. They are applicable for development projects that involve the construction of roof surfaces that can collect and convey stormwater to a storage tank, commonly referred to as “cisterns.” Given the wide range of options for tank configuration (e.g., aboveground, belowground, in-building) rainwater harvesting is applicable to most development sites involving building construction including highly constrained/urban sites.

That said, rainwater harvesting systems can be used in commercial, residential, industrial, urban, and non-urban sites. Rainwater harvesting systems are not designed at Level 1 and Level 2. Instead, runoff reduction credits are based on the total amount of annual water demand calculated using the VCD spreadsheet. The annual runoff volume reduction and pollutant removal performance credits of rainwater harvesting systems are a function of the cistern tank size, configuration, and water demand or use.

## 3.0 Planning and Considerations

The following feasibility criteria, environmental and community concerns, and uses of harvested rainwater should be evaluated when designing a rainwater harvesting system.

**Table P-BAS-04-1 Rainwater Harvesting Considerations**

| Consideration | Details |
|---|---|
| Available Hydraulic Head | Site topography and cistern location should be considered as they relate to the inlet and outlet invert elevations in the rainwater harvesting system. The available hydraulic head or total elevation drop is measured from the downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow from the cistern.<br><br>Elevation drops will occur along the sloping lengths of the roof drain piping from the downspout leader at the building to the cistern. A vertical drop also occurs within a filter before the cistern and finally through the cistern itself. An overflow outlet will typically be located near the top of the storage volume, and when the cistern is designed to include additional detention volume for channel and/or flood protection, an outlet may be included at a midlevel invert specified by the designer. Both the overflow and detention outlet orifices (if specified) will drain the tank during large storms, routing this water through an outlet pipe, the length and slope of which will vary among sites.<br><br>All these components of the system are associated with an elevation drop. The final invert of the outlet pipe must match the invert of the receiving mechanism (e.g., natural channel, storm drain system) that receives the overflow. These elevation drops and associated inverts should be considered early in the design to assess the feasibility of a gravity-fed cistern for the site. |
| Depth to Water Table and Bedrock | Underground cisterns are most appropriate where the tank can be buried above the water table. The tank should be installed in a manner that will not subject it to flooding. Where the tank is to be buried partially below the water table, buoyancy should be calculated to determine if any special design features, such as earth anchors or ballast, are necessary to keep it from "floating" when the tank is empty. |
| Contributing Drainage Area | The contributing drainage area (CDA) to the cistern is the impervious roof area draining to it. Roof areas of any size, including only portions of a rooftop area, can be used based on the sizing guidelines in this design specification. Only rooftop surfaces should be considered as CDAs for cisterns. Parking lots and other paved surfaces typically contribute too many particulates (e.g., sediment, organic debris, trash) and/or pollutants from automobiles, spills, and other sources for storage and distribution in a rainwater harvesting system. Runoff should be routed directly from rooftops to rainwater harvesting systems in closed-roof drain systems or storm drainpipes, avoiding surface drainage, which could allow for increased contamination of the water. |

| Table P-BAS-04-1 Rainwater Harvesting Considerations | |
|---|---|
| **Consideration** | **Details** |
| Space Required | Adequate space is needed to house the storage tank or cistern and any overflow. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Cisterns can be placed underground, indoors, on rooftops, within buildings (that are structurally designed to support the added weight), and adjacent to buildings. Designers can work with architects and landscape architects to creatively locate a cistern within the building or site infrastructure. Underground utilities or other obstructions should always be identified prior to final determination of the tank location. |
| Soils | Cisterns should only be placed on native soils, on fill in accordance with the manufacturer's guidelines, or recommendations provided by a structural engineer. The bearing capacity of the soil upon which the cistern will be placed should be considered, as full cisterns can be very heavy and may require an aggregate or concrete base. This is particularly important for aboveground cisterns because settling could cause the cistern to lean or impact plumbing connections. Additionally, the pH of the soil should be considered in relation to the cistern material. |
| Mosquitoes | In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding. Designers should provide screens on above- and belowground tanks to prevent mosquitoes and other insects from entering the tanks. If screening is not sufficient to deter mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use only. |
| Local Plumbing Codes | Designers and plan reviewers should consult local building codes to determine if they explicitly allow the use of harvested rainwater for toilet, laundry, and/or urinal flushing. Where a municipal backup supply is used, rainwater harvesting systems are typically required to have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable. |
| Proximity of Underground Utilities | All underground utilities must be considered during the design of rainwater harvesting systems, treating all the system components and storm drains as typical stormwater facilities and pipes. Appropriate minimum setbacks from septic drain fields should be observed as specified by Virginia law and regulations. |
| Water Quality of Rainwater | Designers should also note that the pH of rainfall in Virginia tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from the roof surface, tank lining, or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0.<br>Limestone or other materials may be added in the tank to buffer acidity if desired. |

| Table P-BAS-04-1 Rainwater Harvesting Considerations | |
|---|---|
| **Consideration** | **Details** |
| Hot Spot Land Uses | Collecting rooftop runoff can be an effective method to prevent mixing and possible contamination of rooftop runoff with ground-level runoff from a stormwater hot spot operation. In some cases, however, industrial roof surfaces may also be designated as stormwater hot spots. |
| Setbacks from Buildings | Cistern overflow devices should be designed to avoid ponding or soil saturation within 10 feet of building or other structure foundations. Cisterns should be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation. |
| Vehicle Loading | Whenever possible, underground cisterns should be placed in areas without vehicle traffic or be designed to support live loads from heavy trucks, a requirement that may significantly increase construction costs. |
| Stormwater Uses | The capture and use of rainwater can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water, cisterns can also offer environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during mandatory municipal water use restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end user). |
| Potable Water Use | Rainwater for potable water supply is not addressed in this design specification. In situations with insufficient potable water supply, rainwater can be treated and used for potable water supply subject to state and local health requirements (the Virginia Department of Health maintains regulations pertaining to use of rainwater to meet potable water demand). If this use is permitted by the appropriate public health authority, and the rainwater harvesting system is equipped with proper filtering equipment, the increased annual water demand would increase the runoff reduction volume credit while reducing the demand on the municipal water supply, resulting in commensurate cost savings. It would also enable the use of a more standard plumbing system because potable and non-potable water would no longer need to be separated. |

| Table P-BAS-04-1 Rainwater Harvesting Considerations | |
|---|---|
| **Consideration** | **Details** |
| Rooftop Material | The quality of rooftop runoff will vary according to the roof material over which it flows. Runoff from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted or galvanized metal, sheet metal, or any material that may contain asbestos, may leach trace metals and other toxic compounds. In general, collecting rainwater from such roofs should be avoided unless sufficient information indicates that these materials will not negatively affect the proposed water use and are allowed by Virginia laws and regulations. If a sealant or paint coating on the roof surface is desired, it is recommended to use one that has been certified for such purposes by the American National Standards Institute (ANSI) National Sanitation Foundation (ANSI/NSF standard). The 2009 Virginia Rainwater Harvesting Manual and other references listed at the end of this specification describe the advantages and disadvantages of different roofing materials. |
| Conveyance | Runoff should be routed directly from rooftops to rainwater harvesting systems in closed-roof drain systems or storm drainpipes and avoid surface drainage, which could allow for increased contamination of the water. |
| Child Safety | Above-grade rainwater harvesting systems must not have unsecured openings large enough for children to enter the tank. For underground cisterns, manhole access should be locked or otherwise secured to prevent unwanted access. |

Rainwater harvesting designs must be modified to accommodate regional differences and special case design applications. A summary of suggested design adjustments for various conditions is provided in Table P-BAS-04-2.

| Table P-BAS-04-2 Summary of Design Adjustments | |
|---|---|
| **Constraint** | **Design Adjustment** |
| Karst Terrain | Cisterns are a good option in karst areas because they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination. Aboveground rainwater harvesting systems are a preferred practice in karst if the rooftop surface is not designated as a stormwater hot spot. However, the substrate should be examined by a professional geotechnical engineer to ensure the cistern location can support the weight of the structure when full. Construction inspection should certify that the tank and fittings are watertight, and that excavation will not extend into a karst layer. |
| Coastal Plain Terrain | Areas in the coastal plain have flat terrain, low head, and high-water tables, making subsurface storage and gravity distribution difficult. Designers should look to maximize the use of aboveground cisterns in these areas as well as management of rooftop runoff (as opposed to ground level impervious). |

| Table P-BAS-04-2 Summary of Design Adjustments | |
|---|---|
| **Constraint** | **Design Adjustment** |
| Steep Terrain | The use of cisterns within steeply sloping terrain is not necessarily problematic if the cistern is able to rest on a locally leveled surface. Steep terrain can be beneficial in terms of elevation change that can produce significant hydraulic head to drive gravity-fed systems. |
| Cold Climate and Winter Performance | Winter conditions can cause several performance issues for cisterns including the inability to move water into or out of the system and clogging of pre-treatment and distribution systems. Rainwater harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation, and associated system damage.<br><br>Alternately, an outdoor system can be used seasonally or year-round if special measures and design considerations are incorporated. Wintertime operation of aboveground systems may be challenging depending on tank size and whether heat tape is used on piping. If not protected from freezing, rainwater harvesting systems should be disconnected, drained, and taken off line for the winter, resulting in a seasonal use (and thereby eliminating the runoff reduction volume credit).<br><br>For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.<br>Use heat tracing to avoid freezing of lines and tanks.<br>Locate the storage tank and other critical conveyance infrastructure below the frost line. |

Many cistern system variations can be designed to meet water user demand and stormwater objectives. This specification focuses on providing a design framework for addressing the Tv reduction objectives and achieving compliance with the Virginia Stormwater Regulations. From a cistern design and water use standpoint, there are multiple potential water uses and system configurations that could be implemented.

Therefore, the basic cistern design configurations include:

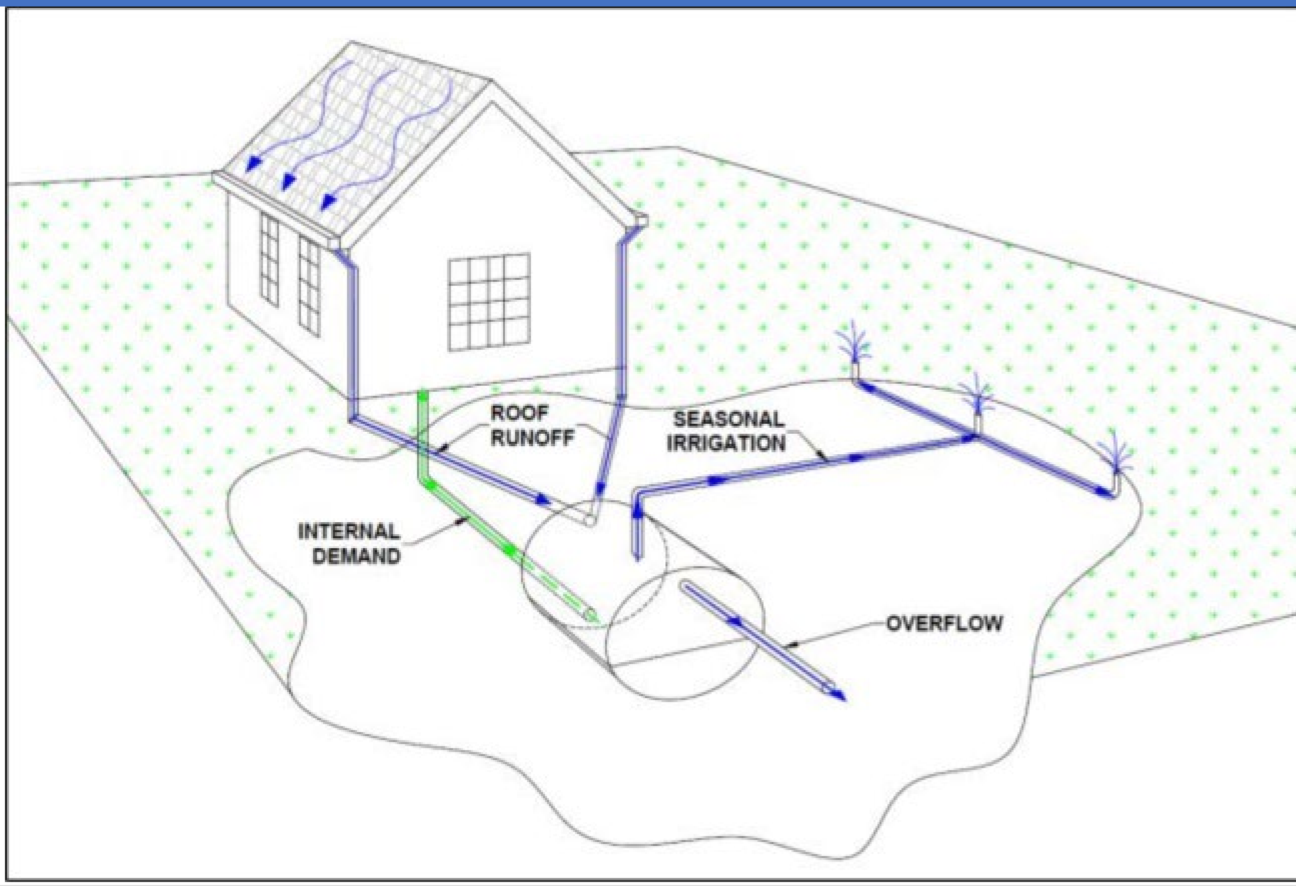
1. Year-round indoor use with seasonal indoor and/or outdoor uses;
2. Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice; and
3. Seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice.

Several variations of rainwater harvesting systems can be designed to meet water user demand and stormwater objectives. There are multiple variations within each of the three design configurations to consider.

The design logic and sizing parameters presented within this chapter can be readily applied to any design that is intended to achieve a stormwater management credit.

**Configuration 1: Year-round indoor use with seasonal indoor and/or outdoor uses (Figure P-BAS-04-1).** The first configuration is for year-round indoor use. Typical year-round uses captured in the VCD spreadsheet include toilet and urinal flushing and laundry. Additional uses captured in the VCD spreadsheet include irrigation, cooling towers, and a catch-all category of other uses that may include vehicle washing, supply for street sweepers, and other not yet defined year-round or seasonal uses.

***Figure P-BAS- 04-1 Configuration 1: Year-round indoor use with optional seasonal outdoor use.***

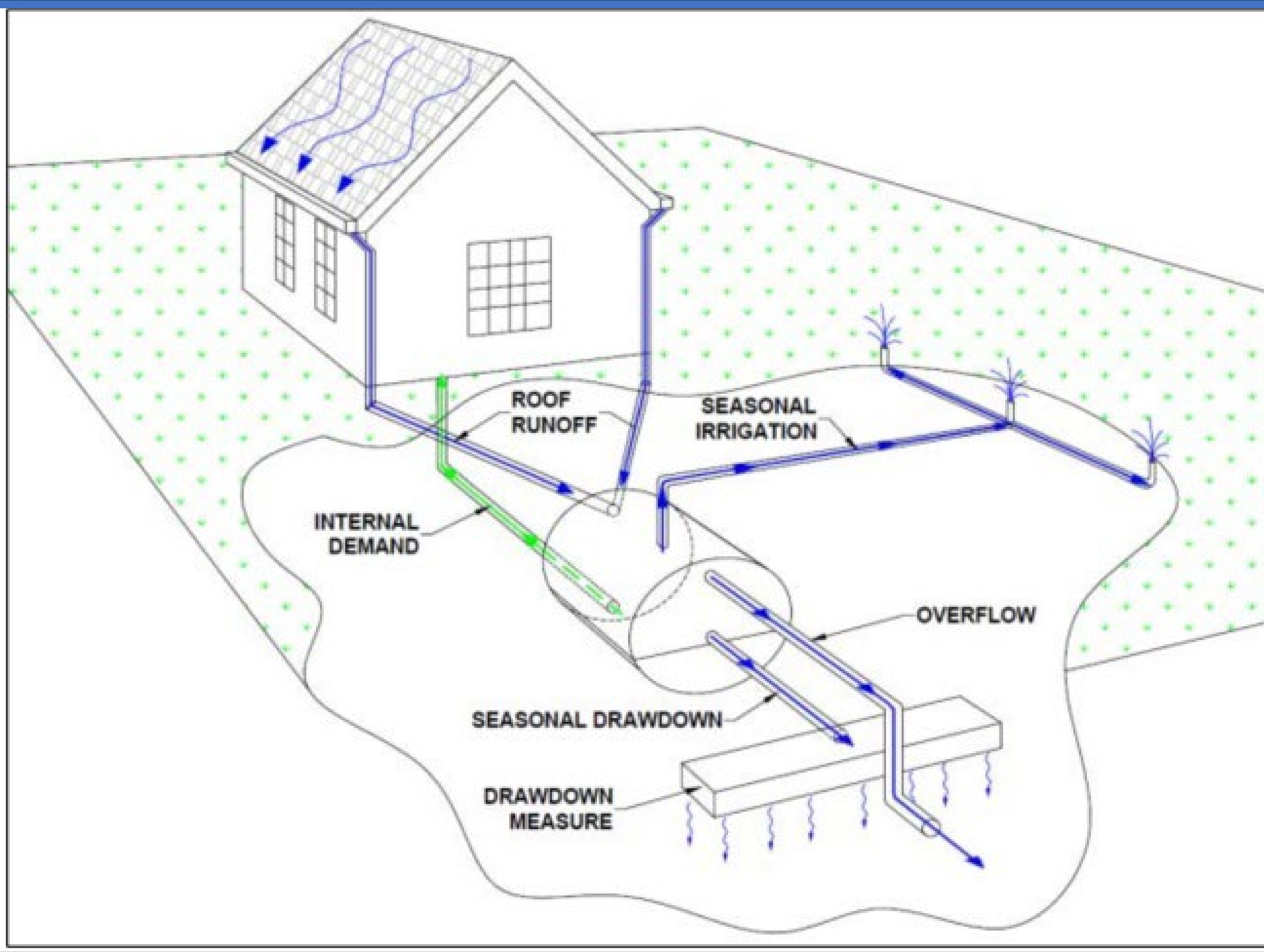



The only runoff reduction volume credit derived from this configuration is the year-round indoor use. While the seasonal uses do not provide an annual credit, they generally use a large volume of water (i.e., irrigation) such that the owner may elect to increase the system size to provide for the seasonal demand and reduce potable water usage.

**Configuration 2: Year-round indoor use with seasonal indoor and/or outdoor uses supplemented with a secondary runoff reduction drawdown practice (Figure P-BAS- 04-2).** The second configuration builds on the first with the addition of a secondary runoff reduction drawdown practice to supplement the seasonal uses and establish an annual runoff reduction volume credit (in addition to the credit based on the year-round indoor uses). Therefore, the system must account for three uses: year-round internal non-potable water demand, a seasonal outdoor use such as automated irrigation system or cooling towers, and an engineered drawdown to a secondary runoff reduction drawdown practice for volume reduction during non-irrigation (or non-seasonal) months.

The cistern acts as a detention system during the non-seasonal months that must be designed to slowly draw down at a rate comparable to seasonal use to provide storage for the next storm event. In this way, the system achieves a year-round use and a corresponding annual runoff reduction volume credit. The design and sizing of the secondary runoff reduction drawdown practice is based on a specific drawdown rate, as opposed to the standard best management practice (BMP) sizing criteria of the design (TvBMP; or the corresponding peak discharge) required to manage the 1-inch Tv design storm. The secondary drawdown practice sizing will also be influenced by the hydraulic properties of the practice and the site conditions such as soil infiltration rates, surface area, and/or retention capacity. The resulting size and/or storage volume of the secondary runoff reduction drawdown practice will generally be smaller than the stand-alone BMP (e.g., without the upgradient storage tank).

***Figure P-BAS- 04-2 Configuration 2: Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice***

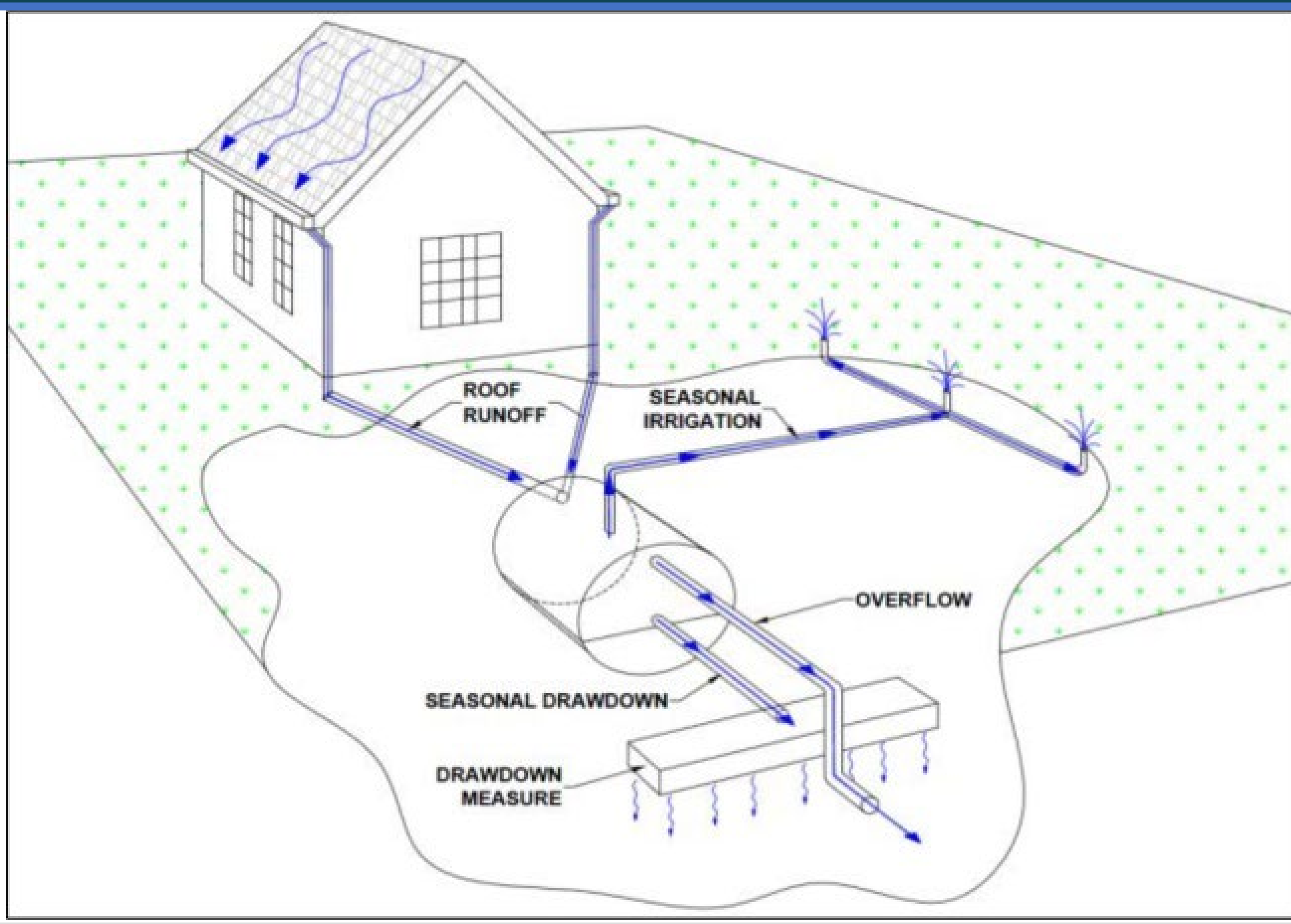



Several system design elements are discussed herein including considerations related to secondary drawdown in conjunction with large storm controls (for channel or flood protection).

**Configuration 3: Seasonal-only indoor and/or outdoor uses supplemented with a secondary runoff reduction drawdown practice (Figure P-BAS- 04-3).** The third configuration does not have any year-round uses and therefore uses stored rainwater to meet seasonal or intermittent water uses, while using a secondary runoff reduction drawdown practice to supplement the seasonal uses and establish an annual runoff reduction volume credit. In this configuration, the system designer needs to account for only two uses: the seasonal use (e.g., automated irrigation system, cooling towers) and the engineered drawdown to a secondary runoff reduction practice. Similar to the previous configuration (Configuration 2), the tank drawdown rate should be designed to be, at a minimum, comparable to the periodic seasonal use. The drawdown rate and practice sizing may also be influenced by the hydraulic properties of the practice and the site conditions such as soil infiltration rates, surface area, and/or retention capacity.

In the case of both Configuration 2 and Configuration 3, the design of the tank size, its drawdown rate, the exfiltration rate, and surface area of the drawdown practice may be used to establish a hydraulic routing of the system for sizing purposes.

***Figure P-BAS- 04-3 Configuration 3: Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice.***




Appendix A provides guidance on the sizing of the secondary runoff reduction drawdown practice.

**Secondary Runoff Reduction Drawdown Practice**

The secondary runoff reduction drawdown practice is, in essence, a stand-alone infiltrating BMP that mimics, at a minimum, the same rate of pumping or drawdown during non-seasonal months to establish the annual credit. This "combined" drawdown and downstream BMP will include complex sizing parameters and must include sufficient documentation to ensure that: (1) the contributing drainage areas are accounted for in the Virginia Runoff Reduction Method (VRRM) compliance spreadsheet and (2) the downstream drawdown BMP is sized properly (see text box this page).

Secondary runoff reduction drawdown practices are generally those practices that offer a volume reduction credit. They may include variations of the following among others:

- Sheetflow to a Vegetated Filter or Conserved Open Space: BMP P-FIL-07;
- Infiltration Practices: P-FIL-04;
- Bioretention and Micro-Bioretention (rain garden): P-FIL-05; and
- Dry Swale: P-CNV-02.

**Using the VCD and VRRM Spreadsheets to Model Secondary Drawdown**

The use of a secondary drawdown practice is entered into the VCD spreadsheet and is considered an integral part of the rainwater harvesting system and the resulting runoff reduction volume credit computed by the VCD spreadsheet. This drawdown must not be added (or double-counted) on the VRRM compliance spreadsheet. An exception would occur if the secondary drawdown practice were also located to capture and manage developed area beyond the rooftop area captured by the cistern (e.g., the adjacent yard, driveway). In those cases, the drawdown practice is sized for the cistern drawdown volume, rate of flow, and for the TvBMP from the additional areas (using the sizing criteria from the corresponding BMP Design Specification).

The secondary runoff reduction drawdown used to compute an annual water demand in the VCD spreadsheet is a component of the rainwater harvesting system design that establishes the "user input" volume reduction credit and is not entered as a "Downstream Treatment to be Employed" when computing overall BMP strategy compliance using the VRRM compliance spreadsheet.

The sizing of the drawdown practice is based on the rate of the cistern drawdown and the infiltration of the underlying soils. Where an underdrain is used, the design is based on the rate of flow through the underdrain.

## 4.0 Stormwater Performance Summary

The annual runoff volume reduction and pollutant removal performance credits of rainwater harvesting systems are a function of the cistern tank size, configuration, and water demand or use. These are summarized in Table P-BAS-04-3.

**Table P-BAS-04-3 Summary of Stormwater Functions Provided by Rainwater Harvesting**

| Stormwater Function | Performance |
|---|---|
| Annual Runoff Volume Reduction (RR) | Variable up to 90%[2] |
| Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process | 0% |
| TP Mass Load Removal | Variable up to 90%[2] |

| Table P-BAS-04-3 Summary of Stormwater Functions Provided by Rainwater Harvesting | |
|---|---|
| **Stormwater Function** | **Performance** |
| Total Nitrogen (TN) EMC Reduction1 by BMP Treatment Process | 0% |
| TN Mass Load Removal | Variable up to 90%[2] |
| **Channel Protection** | Partial: reduced curve numbers and increased time of concentration |
| **Flood Mitigation** | Partial: reduced curve numbers and increased time of concentration |

1. Nutrient mass load removal is equal to the runoff volume reduction rate. Zero pollutant removal rate is applied to the rainwater harvesting system only. Nutrient removal rates for secondary practices will be in accordance with the design criteria for those practices.
2. Credit varies and is determined using the Cistern Design Spreadsheet. Credit up to 90% is possible if all water from storms with rainfall of 1 inch or less is used through demand, and the tank is sized such that no overflow from this size event occurs. The total credit may not exceed 90%.

In terms of the goal of addressing the design Tv, this specification adheres to the following concepts to properly meet the stormwater volume reduction goals:

- System design is encouraged to use rainwater as a resource to meet onsite demand or in conjunction with other runoff reduction practices (especially those that promote groundwater recharge).
- Annual runoff reduction volume credit is only awarded for dedicated year-round drawdown/demand for the water.
- Seasonal practices (such as irrigation) may be incorporated into the site design, but the cistern design must be supplemented by a secondary runoff reduction drawdown practice with an equal or greater drawdown rate during the non-seasonal months to be credited with an annual runoff reduction volume credit (for stormwater purposes).
- Pollutant load reduction is realized through reduction of the volume of runoff leaving the site and, when applicable, a downstream treatment practice.
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

**Accounting for Annual Volume Credit in VRRM**

The annual volume reduction credit is user defined and is a “user input” cell in the VRRM compliance spreadsheet. The designer can calculate the annual water demand based on single or multiple uses that may be constant monthly, such as toilet/urinal flushing and laundry, or that vary seasonally, such as landscape irrigation, cooling towers, and vehicle washing. A use that is seasonal can be supplemented with a secondary runoff reduction drawdown to establish an annual demand. The internal and external constant and variable monthly water uses are itemized and tabulated within the VCD spreadsheet to generate the “user input” volume reduction credit.

Note: The secondary runoff reduction drawdown used to compute an annual water demand in the VCD spreadsheet is a component of the rainwater harvesting system design that establishes the “user input” volume reduction credit and is not entered as a “Downstream Treatment to be Employed” when computing overall BMP strategy compliance using the VRRM compliance spreadsheet.

## 5.0 Design Criteria

### 5.1 System Components

**Storage Tank.** The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities range from 250 to more than 30,000 gallons. Multiple tanks can be placed adjacent and connected with pipes to balance water levels and increase overall storage onsite as needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. The performance of different sized storage tanks can be evaluated using the VCD spreadsheet to meet the water demand and stormwater treatment volume credit objectives.

While many of the graphics and photos in this design specification depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in multiple shapes depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped, or vertically stepped to match the topography of a site.

The following factors should be considered when designing a rainwater harvesting system and selecting a storage tank:

**Table P-BAS-04-4 Advantages and Disadvantages of Various Cistern Materials**

| Tank Material | Advantages | Disadvantages |
|---|---|---|
| Fiberglass | Commercially available, alterable, and moveable; durable with little maintenance; lightweight; integral fittings (no leaks); broad application | Must be installed on smooth, solid, level footing; pressure-proof for belowground installation; expensive in smaller sizes |
| Polyethylene | Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install | Can be UV-degradable; must be painted or tinted for aboveground |
| | above or below ground; little maintenance; broad application | installations; pressure-proof for belowground installation |

| Table P-BAS-04-4 Advantages and Disadvantages of Various Cistern Materials | | |
|---|---|---|
| **Tank Material** | **Advantages** | **Disadvantages** |
| Modular Storage | Can modify to topography; can alter footprint and create shapes to fit site; relatively inexpensive | Longevity may be less than other materials; higher risk of puncturing watertight membrane during construction |
| Plastic Barrels | Commercially available; inexpensive | Low storage capacity (20 to 50 gallons); limited application |
| Galvanized Steel | Commercially available, alterable and moveable; available in a range of sizes; film develops inside to prevent corrosion | Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications |
| Steel Drums | Commercially available, alterable, and moveable | Potential to crack and leak; expensive |
| FerroConcrete | Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain | Potential to crack and leak; expensive |
| Cast-in-Place Concrete | Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain | Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils |
| Stone or Concrete Block | Durable and immoveable; keeps water cool in summer months | Difficult to maintain; expensive to build |
| Source: Cabell Brand 2007, 2009 | | |

The images provided as Figure P-BAS-04-4 to Figure P-BAS-04-8 display examples of various materials and shapes of cisterns discussed in Table P-BAS-04-4.

**Figure P-BAS-04-4 Example of Multiple Fiberglass Cisterns in Series**

**Figure P-BAS-04-5 Example of two Polyethylene Cisterns**

***Figure P-BAS-04-6 Galvanized Steel Tanks***

*Source: Practical Environmentalist (www.practicalenvironmentalist.com)*

**Figure P-BAS- 04-7 Residential Application of a Brick and Stucco Cistern**

Source: Village Craftsmen (www.villagecraftsmen.com)

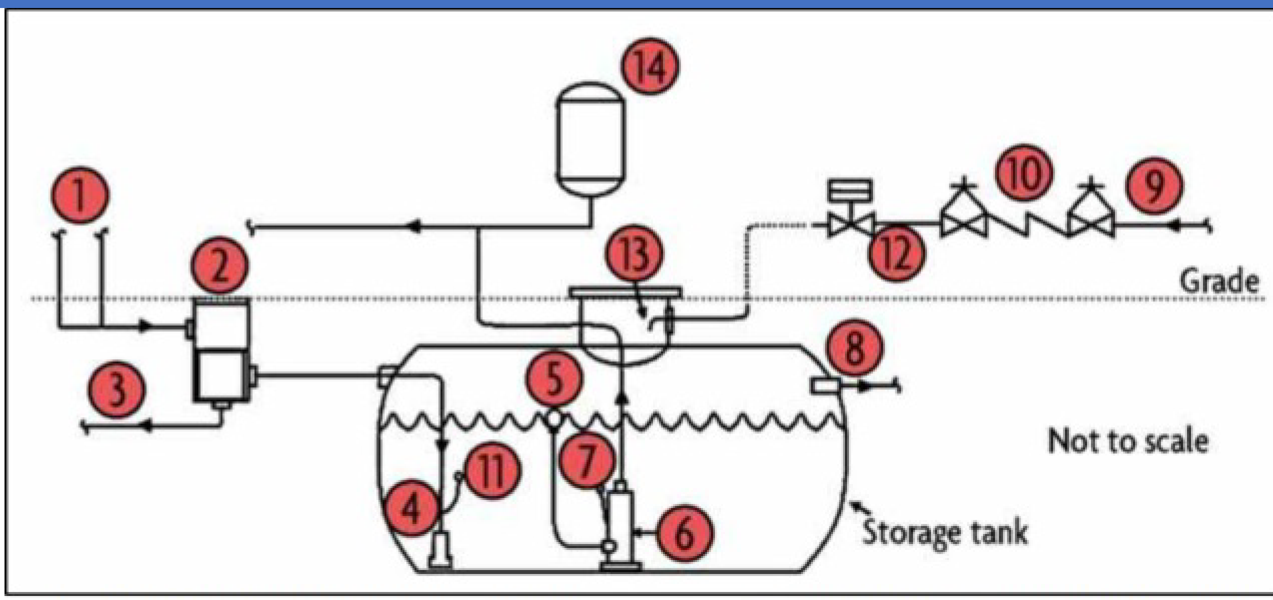
**Figure P-BAS-04-8 Residential Application Polyethylene**

Source: Village Craftsmen (www.villagecraftsmen.com)

### 5.2 Other Components of a Rainwater Harvesting System

Most rainwater harvesting systems require a pump to convey collected rainwater from the storage tank to its destination, whether that is a pressure tank inside a building, an automated irrigation system, or a gradual discharge to a secondary runoff reduction drawdown practice. The typical pump and pressure tank arrangement (Figure 5-2) consists of a submersible pump inside the storage tank with a float switch and water level sensors that send water on demand out of the storage tank and into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the pressure tank. The components of a sample rainwater harvesting system are described briefly below.

***Figure P-BAS-04-9 Sample Rainwater Harvesting System Detail***




1. Rooftop surface and rainwater collection system (roof drains, gutters, etc.)
2. Pre-treatment (screening, first flush diverters, filters, etc.)
3. Discharge of excess or diverted first flush to overflow or downstream practice
4. Flow calming inlet
5. Floating (outlet) filter
6. Submersible pump
7. Low water cut off float switch
8. Overflow to secondary runoff reduction drawdown practice, downstream runoff reduction or pollutant removal BMP, or conveyance system
9. Municipal back-up water supply
10. Back flow preventer
11. Float switch to control water levels
12. Solenoid valve
13. Air gap
14. Pressure tank

*Source: Rainwater Resources (www.rainwaterresources.com)*

*Rooftop Surface and Collection System (item 1 on Figure P-BAS-04-9).* The rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be used for potable uses or other uses with significant human exposure (e.g., pool filling, watering vegetable gardens), care should be taken in the choice of roof materials. Some materials may leach toxic chemicals, making the water unsafe for humans.

The collection and conveyance system consists of the roof, gutters, downspouts, and pipes that channel stormwater runoff into storage tanks. The rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality. Some roof materials may leach toxic chemicals, which could impact the use of harvested rainwater.

Gutters and downspouts convey roof water to the storage tank. The lengths of gutters and downspouts are determined by the size and layout of the catchment (i.e., roof area where rainfall is collected) and the locations of the storage tanks. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Other materials commonly used for gutters and downspouts include polyvinyl chloride (PVC) pipe, vinyl, and galvanized steel. Lead should not be used as gutter and downspout solder because rainwater can dissolve the lead and contaminate the water supply. At a minimum, gutters should be sized with slopes specified to contain the 1-inch storm at a rate of 1 inch/hour for treatment volume credit. If volume quantity control credit will also be sought for stream channel and flood protection, the gutters should be designed to convey the 2- and 10-year storms, using the appropriate 2- and 10-year storm intensities, specifying size and minimum slope. In all cases, gutters should be hung at a minimum of 0.5 percent for the first two thirds of the length and at 1 percent for the remaining third of the length leading to the downspout. Gutters and downspouts should be kept clean and free of debris and rust.

Pipes (connecting downspouts to the cistern tank) should be at a minimum slope of 1.5 percent and sized/designed to convey the intended design storm as specified above. In some cases, a steeper slope and larger size may be recommended and/or necessary to convey the required runoff depending on the design objective and design storm intensity. Bends and tees should be included as needed.

*Pre-treatment (e.g., screening, first flush diverters, filters; item 2 on Figure P-BAS-04-9).* Pre-treatment is required to keep sediment, leaves, contaminants, and other debris from the system. Such debris can create clogging and collect in the cistern, displacing some of the design storage volume. Pre-treatment minimizes the buildup of organic material in the tank to decrease microbial food sources and decrease potential system maintenance. All rainwater needs to pass through pre-treatment prior to entering the cistern.

Rainwater harvesting systems must use at least one of the following for pre-treatment:

- Leaf screen;
- First flush diverter;
- Roof washer; and
- Approved manufactured treatment device (MTD).

All pre-treatment devices should be low-maintenance or maintenance-free.

Each pre-treatment method has an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed to the storage tank. If pre-treatment devices are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1 inch/hour should be used for sizing pre-tank conveyance and pre-treatment components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA 2004). If the system will be used for channel and flood protection as well, the 2- and 10-year storm intensities should be used for the design of the conveyance and pre-treatment portion of the system. For the 1-inch storm treatment volume, a minimum of 95 percent filter efficiency is required. This efficiency includes the first flush diversion. The VCD spreadsheet assumes a filter efficiency rate of 95 percent for the 1-inch storm. For the 2- and 10-year storms, a minimum filter efficiency of at least 90 percent should be met.

*Leaf Screen* Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Screens should have a 1 mm mesh size. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built up debris can also harbor bacterial growth within gutters or downspouts (TWDB 2005).

*First Flush Diverters* (Figure P-BAS-04-10) First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces. Simple first flush diverters require active management by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pre-treatment method if the water is to be used for indoor purposes. An approved MTD may serve as an effective pre-tank filtration device and first flush diverter.

*Roof Washers* (Figure P-BAS-04-11). Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater. Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30 microns (TWDB 2005). The filter removes very small particulate matter from harvested rainwater. All roof washers must be cleaned regularly.

***Figure P-BAS-04-10 First Flush Diverter***

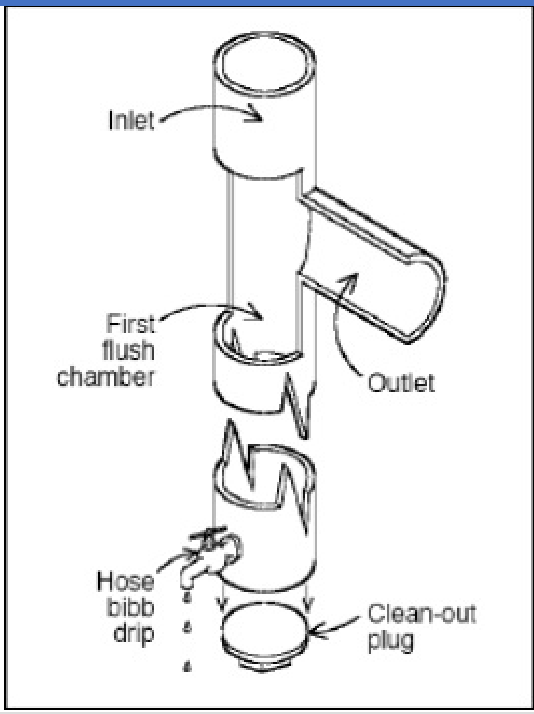
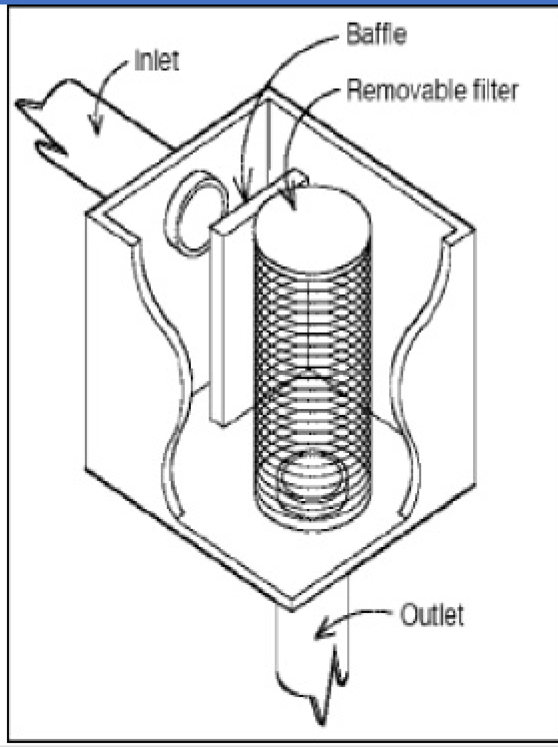


**Figure P-BAS-04-11 Roof Washer**




*Discharge of Excess or Diverted First Flush (item 3 on Figure P-BAS-04-9)*. As described in the pre-treatment section, first flush diverters direct the initial pulse of stormwater runoff away from the storage tank. Designers should note that the goal for rainwater harvesting systems is to divert the first flush away from the system as opposed to the traditional stormwater treatment strategy of capturing and treating the first flush. The amount diverted can range from the first 0.02 to the first 0.06 inch of rooftop runoff.

Any diverted flows (first flush diversion and overflow from the prefilter) must be directed to an acceptable pervious flow path that will not cause erosion during a 2-year storm or to an appropriate BMP on the property.

Preferably, the diversion will be conveyed to the same secondary runoff reduction practice that receives storage tank overflows.

*Flow Calming Inlet (item 4 on Figure P-BAS-04-9).* Collected roof water enters the storage tank through the inlet pipe at the base of the tank. Flow calming inlets are designed to allow the water to enter the storage tank without disturbing the sediment at the bottom of the tank.

*Floating (outlet) Filter (item 5 on Figure P-BAS-04-9).* A floating filter has a stainless steel mesh filter connected to a flexible water line. The filter is suspended below the tank water surface by a float. The goal is to draw water from below the surface to avoid suspending material in the tank and above particulates that settle to the bottom of the tank. This device withdraws water from approximately 1 foot below the surface, which is considered to be the clearest water. The floating filter is connected to the pump and outlet plumbing.

*Submersible Pump (item 6 on Figure P-BAS-04-9).* A shallow-well submersible pump designed to push water is placed in the lower portion of the cistern to deliver water to a pressure tank. As water is drawn from the pressure tank, the pump is triggered and delivers more water to the pressure tank. A check valve prevents the pressurized water from returning to the cistern.

*Low Water Cutoff Float Switch (item 7 on Figure P-BAS-04-9).* Several different forms of water level switches are available to shut off the submersible pump when the water level is below the optimal operating depth. A submersible pump is highly susceptible to failure from overheating if operating in dry conditions. (The mechanical systems, including the pump, pressure tank, and backup supply, must all be coordinated to ensure the proper function and longevity of the system.)

*Overflow (item 8 on Figure P-BAS-04-9).* An overflow mechanism should be included in the rainwater harvesting system design to manage individual or combined storm events that exceed the design capacity of the cistern. An external overflow system would simply back up the inflow pipe and force any additional flow to be diverted to the overflow conveyance. An internal overflow system (i.e., pump discharge) should have a flow capacity equal to or greater than that of the inflow pipe(s) in order to prevent water from backing up into the collector system or be combined with an external overflow. The overflow system must be designed with an adequate pipe diameter and slope sufficient to convey the discharge to the designated outlet.

*Backup Water Supply (item 9 on Figure P-BAS-04-9).* The backup water supply is accounted for in the VCD spreadsheet and is intended for a connection that feeds water directly into the cistern. Note: It is recommended that, if municipal water serves as the backup supply, it should not discharge directly into the cistern because the chemicals of the municipal water supply may kill the biofilm in the tank. Rather, the municipal backup should bypass the tank through the solenoid valve (item 12 on Figure P-BAS-04-9) and backflow preventer (Cabell Brand 2009). However, the spreadsheet does not account for this backup configuration (which connects to the supply line between the cistern and the building). In either case, the backup is triggered by low and high water levels when used and is calibrated as a percentage of total cistern volume (cistern tank invert to overflow invert). This percent format allows the application of the VCD spreadsheet to all cistern sizes.

*Backflow Preventer (item 10 on Figure P-BAS-04-9).* A backflow preventer is required to separate harvested rainwater from the main potable water distribution lines. The backflow preventer can take the form of an air gap or check valve and prevent flows from the storage tank into the municipal supply line.

*Float Switch (item 11 in Figure P-BAS-04-9).* The float switch controls the submersible pump in the storage tank and the distribution of water based on the demand (e.g., internal, seasonal, drawdown, pressure tank, and water levels in the tank). The float switch will also open and close the backup supply solenoid valve (item 12 on Figure P-BAS-04-9).

*Solenoid Valve (item 12 on Figure P-BAS-04-9).* Solenoid valves are control units which, when energized, open and allow water to flow. Once they are de-energized, they close, stopping the flow of water.

*Air Gap (item 13 in Figure P-BAS-04-9).* The air gap prevents stormwater backflow from entering a rainwater tank/cistern, by creating a physical air break before the distribution system. The air gap also serves as a point for visual inspections of the system.

*Pressure Tank (item 14 in Figure P-BAS-04-9).* The pressure tank keeps a certain amount of water stored under pressure for immediate use so that the pump does not need to turn on each time water is used.

Table P-BAS-04-5 presents design information for the different components of a rainwater harvesting system.

| Table P-BAS-04-5 Rainwater Harvesting Design Components | |
|---|---|
| **Item** | **Specification** |
| Storage Tank | Tanks should be constructed/installed where native soils can support the load associated with stored water.<br>The size of the rainwater harvesting system(s) is determined by the design calculations.<br>Materials used to construct storage tanks should be structurally sound. Reused tanks should have been used previously for potable water or food-grade products.<br>All storage tanks should be watertight and sealed using a water-safe, non-toxic substance.<br>Aboveground storage tanks should be both UV- and impact-resistant and should be opaque to prevent the growth of algae.<br>Underground rainwater harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line.<br>Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic).<br>Underground rainwater harvesting systems should have a standard-size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance. This access point should be locked or otherwise secured to prevent unwanted access.<br>Storage tanks should be screened to discourage mosquito breeding and reproduction.<br>The inflow pipe should consist of an upturned elbow or other form of a flow- calming configuration to minimize the suspension of solids settled on the tank bottom.<br>Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications. |
| Gutters and Downspouts | Materials commonly used for gutters and downspouts include PVC pipe, vinyl, aluminum, and galvanized steel. Lead should not be used as gutter and downspout solder because rainwater can dissolve the lead and contaminate the water supply.<br>The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tank. |

| Table P-BAS-04-5 Rainwater Harvesting Design Components | |
|---|---|
| **Item** | **Specification** |
| Pre-Treatment | All harvested rainwater needs to pass through pre-treatment (at least one of the following):<br>• Leaf screen (1 mm mesh size);<br>• First flush diverter;<br>• Roof washer; and<br>• Approved MTD |
| Distribution Lines | Distribution lines to and from the storage tank should be buried beneath the frost line.<br>Distribution lines from the rainwater harvesting system to the building should have shutoff valves that are accessible when snow cover is present.<br>The distribution lines should include a drain plug, cleanout sump, or other access point so the lines can be completely drained if needed. |

**Note:** This table does not address indoor systems or pumps.

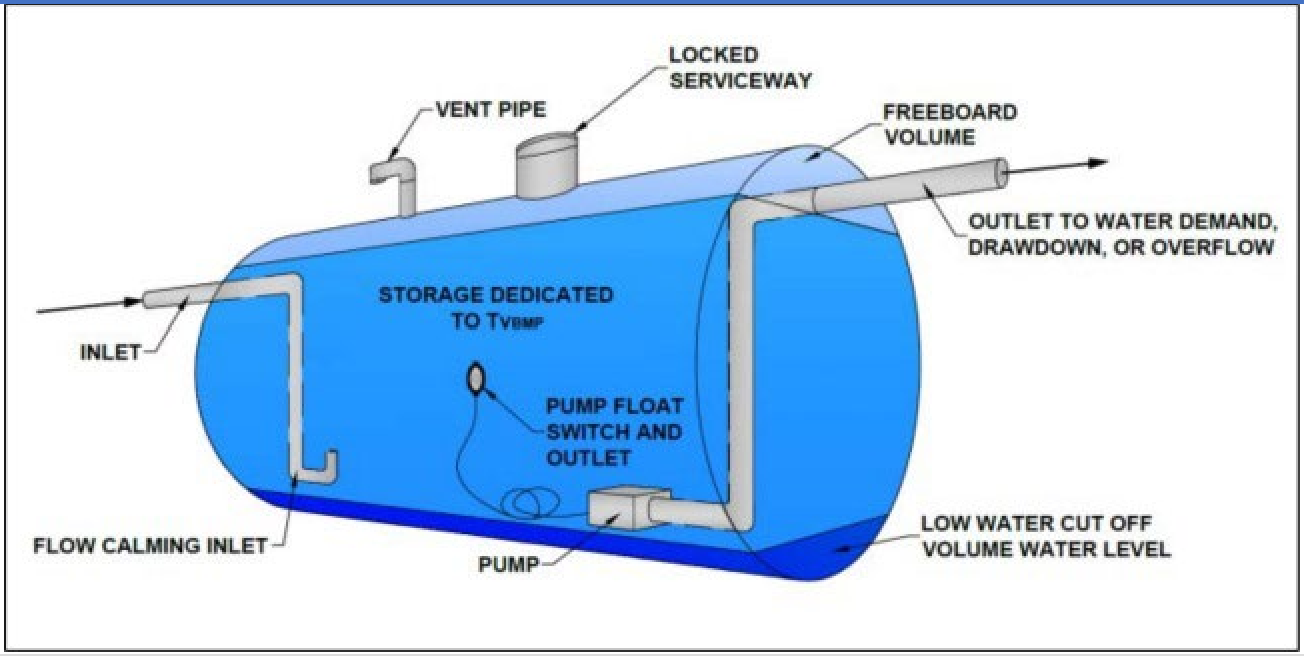
### 5.3 Design Objectives and Tank Design Setups

There are two basic tank design configurations used to meet the rainwater harvesting system configurations previously described.

***Tank Design 1.*** The first tank setup (Figure P-BAS-04-12) maximizes the available tank storage volume to accommodate the Tv to meet the water demand and achieve the desired runoff reduction volume credit. An emergency overflow exists near the top of the tank. The overflow outlet may be a gravity flow outlet or a pumped outlet. Alternatively, the overflow may be an external control that backs up the flow before the tank, thereby diverting any additional inflow.

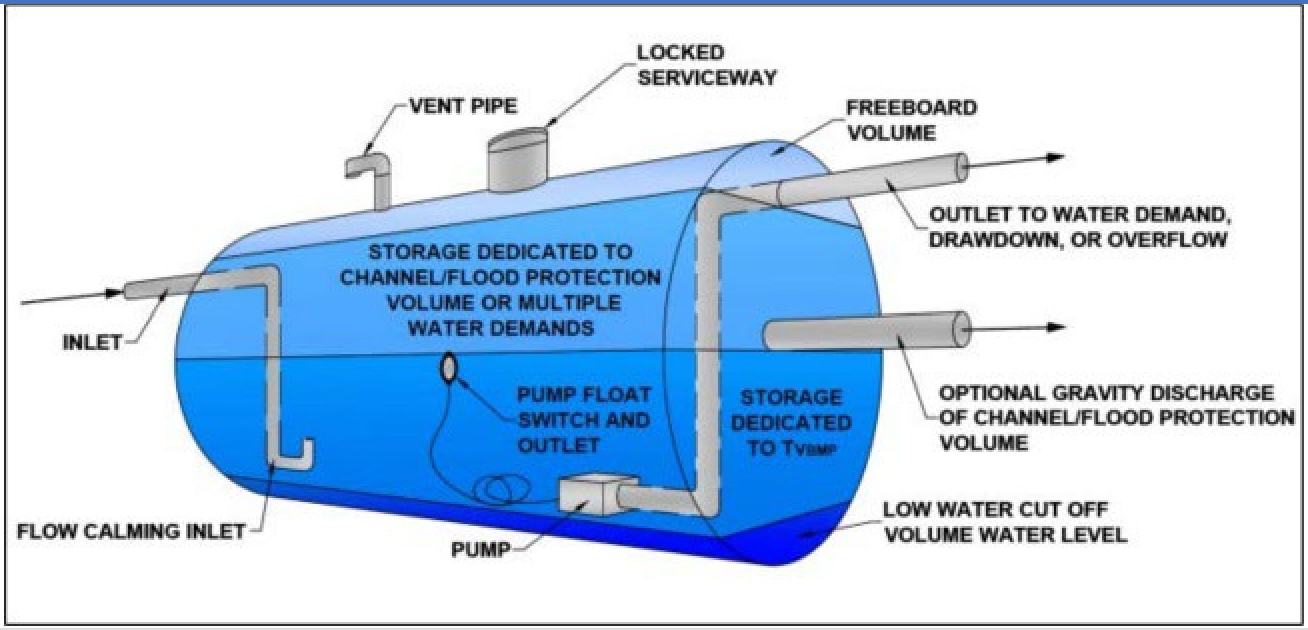
***Note:*** *Figure P-BAS-04-12 and Figure P-BAS-04-13 are schematic representations of the relative configuration of the storage volume and outlets. If these tanks are configured below grade, there would be a mechanical system to pump the required flow to meet the water demand or drawdown, requiring a float switch or other water level sensor to trigger the pump for meeting a variable demand. An above grade system may include a combination of gravity overflow orifices and a pump system to generate adequate pressure for the intended uses.*

**Figure P-BAS-04-12 Tank Design 1: Storage Associated with Treatment Volume (Tv) only**




***Tank Design 2.*** The second tank setup (Figure P-BAS-04-13) uses tank storage to manage the Tv and runoff reduction volume credit objectives as well as using an additional detention volume above the Tv to also meet some or all the channel and/or flood protection volume quantity control requirements. For an aboveground system, the channel and/or flood protection storage outlet orifice is located at the top of the Tv design storage and sized according to the channel and/or flood protection peak flow requirements. Alternatively, a below grade system would rely on a float switch and pump to achieve the same objectives. An emergency overflow is located at the top of the detention volume level. The VRRM compliance spreadsheet can be used in combination with other approved hydrologic routing programs to model and size the channel protection and flood protection (detention) volumes.

***Figure P-BAS-04-13 Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume***




In both cases, the Tv storage is managed with either a gravity discharge or a pump based on the demand.

When a secondary stormwater management BMP is used to enhance the effectiveness of rainwater harvesting as a stormwater management practice, there are two basic applications that can be considered:

- A secondary runoff reduction drawdown practice that is part of the cistern system and is used to supplement a seasonal demand by providing a runoff reduction drawdown during the non-seasonal months (thereby establishing an annual runoff reduction volume credit); or
- A downstream runoff reduction or pollutant removal BMP selected as a downstream treatment practice to manage the remaining portion of the year-round demand. In this case, the year-round demand and runoff reduction volume credit computed in the VCD spreadsheet is less than 100 percent of the annual Tv, and the downstream practice to be employed is selected in the VRRM compliance spreadsheet to provide additional volume reduction, pollutant removal, or both.

**5.4 Sizing**

**5.4.1 Sizing for the 1 Inch Event**

**Using the VCD Spreadsheet**

The VCD spreadsheet performs continuous simulation in order to help the designer select the optimal cistern size. The VCD can be downloaded from the Virginia Stormwater BMP Clearinghouse web site at: https://swbmp.vwrrc.vt.edu/.

The spreadsheet uses 30 years of daily rainfall data from four localities in Virginia (Richmond, Alexandria, Lynchburg, and Harrisonburg) to model the performance parameters of the cistern under varying rooftop capture areas, water demands, and tank sizes. As such, the VCD spreadsheet is a design tool for estimating the optimal size of a cistern based on the design rainfall, rooftop area, and water demand and computing a corresponding runoff reduction volume credit (Forasté and Hirschman 2010). This credit is then plugged into the VRRM compliance spreadsheet to evaluate the overall compliance of the BMP strategy.

The sizing criteria for the rainwater harvesting cistern presented in this specification and the VCD spreadsheet were developed using best estimates of indoor and outdoor year-round and seasonal water demand, long-term rainfall data, and rooftop capture area data (Forasté and Lawson 2009; Forasté 2013). The VCD spreadsheet is primarily intended to provide guidance in sizing cisterns for the purposes of achieving a runoff reduction volume credit for storms less than or equal to a depth of 1 inch. This credit is then entered into the VRRM compliance spreadsheet to determine compliance with the water quality requirements.

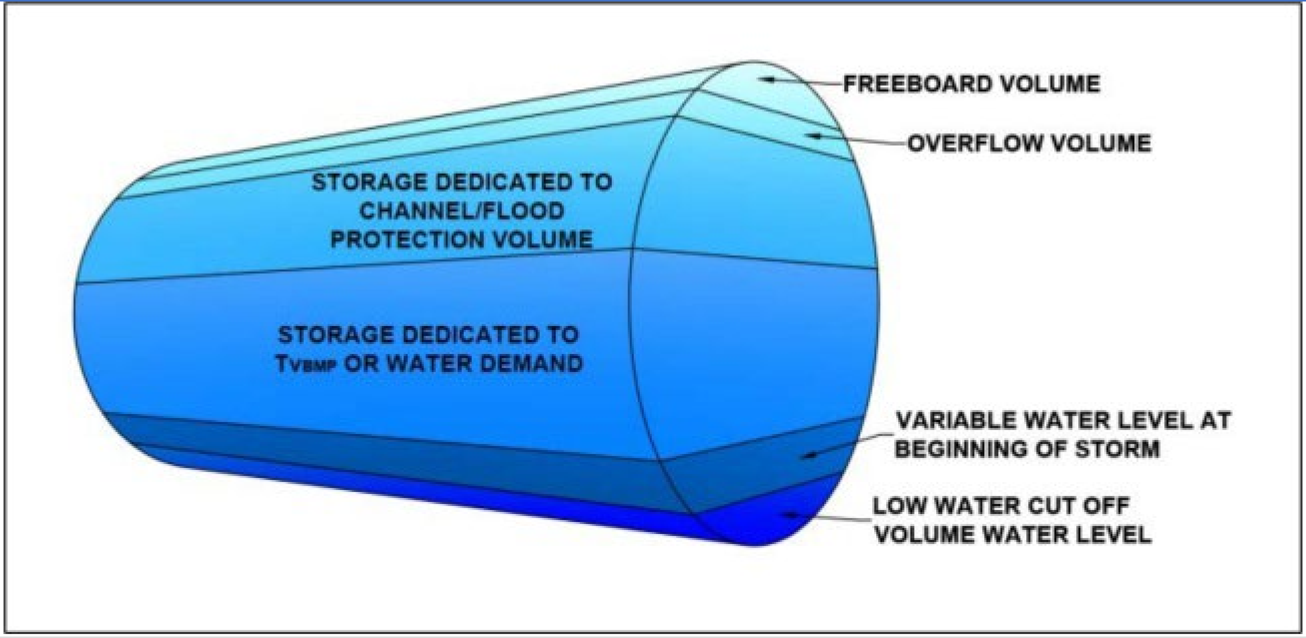
### 5.4.2 Sizing for Management of Larger Storms

In addition to sizing the cistern for the 1-inch design rainfall, the designer may size the cistern for the management of larger storms (channel and flood protection requirements). In general, the cistern size is increased as needed to accommodate the additional storage beyond the 1-inch TvBMP volume level. The additional storage is that needed to accommodate the attenuation of the 1-year or 10-year design storm runoff for channel protection (energy balance) or flood protection, respectively. A gravity discharge orifice is located above the TvBMP volume and sized for the allowable discharge, or a regulated pump discharge is installed that is activated by a float switch when the water surface in the cistern exceeds the TvBMP level. Figure 5-2 provides a schematic representation of the potential incremental design volumes when managing the additional storm events.

The "Storage Dedicated to TvBMP" labeled on Figure P-BAS-04-12 is the storage modeled and available for use to meet the annual water demand. While the design TvBMP is a function of the roof area and is constant. The actual storage volume dedicated to meeting the demand may vary depending on the size of the tank selected and corresponding runoff reduction volume credit. The cistern design will also include volume dedicated to a low water cutoff at the bottom (meaning the tank should never run completely dry) as well as an overflow volume and freeboard at the top.

This specification is primarily focused on guidance for managing the 1-inch target TvBMP and does not address the design or sizing for channel and flood protection volume within a cistern. See Appendix A for more information on design volumes and outlet sizing criteria associated with other target design storms.

***Figure P-BAS-04-14 Incremental Design Volumes associated with tank sizing***




## 6.0 Construction Specifications

### 6.1 Construction Sequence

It is advisable to have a single contractor install the rainwater harvesting system, outdoor irrigation system, and secondary runoff reduction practices. The contractor should be familiar with the sizing, installation, and placement of rainwater harvesting systems. The rainwater harvesting system must be connected to components to the plumbing system by a licensed plumber.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This sequence can be modified to reflect different rainwater harvesting system applications or expected site conditions.

- Identify the tank location on the site.
- Route all downspouts or roof drains to pre-screening devices and first flush diverters.
- Install the tank in accordance with the approved plans or the manufacturer's recommendations.
- Install the pump (if required and if not pre-engineered into the tank) and piping to end uses (indoor, outdoor irrigation, or tank dewatering release).
- Route all pipes to the tank.
- Stormwater should not be diverted to the rainwater harvesting system until the overflow path has been stabilized with vegetation.

### 6.2 Construction Inspection

The following items should be inspected prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans.
- Rainwater harvesting system foundation is constructed as shown on plans.
- Diversion system is properly sized and installed.

- Pre-treatment system is installed.
- Mosquito screens are installed on all openings.
- Inflow and outflow pipes and distribution system are constructed in accordance with the approved plans and have been tested for watertightness.
- Overflow device is installed and discharges as shown on plans
- Secondary runoff reduction practice(s) is installed as shown on plans.
- Catchment area and overflow area are stabilized.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the rainwater harvesting system, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

Rainwater harvesting systems can be complex and often will include mechanical components. Therefore, they should be inspected and maintained by qualified personnel. The following are minimum requirements for establishing accountability for the system to remain operational when a runoff reduction volume credit is applied to the system:

- A rainwater harvesting system must include a long-term maintenance agreement consistent with the provisions of the VESMP regulation, a list of the recommended maintenance tasks, and a copy of an annual inspection checklist.
- When a rainwater harvesting system is installed on a private residential lot, the homeowner should be educated by being provided a simple document that explains the purpose of the system and its routine maintenance needs.
- A deed restriction, drainage easement, or other legal mechanism enforceable by the VESMP Authority must be in place to help ensure that the rainwater harvesting system is maintained and operational as well as to pass the knowledge along to any subsequent owners.
- Ideally, this legal mechanism should grant access for the VESMP Authority for inspection of the tank (if external), the overflow conveyance, and any secondary runoff reduction drawdown BMP(s).
- As an alternative, a property owner may document that the system has been inspected and maintained by a qualified third-party inspector.

### 7.2 Maintenance Inspections

All rainwater harvesting system components should be inspected by the property each spring and fall. A comprehensive inspection by a qualified third-party inspector is recommended at least once a year but, at a minimum, should occur and be documented once every 3 years. An example maintenance inspection checklist for rainwater harvesting is included in Appendix H.

### 7.3 Rainwater Harvesting System Maintenance Schedule

Maintenance requirements for rainwater harvesting systems vary according to use. Systems used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table P-BAS-04-6 describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

| Table P-BAS-04-6 Suggested Maintenance Tasks for Rainwater Harvesting Systems | |
|---|---|
| **Activity** | **Frequency** |
| Keep gutters and downspouts free of leaves and other debris | O: Twice a Year |
| Inspect and clean pre-screening devices and first flush diverters | O: Four times a year |
| Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately | O: Once a year |
| Inspect condition of overflow pipes, overflow filter path, and/or secondary runoff reduction practices | O: Once a year |
| Inspect tank for sediment buildup | I: Every third year |
| Clear overhanging vegetation and trees over roof surface | I: Every third year |
| Check integrity of backflow preventer | I: Every third year |
| Inspect structural integrity of tank, pump, pipe, and electrical system | I: Every third year |
| Replace damaged or defective system components | I: As needed |
| O: Owner<br>I: Third-party inspector | |

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# P-CNV-01 Grass Channels

## 1.0 Definition

A grass channel is a broad and shallow open channel vegetated with grass sides, used for water quality treatment and water quantity control, and can be a component of pre-treatment for some best management practices (BMPs).

## 2.0 Purpose and Applicability of Best Management Practice

Grass channels can be implemented on suitable development sites where development density, topography, and soils are suitable. The linear nature of grass channels makes them well-suited to treat highway runoff, low- and medium-density residential road and yard runoff (if there is an adequate right-of-way width and distance between driveways), and small commercial parking areas or driveways. The maximum total contributing drainage area to any individual grass channel is 5 acres.

Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system where development density, topography, and soils permit. Grass channels can also treat runoff from the managed turf areas of turf-intensive land uses, such as sports fields and golf courses, and drainage areas with combined impervious and turf cover (e.g., roads and yards). Grass channels, when combined with weeping check dams, can provide water quantity for low-density residential and turf-intensive land uses.

Grass channels can also provide pre-treatment for and conveyance to or away from other stormwater treatment practices.

## 3.0 Planning and Considerations

Grass channels are typically most feasible in lower-density developments but can be implemented where the design criteria can be met. Frequent driveway crossings may impose channel maintenance or constructability issues in higher-density applications. Grass channels should be installed at a time of year that is best to establish turf cover, typically February 15 through April 15 and 29 September 15 through November 15. Establishment outside of these periods may require additional measures to ensure successful stabilization and turf growth. Large commercial site applications may require multiple channels to effectively break up the drainage areas and meet the design criteria.

Check dams can be strategically placed to minimize erosive velocity and provide quantity control. Their runoff reduction performance can be boosted when compost amendments are added to the bottom of the swale (See P-FIL-08 Soil Compost Amendments).

The linear nature of grass channels makes them well-suited to treat highway or low- and medium-density residential road runoff if there is adequate right-of-way width and distance between driveways.

**Table P-CNV-01-1 Design Feasibility**

| Parameter | Details |
|---|---|
| Site Topography | While some gradient is needed to provide positive drainage through the system, grass channels generally work best on sites with flat to rolling slopes. Slopes should be less than 2% with a maximum of 4% when check dams are used. For sites with steep slopes greater than 2%, designers can use check dams to reduce the effective slope control and flow velocity. |
| Soils | Grass channels can be used on sites with any type of underlying soil. Grass channels situated on Hydrologic Soil Group (HSG) C and D soils can achieve greater runoff reduction with the incorporation of soil amendments in the design as noted in Table P-CNV-01-2 when incorporating soil compost amendments in accordance with P-FIL-08 Soil Compost Amendment. |
| Hydraulic Capacity | Grass channels are typically an on-line practice and, as such, must be designed with enough capacity to convey runoff from the 10-year design storm event within the channel banks, providing a minimum of 6 inches of freeboard, and be non-erosive during the 2-year storm event. This means that most surface dimensions are driven by the need to pass these larger storm events. |
| Depth to Water Table | Designers should ensure that the bottom of the grass channel does not intercept the seasonally high water table to keep the channel dry between storm events. Additional separation is required in the Coastal Plain, as specified in Table P-CNV-01-6. |
| Utilities | Designers should consult local utility design guidance for the horizontal and vertical clearance between utilities and the channels. Typically, utilities can cross grass channels if they are specially protected (e.g., double casing) or are located below the channel invert. |
| Hot Spot Land Uses | Grass channels are not recommended to treat stormwater hot spots due to the potential for infiltration of hydrocarbons, trace metals, and other toxic pollutants into groundwater. For a list of typical stormwater hot spots, see BMP P-FIL-05 Infiltration Practices. |

| Table P-CNV-01-1 Design Feasibility | |
|---|---|
| **Parameter** | **Details** |
| Minimum Setbacks | Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. As a rule, grass channels should offset from the 1H:1V bearing zone or at least 10 feet from building foundations, 10 feet from residential structures, 35 feet from septic system fields, and 50 feet from private wells. |
| Sequencing Considerations | While all construction sequences will vary by site, the following items should be considered by the designer when planning the construction sequence:<br>Ideally, grass channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical given that the channels are a key part of the drainage system at most sites. In these cases, temporary erosion and sedimentation controls (such as dikes, silt fences, and other erosion control measures) should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control fabric should be used to protect the channel.<br>Grass channel installation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments within the channel must be removed during the final stages of grading to achieve the design cross-section. Erosion and sediment controls for construction of the grass channel should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the grass channel until the bottom and side slopes are fully stabilized. |

## 4.0 Stormwater Performance Summary

| Table P-CNV-01-2 Summary of Stormwater Functions Provided by Grass Channels | | | | |
|---|---|---|---|---|
| **Stormwater Function** | **HSG Soils A and B** | | **HSG Soils C and D** | |
| | **No CA[1]** | **With CA** | **No CA** | **With CA** |
| Annual Runoff Volume Reduction (RR) | 20% | NA[2] | 10& | 20% |
| Total Phosphorus (TP) event mean concentration (EMC) Reduction[3] by BMP Treatment Process | 15% | | 15% | |
| TP Mass Load Removal | 32% | | 24% (no CA) to 32% (with CA) | |
| Total Nitrogen (TN) EMC Reduction[3] by BMP Treatment Process | 20% | | 20% | |
| TN Mass Load Removal | 36% | | 28% (no CA) to 36% (with CA) | |

| Table P-CNV-01-2 Summary of Stormwater Functions Provided by Grass Channels | | |
|---|---|---|
| Stormwater Function | HSG Soils A and B | HSG Soils C and D |
| Channel & Flood Protection | Partial<br>▪ Use Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a curve number (CN) adjustment | |

1. CA= Compost Amended Soils, see P-FIL-08 Soil Compost Amendment.
2. Compost amendments are generally not applicable for HSG A and B soils, although it may be advisable to incorporate them on mass-graded and/or excavated soils to maintain runoff reduction rates. In these cases, the 30 percent runoff reduction rate may be claimed regardless of the pre-construction HSG.
3. Change in EMC through the practice. Actual nutrient mass load removed is the product of the pollutant removal rate and the runoff volume reduction rate (see Table 1 in the Introduction to the New Virginia Stormwater Design Specifications).

## 5.0 Design Criteria

Grass channels can be used for water quality treatment, quantity control, or as a component of pre-treatment. The minimum criteria outlined in Table P-CNV-01-3 apply to all grass channel applications.

| Table P-CNV-01-3 Grass Channel Design Guidance |
|---|
| Design Criteria |
| The bottom width of the channel should be set to maintain the peak flowrate for the 1-inch storm design treatment volume (Tv)1 at less than 4 inches in depth and ≤ 1 ft/s velocity. |
| The channel side slopes should be 3H:1V or flatter. |
| The maximum total contributing drainage area to any individual grass channel is 5 acres. |
| The longitudinal slope of the channel should be no greater than 4%. (Check dams may be used to reduce the effective slope to meet the limiting velocity requirements.) |
| Manning's "n" value for grass channels should be 0.15 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches. |
| The dimensions of the channel should ensure that flow velocity is non-erosive during the 2-year design storm events and the 10-year design flow is contained within the channel with a minimum of 6 inches of freeboard. |

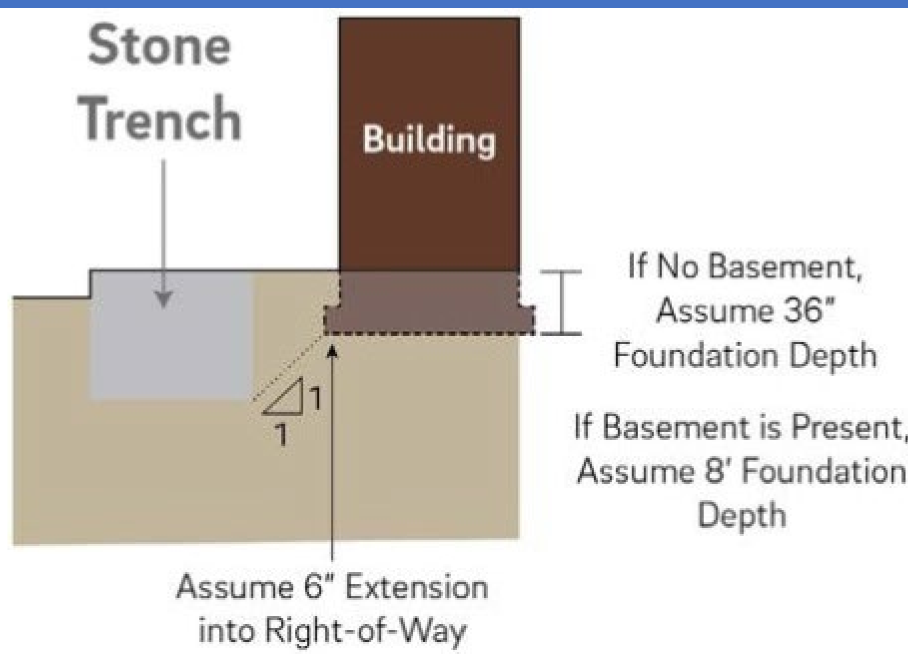
1. The design of grass channels should consider the entire Tv of the contributing drainage area (rather than the TvBMP, which would reflect a decrease in Tv based on upstream runoff reduction practices) to ensure non-erosive conveyance during all design storm conditions.

| Table P-CNV-01-4 Grass Channel Offset Guidance | | |
|---|---|---|
| Feature | Offset* | Notes |
| Existing buildings, retaining walls, bridge supports, and other such structures. | 1H:1V zone of influence as shown on Figure P-CNV-01-1 | Closer offsets may be considered on a case-by-case basis where impermeable liners are specified by the designer. |
| Sewer mains | 2V:1H zone of influence | |

| Table P-CNV-01-4 Grass Channel Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Sewer laterals | 5 feet horizontal, 12 to 18 inches vertical | |
| Water mains | 5 feet horizontal | |
| Large utilities | 10 feet horizontal, 18 inches vertical | Includes water transmission mains, high- pressure gas mains, large conduits. |
| Utility lines, service lines (not otherwise specified above) | 3 feet horizontal, 12 to 18 inches vertical | Coordination with utilities required where offsets cannot be achieved. |
| Existing inlets | 5 feet horizontal | Closer offsets may be considered on a case-by-case basis. |
| Telephone poles, utility poles, traffic signals or comparable | 5 feet horizontal | |
| Bedrock layer | 1.5 feet vertical | |

* Unless otherwise specified by locality or utility.

***Figure P-CNV-01-1 Zone of Influence***



*An impermeable liner may be used where the desired setback from the bearing plane cannot be satisfied.*

### 5.1 Sizing of Grass Channels

Unlike other stormwater practices, grass channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- The longitudinal slope of the channel should ideally be between 1 and 2 percent in order to avoid scour and short-circuiting within the channel. Longitudinal slopes up to 4 percent are acceptable; however, check dams will likely be required to meet the allowable maximum flow velocities.
- Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method such as erodibility factors and vegetal retardance (NOVA 2007).
  - The flow depth for the Tv peak flow (1 inch rainfall) should be maintained at 4 inches or less.
  - Manning's "n" value for grass channels should be 0.15 for flow depths up to 4 inches, decreasing to 0.03 at a depth of 12 inches (which would apply to the 2-year and 10-year storms if an on-line application – NOVA 2007; Haan et al. 1994).
  - o Peak flowrates for the 2-year frequency storm must be non-erosive, in accordance with Table P-CNV-01-3, or subject to a site-specific analysis of the channel lining material and vegetation, and the 10-year peak flowrate must be contained within the channel banks with a minimum of 6 inches of freeboard.
- Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel as appropriate. If a single flow is used, the flow at the outlet should be used.
- The hydraulic residence time (the time for runoff to travel the full length of the channel) should be a minimum of 9 minutes for the Tv (1-inch rainfall) design storm (Spyridakis et al. 1982; Keblin et al. 1998; Washington State Department of Ecology 2005). If flow enters the swale at several locations, a 9-minute minimum hydraulic residence time should be demonstrated for each entry point using Equations P-CNV- 01-1 and P-CNV-01-2 (Equations 5-1 and 5-2, NOVA 2007) The minimum length or residence time may be achieved with multiple swale segments connected by culverts with energy dissipaters.

The bottom width of the grass channel is sized to maintain the appropriate flow geometry based on the water quality (WQ) treatment flow (qptv). Consolidating the Manning's Equation and continuity equation, the following equation is used to size the width.

***Equation P-CNV-01-1. Channel Width***

W=(n)(qptv)/(1.49D^5/3S^1/2)

***Equation P-CNV-01-2. Channel Velocity***

The corresponding velocity is solved using

$$V = \frac{qptv}{WxD}$$

This equation provides a solution for the minimum width:

***Equation P-CNV-01-3. Minimum Channel Width***

$$W = (n)\left(q_{pTv}\right)/\left(1.49D^{5/3}s^{1/2}\right)$$

Solving Equation for the corresponding velocity provides:

***Equation P-CNV-01-4. Channel Velocity***

**Equation 3.4: Corresponding Velocity**

$$V = q_{pTv} / (W \times D)$$

The resulting velocity should be less than 1 ft/sec. The width, slope, or Manning's "n" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "n" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that the denser vegetation is actually established. Equation P-CNV-01-5 can then be used to ensure adequate hydraulic residence time.

***Equation P-CNV-01-5. Minimum Swale Length***

$$L = 540V$$

Where:

$L$ = minimum swale length (ft.)

$V$ = flow velocity (ft./sec.)

**Table P-CNV-01-5 Maximum Permissible Velocities for Grass Channels**

| Cover Type | Slope (%) | Erosion Resistant Soils (ft./sec.) | Easily Eroded Soils (ft./sec.) |
|---|---|---|---|
| Bermudagrass | 0 - 5<br>5 – 10 | 6<br>5 | 4.5<br>3.8 |
| Kentucky bluegrass / Tall fescue | 0 – 5<br>5 – 10<br>> 10 | 5<br>4<br>3 | 3.8<br>3<br>2.3 |
| Grass-legume mixture | 0 – 5<br>5 - 10 | 4<br>3 | 3<br>2.3 |
| Redtop | 0 - 5 | 2.5 | 1.9 |
| Sources: Virginia E&S Control Handbook 1992; Ree 1949; Temple et al. 1987; NOVA 2007 | | | |

### 5.2 Geometry and Site Layout

- Grass channels should generally be aligned adjacent to and the same length (minimum) as the contributing drainage area identified for treatment.
- Grass channels should be designed with a trapezoidal or parabolic cross-section. A parabolic shape is preferred for aesthetic, maintenance, and hydraulic reasons.
- The bottom width of the channel should be between 4 to 8 feet wide. If a channel will be wider than 8 feet, the designer should incorporate benches, check dams, level spreaders, or multi-level cross-sections to prevent braiding and erosion along the channel bottom.
- Grass channel side slopes should be no steeper than 4H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to aid in pre-treatment of sheet flows entering the channel. Under no circumstances are side slopes to exceed 3H:1V.

### 5.3 Pre-treatment

Provide pre-treatment for a water quality grass channel. Pre-treatment should dissipate and disperse concentrated flows entering the practice. No pre-treatment is necessary for sheet flow. When grass channels are used as a pre-treatment component, no additional pollutant removal credit is applied. Refer to Support Component: Pre-treatment P-SUP-06 for design details and specifications for applicable pre-treatment options.

### 5.4 Check Dams

Check dams may be used for pre-treatment, to reduce the effective longitudinal slope, and to increase the hydraulic residence time in the channel. Temporary check dams should always be used during construction. Permanent check dams protect the channel when slopes are steeper than 2 percent. Weeping check dams are used to increase attenuation for quantity controls. Design requirements for check dams are as follow:

- Check dams should be spaced based on the channel slope, as needed to increase residence time, provide Tv storage volume, or any additional volume attenuation requirements. The ponded water at a downhill check dam should not touch the toe of the upstream check dam.
- The maximum desired check dam height is 12 inches (for maintenance purposes). The average ponding depth throughout the channel should be 12 inches.
- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side slopes to prevent outflanking; check dams must also be anchored into the channel bottom a minimum of 6 inches to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the channel design storm peak flow (10-year storm event if an on-line practice).
- The check dam should be designed to facilitate easy mowing, maintenance, and upkeep of the area.
- Each check dam should have a weep hole or similar drainage feature so it can dewater after storms.
- Check dams should be composed of wood, concrete, stone, or other non-erodible material or should be configured with elevated driveway culverts.
- Individual channel segments formed by check dams or driveways should generally be 25 to 40 feet long.

### 5.5 Compost Soil Amendments

Soil compost amendments increase the runoff reduction capability of a grass channel. The following design criteria apply when compost amendments are used:

- The compost-amended strip should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in P-FIL-08 Compost Amendment.
- The amended area will need to be rapidly stabilized with perennial, salt-tolerant grass species.
- For grass channels on steep slopes, it may be necessary to install a protective biodegradable geotextile fabric to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting an appropriate geotextile.
- For re-development or retrofit applications, the final elevation of the grass channel (following compost amendment) must be verified as meeting the original channel design hydraulic capacity.

| Table P-CNV-01-6 Additional Design Guidance | |
|---|---|
| **Consideration** | **Details** |
| Karst Terrain | Grass channels are an acceptable practice in karst terrain if they do not treat hot spot runoff. The following design adaptations apply to grass channels in karst terrain:<br>▪ Soil compost amendments may be incorporated into the bottoms of grass channels to improve their runoff reduction capability as noted in Table P-CNV-01-1.<br>▪ Check dams are generally discouraged for grass swales in karst terrain because they pond too much water (although flow spreaders that are flush with the ground surface and spaced along the channel length may be useful in spreading flows more evenly across the channel width).<br>▪ The minimum depth to the bedrock layer is 18 inches.<br>▪ A minimum slope of 0.5% must be maintained to ensure positive drainage.<br>▪ The grass channel may have off-line cells and should be tied into an adequate discharge point. |
| Coastal Plain | Although grass channels work reasonably well in the flat terrain and low head conditions of many Coastal Plain sites, they have very poor nutrient and bacteria removal rates and should not be used as a stand-alone treatment system. When grass channels are used on Coastal Plain sites, and where HSG A soils occur, the following design considerations should be addressed:<br>▪ The minimum depth from the swale invert to the seasonally high water table should be 12 inches.<br>▪ A minimum slope of 0.5% must be maintained to ensure positive drainage.<br>▪ The grass channel may have off-line cells and should be tied into the ditch system. |
| Steep Terrain | Grass swales are not practical in areas of steep terrain, although terracing a series of grass swale cells may work on slopes from 5% to 10%. The drop in elevation between check dams should be limited to 18 inches in these cases, and the check dams should be armored on the downslope side with suitably sized stone to prevent erosion. |
| Cold Climate and Winter Performance | Grass swales can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is used within the contributory drainage area, grass swales should be planted with salt-tolerant species such as creeping bentgrass or switchgrass. Bluegrass should be avoided in swales where salt loading is high. Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC 2005). |
| Linear Highway Sites | Grass swales are a preferred stormwater practice for linear highway sites. |

### 5.6 Grass Channel Material Specifications

The basic material specifications for grass channels are outlined in Table P-CNV-01-7.

| Table P-CNV-01-7 Grass Channel Materials Specifications | |
|---|---|
| **Component** | **Specification** |
| Turf Grass | C-SSM-10 Permanent Seeding: Designers should choose permanent grass species that can withstand both wet and dry periods as well as relatively high-velocity flows within the channel. For applications along roads and parking lots, salt-tolerant species should be chosen. Taller and denser grasses are preferred, though the species of grass is less important than good stabilization. Grass channels should be seeded (not sodded) at a density to achieve a 90% turf cover after the second growing season. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Storey et al. 2009). |
| Check Dams | C-SCM-07 Rock Check Dam and P-SUP-06 Pre-treatment: Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. Wood used for check dams should consist of pressure-treated logs or timbers or water-resistant tree species such as cedar, hemlock, swamp oak, or locust. |
| Pre-treatment | P-SUP-06 Pre-Treatment |
| Erosion Control Blanket | C-SSM-05 Soil Stabilization Blankets and Matting: Grass channels should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the channel bed and banks. |

## 6.0 Construction Specifications

### 6.1 Construction Inspection

Inspections during construction are needed to ensure that the grass channel is built in accordance with these specifications. An example construction phase inspection checklist for grass channels is provided at the end of this specification.

The following common pitfalls can be avoided by careful post-storm inspection of the grass channel:

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the channel beds and their contributing side slopes.
- Inspect check dams and pre-treatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- Make sure outfall protection/energy dissipation at concentrated inflows is stable.
- Log the filtering practice's global positioning system (GPS) coordinates and submit them for entry into the local BMP maintenance tracking database.

The real test of a grass swale occurs after its first big storm. Minor adjustments are normally needed as part of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams).

### 6.2 Sample Construction Inspection Checklist: Grass Channels

The following checklist provides a basic outline of the anticipated items for the construction inspection of grass channels for use as stormwater BMPs. Users of this information may wish to incorporate these items into a Virginia Stormwater Management Program (VSMP) Authority Construction Checklist format consistent with that used for erosion and sediment control and BMP construction inspections.

- Pre-construction meeting with the contractor designated to install the grass channel practice has been conducted.
- Impervious cover has been constructed/installed, and area is free of construction equipment, vehicles, material storage, and other project components.
- All pervious areas of the contributing drainage areas have been adequately stabilized, and erosion control measures have been removed.
- Grass channel has not been used during construction.
- Grass channel has been used for construction and is scheduled to be restored by removing construction sediment and incorporating soil amendments.
- Stormwater has been diverted for the construction of the inflow measures (level spreader or gravel diaphragm).
- Proper grades have been achieved with light equipment to avoid compaction and provide the required geometry of the grass channel: length and longitudinal slope, bottom width, and side slopes.
- Soil amendments, if required, have been incorporated as specified (thickness of compost material and incorporated to the required depth).
- Check dams (including driveway culverts, if required) have been installed in accordance with the approved plans (e.g., spacing, height, elevation of overflow notch, energy dissipaters, keyed into side slopes).
- Energy dissipater and sediment forebay (if required) have been installed at the areas of concentrated inflow in accordance with the approved plans.
- Pre-treatment practices have been installed for sheet flow entry.
- Channel bed and banks and adjacent disturbed areas have all been adequately stabilized (with matting if required or needed to ensure a dense vegetative cover) before diverting runoff into the channel.
- All erosion and sediment control practices have been removed.
- Follow-up inspection and as-built survey/certification have been scheduled.
- GPS coordinates have been documented for all grass channels on the parcel.

**Figure P-CNV-01-2 Grass Channel – Typical Plan, Profile and Section**

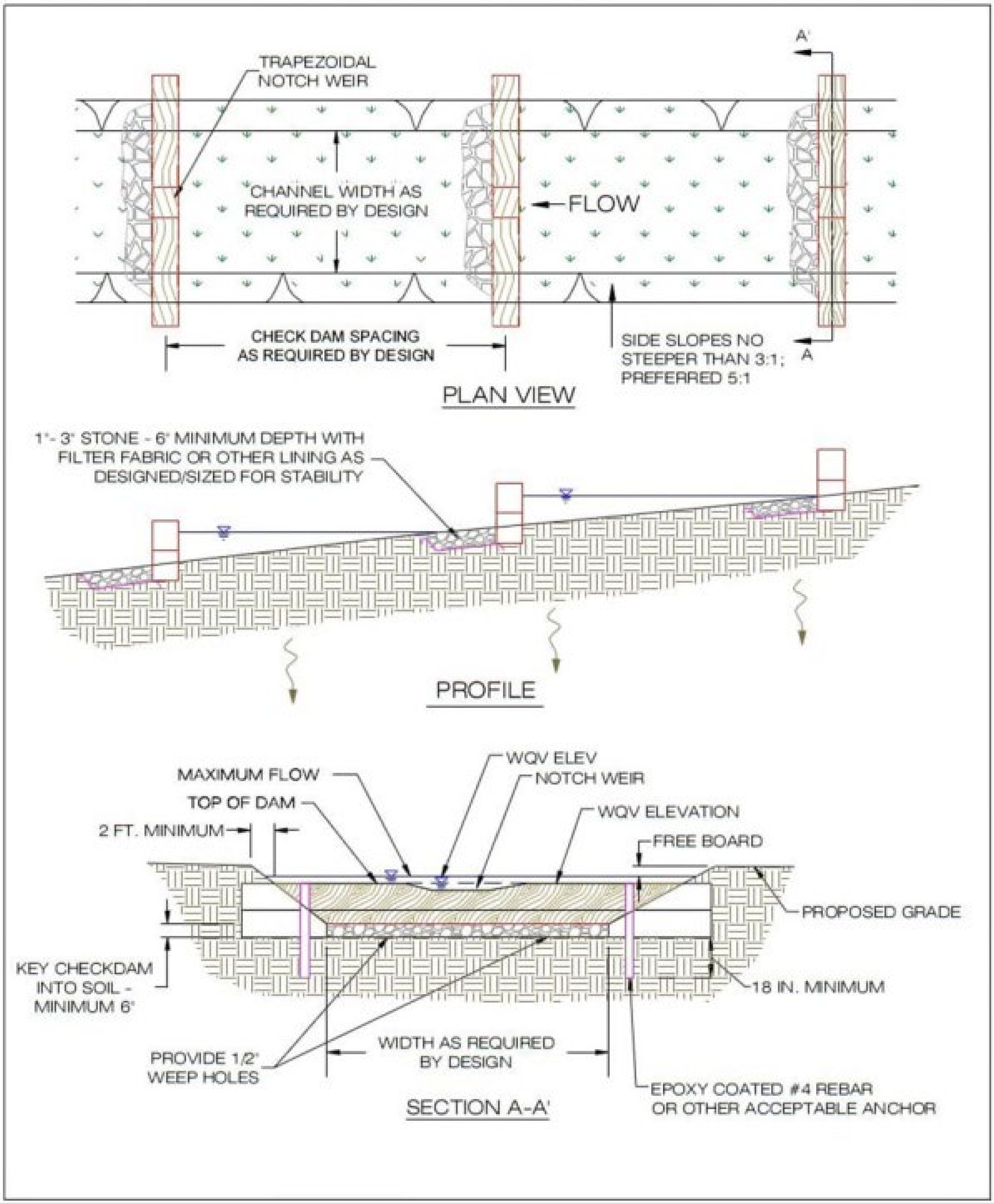


**_Figure P-CNV-01-3 Grass Channel with Check Dams – Typical Plan, Profile, and Section_**

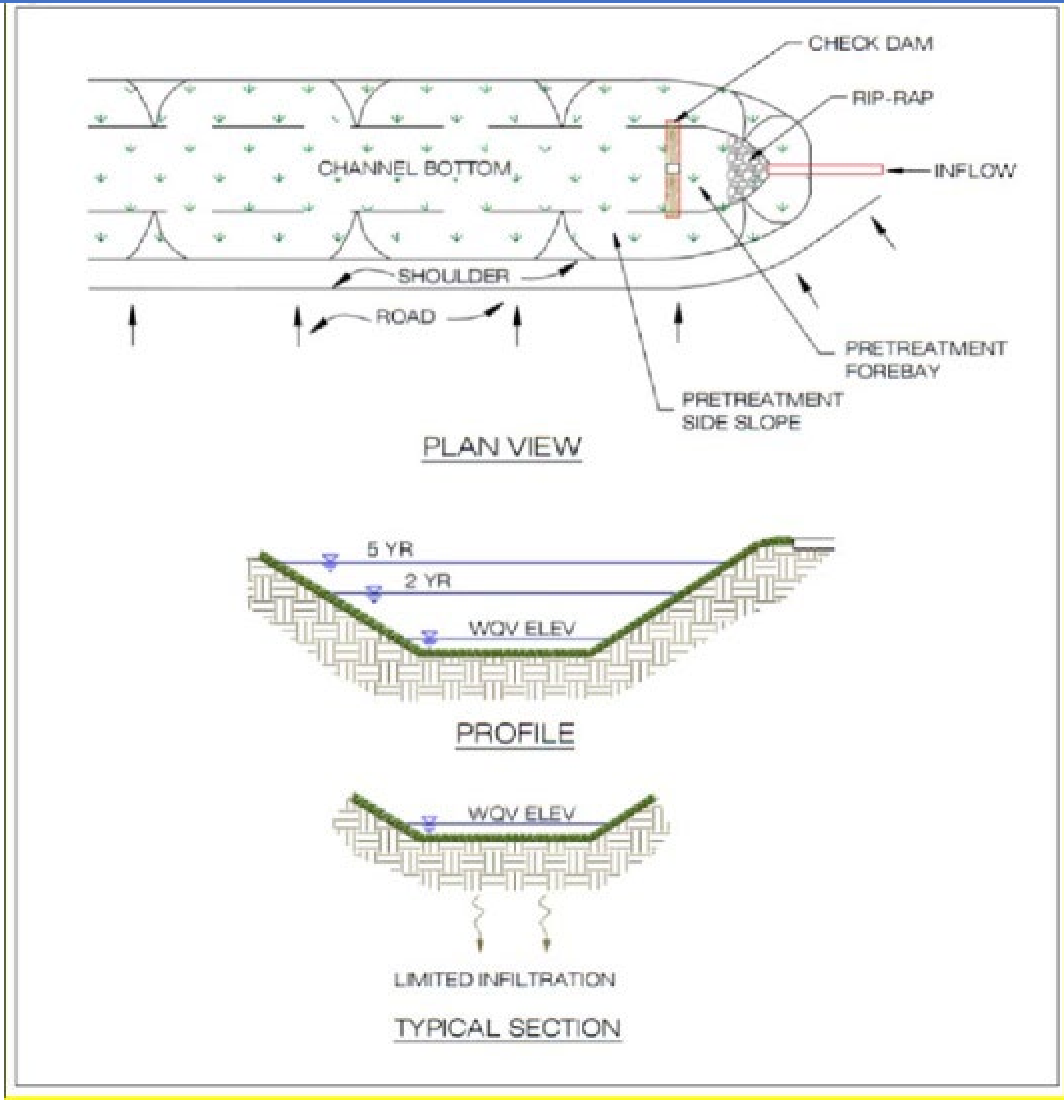
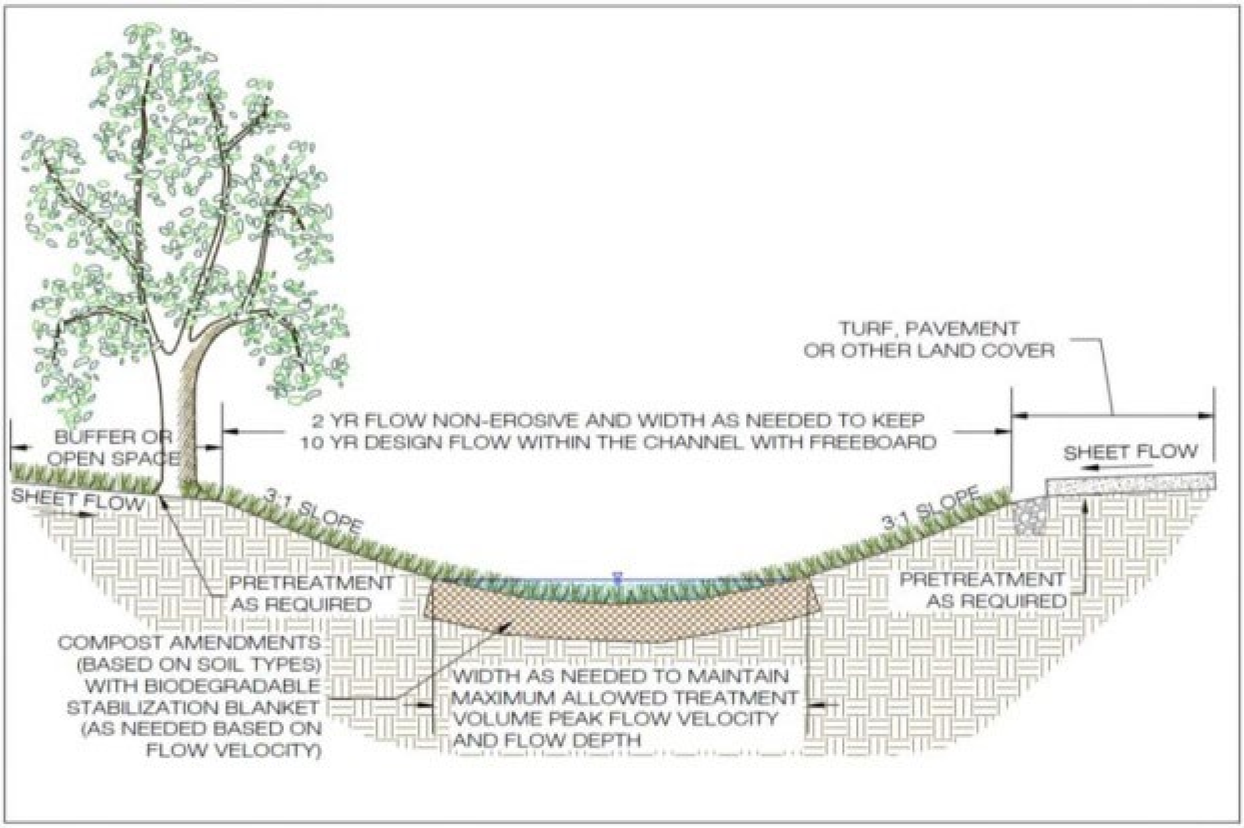
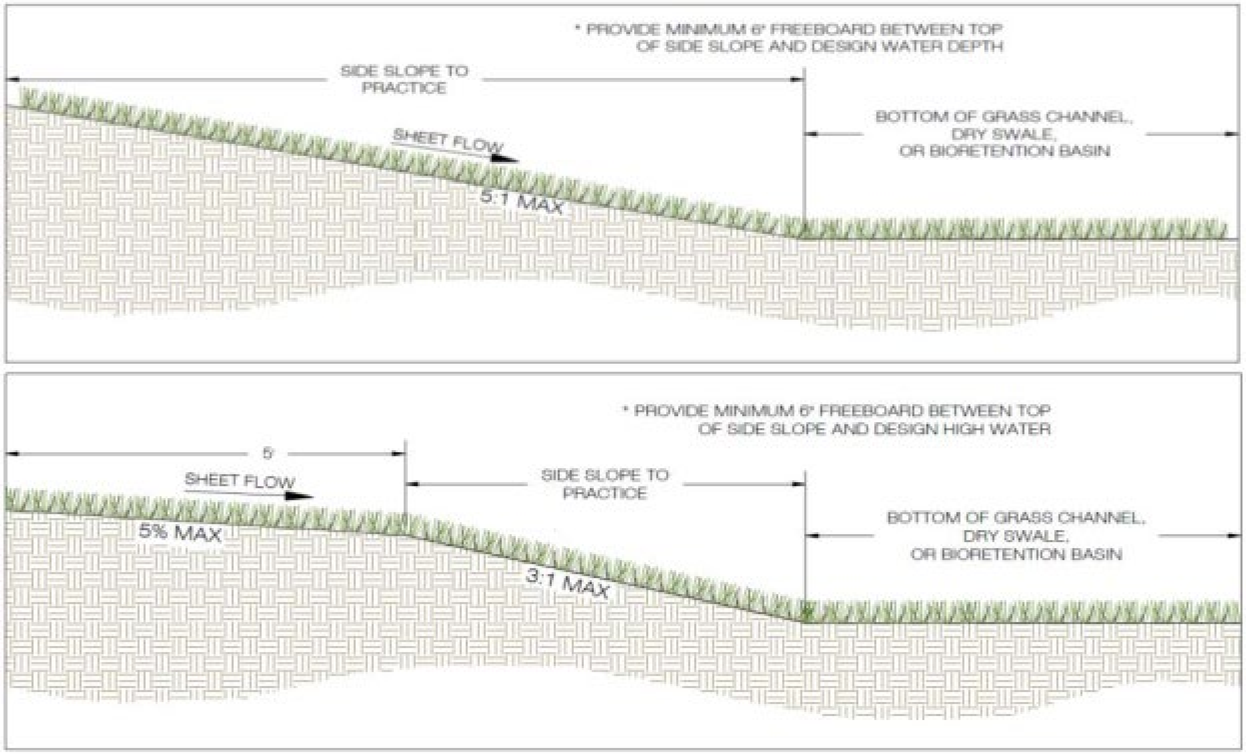


*Figure P-CNV-01-4 Grass Channel with Compost Amendments - Section*



## Figure P-CNV-01-5 Pre-treatment I and II - Grass Filter for Sheet Flow




## Figure P-CNV-01-6 Pre-treatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

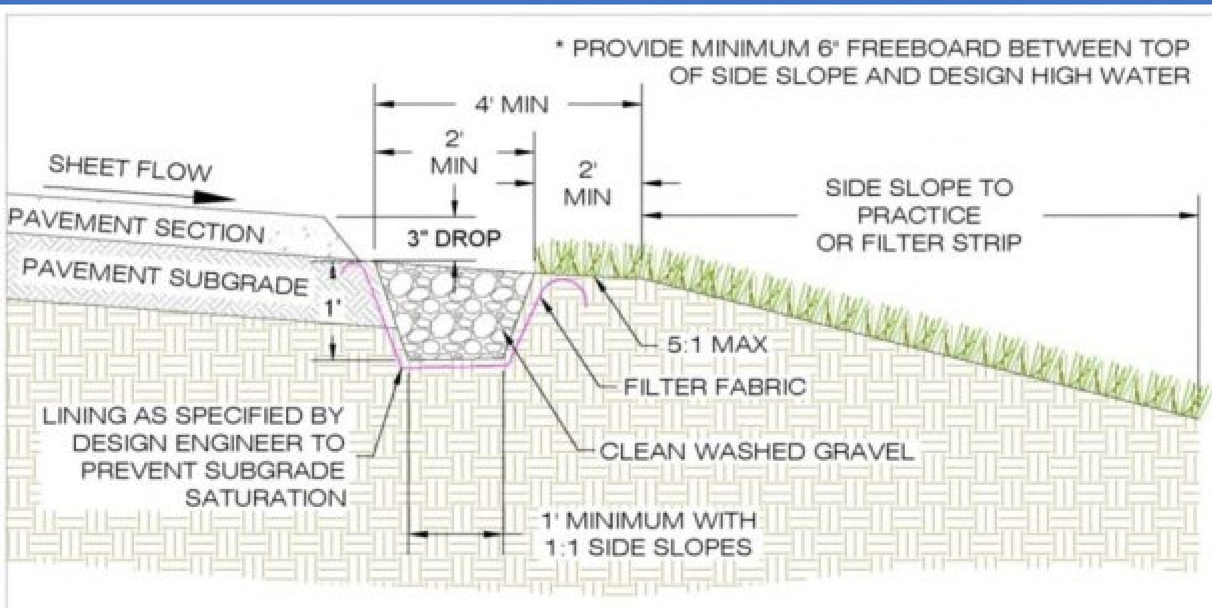


**Figure P-CNV-01-7 Pre-Treatment – Gravel Flow Spreader for Concentrated Flow**

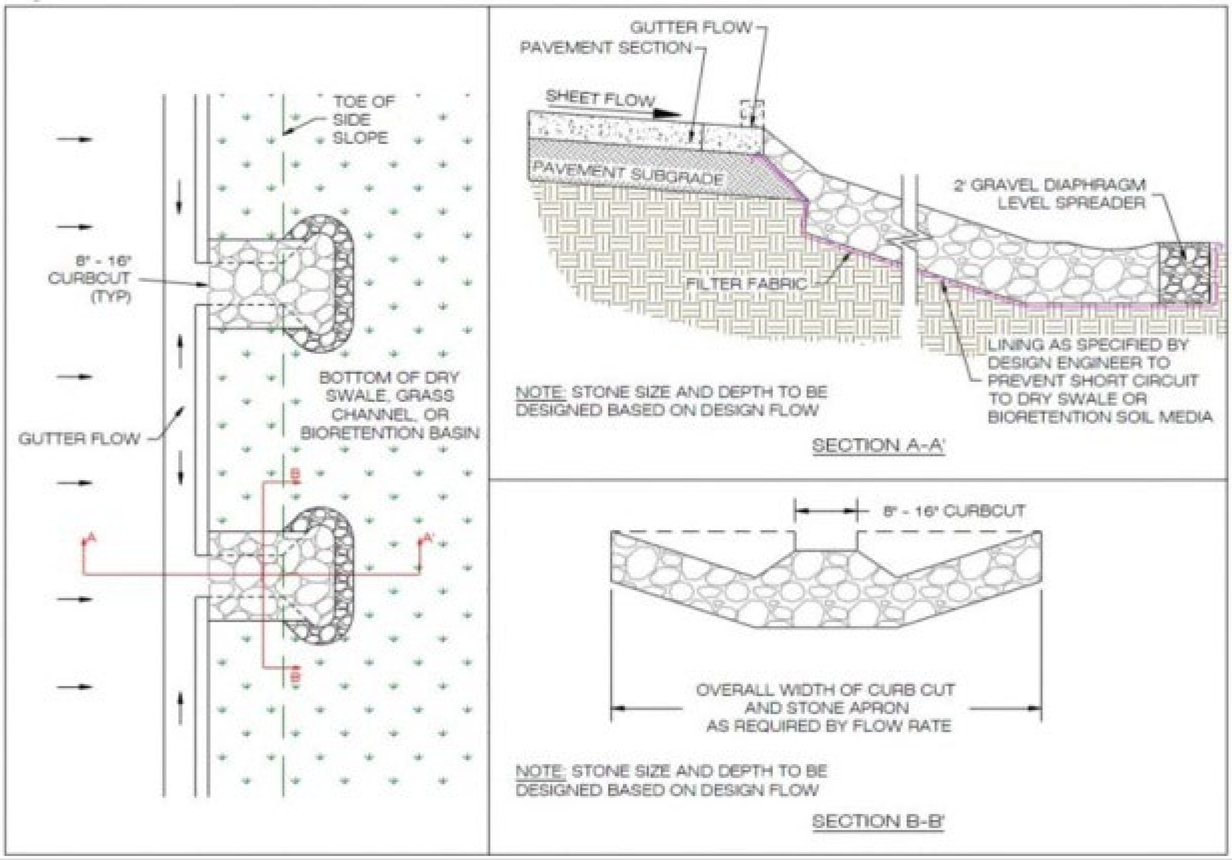
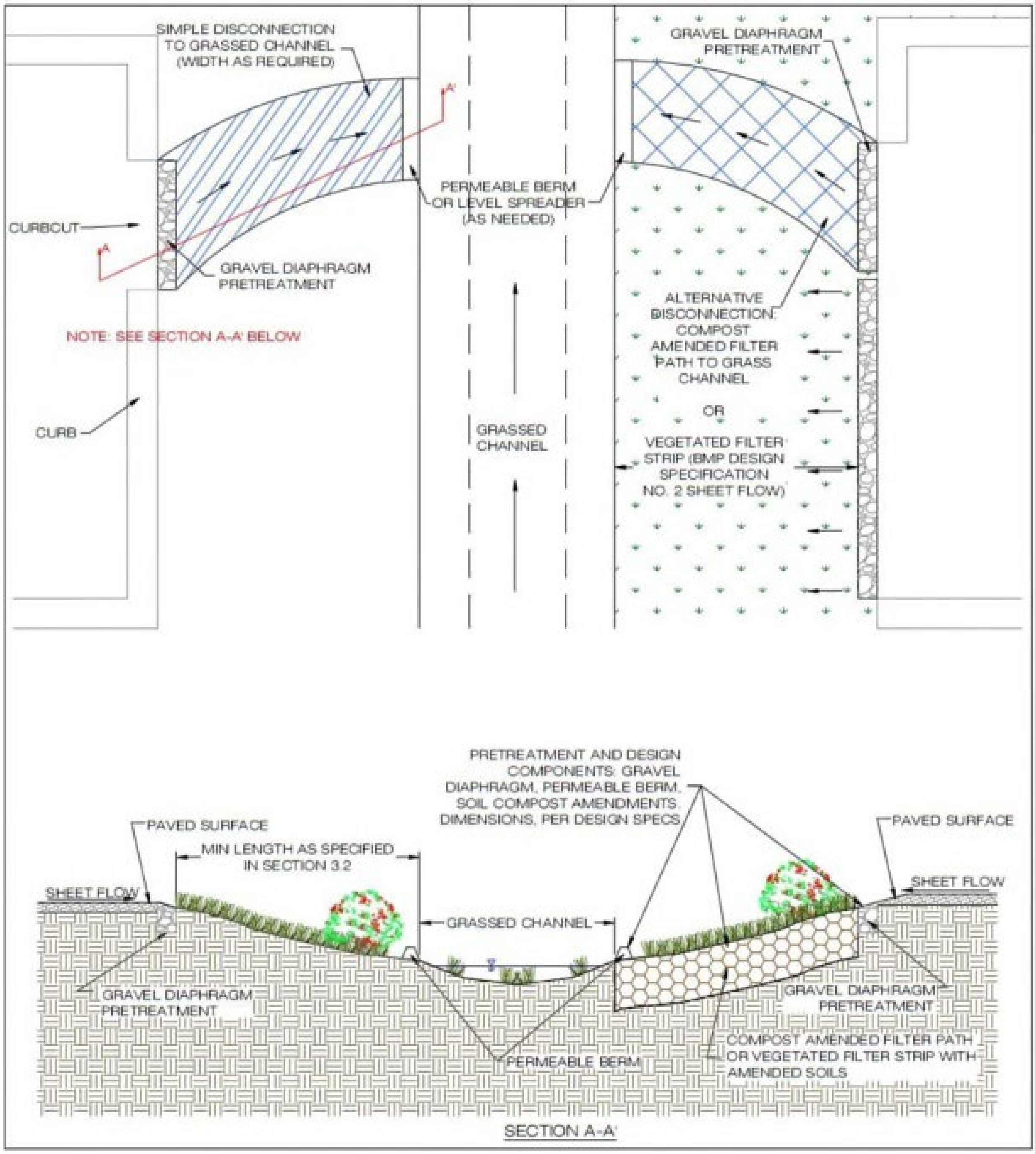


**Figure P-CNV-01-8 Filter Path to Grass Channel**




## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the grass channels, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- ***All water quality grass channels*** must include a long-term Maintenance Agreement consistent with the provisions of the VESMP Regulation and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When grass channels are located on individual private residential lots, homeowners will need to be educated regarding their routine maintenance needs.
- A deed restriction, drainage easement, or other mechanism enforceable by the VESMP Authority must be in place to help ensure that grass channels are maintained as well as to pass the knowledge along to any subsequent owners.
- The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action. Where grass channels are designed to convey runoff from multiple lots or properties, a drainage easement that ensures the access for purposes of inspections and corrective actions must be provided.

#### 7.2 Maintenance Inspections

Annual inspections trigger maintenance operations such as sediment removal, spot re-vegetation, and inlet stabilization. Several key maintenance inspection points are detailed in Table P-CNV-01-8. Ideally, inspections should be conducted in the spring of each year. Example maintenance inspection checklists for grass channels are provided in Chapter 10.

#### 7.3 Ongoing Maintenance

Once established, grass channels have minimal maintenance needs outside of spring cleanup, regular mowing at a tall grass setting, maintenance to height of between 3 and 6 inches, repair of check dams, and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover.

**Table P-CNV-01-8 Suggested Spring Maintenance Inspections/Cleanups for Grass Channels**

| Activity |
|---|
| Add reinforcement planting to maintain 90% turf cover. Reseed any salt-killed vegetation. |
| Remove any accumulated sand or sediment deposits behind check dams. |
| Inspect upstream and downstream of check dams for evidence of undercutting or erosion and remove trash or blockages at weep holes. |
| Examine channel bottom for evidence of erosion, braiding, excessive ponding, or dead grass. Repair areas of observed damage, reseed, and mulch. |
| Check inflow points for clogging and remove any sediment. |
| Inspect side slopes and grass filter strips for evidence of any rill or gully erosion and repair. |
| Look for any bare soil or sediment sources in the contributing drainage area and stabilize immediately. |

## 8.0 References

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# P-CNV-02 Dry Swales

## 1.0 Definition

Dry swales are shallow channels with a series of check dams that provide temporary storage to allow infiltration of the treatment volume. Dry swales use an engineered soil media as the channel bed with an under drain. Dry swales are vegetated with turf or other surface material (including large cobbles and ornamental plants).

## 2.0 Purpose and Applicability of Best Management Practice

**Table P-CNV- 02-1 Well-Suited Conditions for Dry Swales**

| Site Type | Details |
|---|---|
| Road medians or shoulders | Dry swales can be placed adjacent to the roadway shoulder in lieu of a typical drainage ditch, or if the road crown is sloped towards the median, the dry swale can similarly replace the drainage feature in the median, in both cases using a curbless edge. |
| Right-of-way or commercial setback | A linear configuration can be used to convey runoff in sheet flow from the roadway, or a grass channel or pipe may convey flows to the bioretention practice. |

| Table P-CNV- 02-1 Well-Suited Conditions for Dry Swales | |
|---|---|
| **Site Type** | **Details** |
| Commercial buildings | In lieu of a foundation planter, a dry swale can be configured along a minimal setback from the drip line of a structure. Similarly, roof leaders can be directed to dry swales within a courtyard or along the perimeter of a walkway or other pedestrian feature adjacent to a structure. |
| Parking lots | Dry swales are well-suited to be placed along the perimeters of small parking lots or driveways. |
| Dry extended detention (ED) basin | A dry swale can be used as an intermediary conveyance to an extended detention basin or other basin to capture sheet flow entering the basin form immediately adjacent drainage areas or as the final conveyance of runoff to the pre-treatment forebay. |

Dry swales are a linear biofiltration practice used with the goal of providing proper residence time in the swale to filter the stormwater through the soil media and discharge the treated water downstream to a receiving conveyance system. The maximum total contributing drainage area (CDA) to a single dry swale is 5 acres. The linear nature of dry swales makes them well-suited to treat the following conditions:

A dry conveyance swale is a linear adaptation of the bioretention basin that is aligned along a contributing impervious cover such as a roadway or parking lot. The length of the swale is generally equivalent to that of the contributing impervious area. The runoff enters the dry conveyance swale as lateral sheet flow, and the total CDA cumulatively increases along the length of the swale. The treatment component of the swale can extend to a greater length for additional storage.

A dry treatment swale is located to accept runoff as concentrated flow or sheet flow from non-linear drainage areas at one or more locations and, due to site constraints or other issues, is configured as a linear practice (as opposed to a bioretention configuration). A dry treatment swale can also be used to convey stormwater from the CDA to a discharge point; however, the cumulative drainage area does not necessarily increase along the linear dimension. In karst areas, dry treatment swales may only accept runoff as sheet flow and must maintain sheet flow throughout the best management practice (BMP), unless the channel has an impermeable, structurally sound liner.

Both the dry conveyance swale and the dry treatment swale can be configured as a Level 1 or Level 2 design (see Table P-CNV-02-5). The difference is that the typical CDA of a dry conveyance swale is impervious, with an adjacent grass filter strip (or other acceptable measure as described in Section 6.4) providing pre-treatment.

## 3.0 Planning and Considerations

Dry swales rely on a pre-mixed soil media filter underneath the channel that is the same as that used for bioretention. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale, beneath the filter media. Dry swales may appear as simple grass channels with the same shape and turf cover, while others may have more elaborate landscaping. Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees.

Dry swales can be implemented on a variety of development sites where density and topography permit their application. Some key feasibility issues for dry swales include those identified in Table P-CNV-02-2.

| Table P-CNV-02-2 Dry Swale Feasibility Criteria | |
|---|---|
| **Criteria** | **Details** |
| Available Space | Dry swale footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Sizing is based on treatment volume (Tv) and the dimensions of the channel (width and length). Dry swales will not have a width smaller than 2 feet, and if length does not meet requirements, an offline configuration is allowed (such as a check dam) to divert flow into a ponding area. |
| Site Topography | Dry swales should be constructed in areas with longitudinal slopes of less than 4% but preferably less than 2%. Check dams can be used to reduce the effective slope of the swale and lengthen the contact time to enhance filtering and/or infiltration.<br><br>Steeper slopes adjacent to and upstream of the swale can generate rapid runoff velocities into the swale that may carry a high sediment loading (refer to pre-treatment criteria in Section 6.4). Likewise, steep slopes adjacent to the downstream edge may be subject to saturation and failure. For sites with steep slopes, P-CNV-04 Regenerative Soil Stabilization Conveyance may be more appropriate to provide stormwater treatment. |
| Contributing Drainage Area | The maximum CDA to a dry swale should be 5 acres but preferably less. When dry swales treat larger drainage areas, the velocity of flow through the surface channel often becomes too great to treat runoff or prevent erosion in the channel. Similarly, the longitudinal flow of runoff through the soil, stone, and underdrain may cause hydraulic overloading at the downstream sections of the dry swale. An alternative is to provide a series of inlets or diversions that convey the treated water to an outlet location. Inlets and diversions should match the same design criteria as dry swales. |
| Available Hydraulic Head | Dry swales area fundamentally constrained by the invert elevation of the downstream conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the dry swale into the storm drain system). In general, 3 to 4 feet of elevation above this outlet invert, plus the longitudinal slope of the linear dry swale, is needed to create the hydraulic head needed to drive stormwater through the proposed filter bed. Less hydraulic head is needed if the underlying soils are permeable enough to dispense with the underdrain. |
| Depth to Water Table | Designers should ensure that the bottom of the dry swale is at least 1 foot above the seasonally high groundwater table to ensure that groundwater does not intersect the filter bed because this could lead to groundwater contamination or practice failure. |
| Depth to Bedrock | 2 feet vertical separation. |

| Table P-CNV-02-2 Dry Swale Feasibility Criteria | |
|---|---|
| **Criteria** | **Details** |
| Soils | Soil conditions do not constrain the use of dry swales, although they normally determine whether an underdrain is needed. Low-permeability soils with an infiltration rate of less than 0.5 inch per hour, such as those classified in Hydrologic Soil Groups (HSG) C and D, will usually require an underdrain. Designers must verify site-specific soil permeability at the proposed location using the methods for on-site soil investigation presented in Appendix C Soil Characterization and Infiltration Testing in order to eliminate the requirements for an underdrain. |
| Utilities | Interference with underground utilities should be avoided, particularly water and sewer lines. Designers should consult local utility design guidance for the horizontal and vertical clearance between utilities and the swale configuration. Likewise, the routing of other utilities (such as phone, cable, electric) through dry swales should be avoided in order to minimize disturbance of the utilities or the swale during the maintenance of either. |
| Avoidance of Irrigation or Baseflow | Dry swales should be located to avoid inputs of springs, irrigation systems, chlorinated wash water, or other dry weather flows. |
| Setbacks | Given their landscape position, dry swales are not subject to normal building setbacks. The bottom elevations of swales should be at least 1 foot below the invert of an adjacent road bed. To avoid seepage and frost heave concerns, dry swales should not be hydraulically connected to structure foundations or pavement. Setbacks to structures and roads may vary based on the conditions (see Table P-CNV-02-3).<br><br>Expected effluent concentrations of typical urban runoff (total phosphorus [TP], total nitrogen [TN], metals) from dry swales are reported by the International BMP Database and are considered to be acceptable in terms of groundwater impacts provided that the feasibility factors of water table, hot spot land uses, and karst (Section 7) are met. However, if groundwater contamination is a concern, groundwater mapping is recommended to determine possible connections to adjacent groundwater wells. |

| Table P-CNV-02-3 Dry Swale Setback and Offset Guidance | | |
|---|---|---|
| **Feature** | **Recommended Offset*** | **Notes** |
| Existing buildings, retaining walls, bridge supports, and other such structures. | 1H:1V zone of influence | Closer offsets may be considered on a case-by- case basis where impermeable liners are specified by the designer. |
| Sewer mains | 2V:1H zone of influence | In most cases, these will run parallel. |
| Sewer laterals | 5 feet horizontal, 12 to 18 inches vertical | |
| Water mains | 5 feet horizontal | |

| Table P-CNV-02-3 Dry Swale Setback and Offset Guidance | | |
|---|---|---|
| **Feature** | **Recommended Offset*** | **Notes** |
| Large utilities | 10 feet horizontal, 18 inches vertical | Includes water transmission mains, high-pressure gas mains, large conduits. |
| Utility lines, service lines (not otherwise specified above) | 3 feet horizontal, 12 to 18 inches vertical | Coordination with utilities required where offsets cannot be achieved. |
| Existing inlets | 5 feet horizontal | Closer offsets may be considered on a case-by- case basis. |
| Telephone poles, utility poles, traffic signals, or comparable | 5 feet horizontal | |

| Table P-CNV-02-4 Environmental and Community Concerns | |
|---|---|
| **Concern** | **Details** |
| Hot Spot Land Use | Runoff from hot spot land uses should not be treated with infiltrating dry swales (i.e., constructed without an underdrain). For a list of potential stormwater hot spots, please consult P-FIL-04 Infiltration Practices. An impermeable liner should be used for filtration of hot spot runoff. |
| Community Acceptance | Common community concerns with dry swales include the continued ability to mow grass, landscape preferences, weeds, standing water, and mosquitoes. Dry swales are a positive stormwater management alternative because these concerns can be fully addressed through the design process and proper ongoing operation and routine maintenance. If dry swales are installed on private lots, homeowners will need to be educated on their routine maintenance needs, must understand the long-term maintenance plan, and may be subject to a legally binding Maintenance Agreement (see Section 9). The short ponding time of 6 hours is much less than the time required for one mosquito breeding cycle, so well-maintained dry swales should not create mosquito problems or be difficult to mow. The local government my require placement of dry swales in a drainage or maintenance easement in order to ensure long-term maintenance. |

## 4.0 Stormwater Performance Summary

The primary pollutant removal mechanisms operating in swales are settling, filtering, infiltration, and plant uptake. The overall stormwater functions of the dry swale are summarized in Table P-CNV-02-5.

| Table P-CNV-02-5 Summary of Stormwater Functions Provided by Dry Swales | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Volume Reduction (RR) | 40% | 60% |
| TP Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process | 20% | 40% |

| Table P-CNV-02-5 Summary of Stormwater Functions Provided by Dry Swales | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| TP Mass Load Removal | 52% | 76% |
| TN EMC Reduction[1] by BMP Treatment Process | 25% | 35% |
| TN Mass Load Removal | 55% | 74% |
| Channel Protection | Use the Virginia Runoff reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment<br>OR<br>Design for extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm and use Natural Resources Conservation Service (NRCS) TR-55 Runoff Equations to compute the CN Adjustment. | |
| Flood Mitigation | Partial. Reduced CNs and time of concentration | |

1. Change in the EMC through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the Introduction to the New Virginia Stormwater Design Specifications). NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a CN Adjustment for larger storm events based on the retention storage provided by the practice(s).

## 5.0 Design Criteria

| Table P-CNV-02-6 Dry Swale Design Criteria | |
|---|---|
| **Level 1 Design** | **Level 2 Design** |
| Sizing:<br>Surface Area (sq. ft.) = (Tv– the volume reduced by an upstream BMP)/Storage depth[1] | Sizing:<br>Surface Area (sq. ft.) = {(1.1)(Tv) – the volume reduced by an upstream BMP}/Storage Depth[1] |
| Effective swale slope < 4% | Effective swale slope < 2% |
| Media Depth: minimum = 18 inches;<br>Recommended maximum = 36 inches | Media Depth minimum = 24 inches<br>Recommended maximum = 36 inches |
| Sub-soil testing: min. infiltration rate must be > 0.5 inch/hour to remove the underdrain requirement | Sub-soil testing: one soil profile and two infiltration tests for dry swales up to 50 linear feet; add one additional infiltration test for dry swales up to 100 linear feet; min. infiltration rate must be > 0.5 inch/hour to remove the underdrain requirement |
| Underdrain: Schedule 40 PVC with clean-outs | Underdrain and Underground Storage Layer: Schedule 40 PVC with clean-outs, and a minimum 12-inch stone sump below the invert; *OR*<br>none if the soil infiltration requirements are met |
| Media: supplied by the vendor; tested for an acceptable hydraulic conductivity (or permeability) and phosphorus content[3] | |

| Table P-CNV-02-6 Dry Swale Design Criteria | |
|---|---|
| **Level 1 Design** | **Level 2 Design** |
| Inflow: sheet or concentrated flow with appropriate pre-treatment | |
| Pre-Treatment (Support Component P-SUP-06 Pre-Treatment): a pre-treatment cell, grass filter strip, gravel diaphragm, gravel flow spreader, or another approved (manufactured) pre-treatment structure. | |
| On-line/off-line shall be based on available space. | |
| Turf cover | Turf cover with trees and shrubs |
| Building Setbacks:[4]<br>10 feet if downgradient from building or level (coastal plain); 50 feet if upgradient. | |

1. The storage depth is the sum of the void ratio (Vr) of the soil media and gravel layers multiplied by their respective depths, plus the surface ponding depth (Refer to Section 6.1).
2. The effective swale slope can be achieved using check dams – 12-inchheight maximum.
3. Refer to P-FIL-05 Bioretention for soil specifications.
4. These are recommendations for simple building foundations. If an in-ground basement or other special conditions exist, the design should be reviewed by a licensed engineer. Also, a special footing or drainage design may be used to justify a reduction of the setbacks noted above.

### 5.1 Sizing of Dry Conveyance and Dry Treatment Swales

Sizing of the surface area (SA) for dry swales is based on the computed BMP design treatment volume (TvBMP). The TvBMP is treatment volume based on the CDA, less any volume reduced by upstream runoff reduction practices. The required surface area (in square feet) is computed as the TvBMP (in cubic feet) divided by the equivalent storage depth (in feet). The equivalent storage depth is computed as the depth of the soil media, the gravel, and surface ponding (in feet) multiplied by the accepted porosity.

The accepted porosity ($\eta\eta$) for each of the materials is (see Figure P-CNV-02-1):

Dry Swale Soil Media $\eta\eta$ = 0.25

Gravel $\eta\eta$ = 0.40

Surface Storage behind check dams $\eta\eta$ = 1.0

The equivalent storage depth for the Level 1 design (without considering surface ponding) is therefore computed as:

***Equation P-CNV-02-1. Dry Swale Level 1 Design Storage Depth***

$$(1.5 \text{ ft.} \times 0.25) + (0.25 \text{ ft.} \times 0.40) = 0.5 \text{ ft.}$$

The equivalent storage depth for the Level 2 design (without considering surface ponding) is computed as:

***Equation P-CNV-02-2. Dry Swale Level 2 Design Storage Depth***

$$(2.0 \text{ ft.} \times 0.25) + (1.0 \text{ ft.} \times 0.40) = 0.9 \text{ ft}$$

The effective storage depths will vary according to the actual design depths of the soil media and gravel layer.

Equations P-CNV-02-3 or P-CNV-02-4 are used to calculate the required SA of the Level 1 and Level 2 swales described in Equations 1 and 2. If the dry swale includes check dams to decrease the effective swale longitudinal slope or to create storage volume, it is recommended that the designer estimate the design width of the swale and compute the storage volume retained by the check dams, and subtract it from the TvBMP of the dry swale. This will be an iterative computation if the design width of the dry swale is different than that used to estimate the surface storage. Figure P-CNV-02-2 illustrates the storage volume created by 12-inch check dams on a Level 1 dry swale with a longitudinal slope of 3 percent (to create an effective longitudinal slope of 2 percent).

The Level 1 Dry Swale SA is computed as:

***Equation P-CNV-02-3. Dry Swale Level 1 Design SA***

SA (sq. ft.) = (*TvBMP* – volume of surface storage)/0.5 ft.

The Level 2 Dry Swale SA is computed as:

***Equation P-CNV-02-4. Dry Swale Level 2 Design SA***

SA (sq. ft.) = [(1.1 * *TvBMP*) – volume of surface storage)/0.9 ft.

Where:

SA = Minimum surface area of dry swale (sq. ft.)

*TvBMP* = BMP design Treatment Volume (cu. ft.) = [(1.0 in.)(Rv)(A)] / 12

(NOTE: Rv = the composite volumetric runoff coefficient from Appendix B VRRM Guidance)

The final dry swale design geometry will be determined by dividing the SA by the swale length to compute the required width or by dividing the SA by the desired width to compute the required length.

### 5.2 Sizing for Stormwater Quantity

In order to accommodate a greater stormwater quantity credit for channel protection or flood control, designers may be able to create additional surface storage by expanding the surface ponding behind the check dams. This can be accomplished by either increasing the number of check dams or by expanding the swale width at selected areas. However, the expanded surface storage footprint is limited to the ponding area directly behind the check dams and to twice the channel bottom width. Care must be taken to ensure that: (1) the check dams are properly entrenched into the side slopes of the swale and (2) adequate overflow capacity is provided over the weir.

### 5.3 Hydraulic Capacity

Dry swales designed as an on-line practice must be designed with enough capacity to: (1) convey runoff from the 2-year storm at a non-erosive velocity and (2) contain the 10-year flow within the banks of the swale. This means that the swale's surface dimensions are more often determined by the need to pass the 10-year storm event, which can be a constraint in the siting of dry conveyance swales within existing rights-of-way (e.g., constrained by sidewalks). Dry swales can be designed as an off-line practice by using periodic diversion or overflow structures to take the runoff that exceeds the design TvBMP to an alternative conveyance system.

### 5.4 Soil Infiltration Rate Testing

The second key sizing decision is to measure the infiltration rate of subsoils below the dry swale area to determine if an underdrain will be needed and to ensure the practice can infiltrate the design storm. The infiltration rate of the subsoil must exceed 0.5 inch per hour to avoid installation of an underdrain. The acceptable methods for on-site soil infiltration rate testing are outlined in Appendix C Soil Characterization and Infiltration Testing. One soil profile and one infiltration (permeability) test should be conducted for each dry swale. Add one infiltration test for dry swales between 50 and 100 linear feet, and for dry swales longer than 100 linear feet, add one soil profile for each additional 100 linear feet and one infiltration test conducted for each additional 50 linear feet of the swale.

### 5.5 Dry Swale Geometry

Design guidance regarding the geometry and layout of dry swales is provided below.

**Table P-CNV- 02-7 Design Layout and Geometry**

| Parameter | Details |
|---|---|
| Shape | Typical dry swale design references a trapezoidal shape. Construction typically results in a slightly rounded or parabolic shape and is acceptable for aesthetic, maintenance, and hydraulic reasons; however, the boundary of the soil filter area must be within the bottom area of the constructed swale. In either case, the design is simplified by assuming a trapezoidal cross-section. |
| Side Slopes | The side slopes of dry swales should be no steeper than 3H:1V. Flatter slopes (5H:1V) are recommended where adequate space is available to enhance pre-treatment of sheet flows entering the swale and for maintenance considerations (i.e., mowing). |
| Width | Swales should have a minimum bottom width of 2 feet as required to achieve the design flow depth and velocity requirements. If a swale will be wider than 6 feet, the designer should consider off-line treatment cells or additional internal pre-treatment such as gravel diaphragms, check dams, and level spreaders. |
| Swale Longitudinal Slope | The longitudinal slope of the swale should be moderately flat to permit the temporary ponding of the Tv within the channel. The recommended swale slope is a maximum of 4% for a Level 1 design and no more than 1% for a Level 2 design. The minimum slope for both levels of design is 0.5%. A dry swale designed with a longitudinal slope less than 1% may be restricted by the locality. The minimum recommended slope for an on- line dry swale is 0.5%. An off-line dry swale may be designed with a longitudinal slope of less than 0.5% and function similar to a bioretention practice, although this option may be limited by the locality. Refer to Table P-CNV-02-8 for check dam spacing based on the swale longitudinal slope. |

| Table P-CNV- 02-7 Design Layout and Geometry | |
|---|---|
| **Parameter** | **Details** |
| Check Dams | Check dams are constructed of timbers, concrete, gabions, or other durable (non- erodible) material and hold pockets of runoff at the swale surface that will eventually filter through the soil media to the underdrain. Check dams should meet the following criteria:<br>• Check dams must be firmly anchored into the side slopes to prevent outflanking during the maximum design flow (typically the 10-year frequency event unless designed to be an off-line practice).<br>• Earthen check dams should be used where space allows.<br>• The height of the check dam relative to the normal channel elevation should not exceed 12 inches.<br>• The top weir of each check dam should include a contained overflow section (depressed weir) to pass the design storms safely (no erosion or outflanking) (see Figure P-CNV-02-6).<br>• Armoring may be needed on the downhill side of the check dam overflow section to prevent erosion. The combined overflow section and armoring must be designed to spread runoff evenly over the dry swale's filter bed surface. |
| Soil Plugs | Soil plugs help minimize the potential for blow-out of the soil media underneath the check dams due to hydrostatic pressure from the upstream ponding. Soil plugs are appropriate for dry swales: (1) on slopes of 4% or greater, or (2) with 12-inch-high check dams. |

| Table P-CNV-02-8 Typical Check Dam Spacing to Achieve Effective Swale Slope | | | | |
|---|---|---|---|---|
| **Swale Longitudinal Slope** | **LEVEL 1** | **LEVEL 2** | | |
| | **Spacing [1] of 12-inch-high (max.) Check Dams [2, 3] to Create an Effective Slope of 2%** | **Spacing [1] of 12-inch-high (max.) Check Dams [2, 3] to Create an Effective Slope of** | | |
| | | **0** | **to** | **1%** |
| 0.5% | – | 200 ft. | to | – |
| 1.0% | – | 100 ft. | to | – |
| 1.5% | – | 67 ft. | to | 200 ft. |
| 2.0% | – | 50 ft. | to | 100 ft. |
| 2.5% | 200 ft. | 40 ft. | to | 67 ft. |
| 3.0% | 100 ft. | 33 ft. | to | 50 ft. |
| 3.5% | 67 ft. | 30 ft. | to | 40 ft. |
| 4.0% | 50 ft. | 25 ft. | to | 33 ft. |
| 4.5% [4] | 40 ft. | 20 ft. | to | 30 ft. |

| Table P-CNV-02-8 Typical Check Dam Spacing to Achieve Effective Swale Slope | | | | |
|---|---|---|---|---|
| Swale Longitudinal Slope | LEVEL 1 | LEVEL 2 | | |
| | Spacing [1] of 12-inch-high (max.) Check Dams [2, 3] to Create an Effective Slope of 2% | Spacing [1] of 12-inch-high (max.) Check Dams [2, 3] to Create an Effective Slope of | | |
| | | 0 | to | 1% |
| 5.0% [4] | 40 ft. | 20 ft. | to | 30 ft. |

**Notes:**

1. The spacing dimension is half of the distances identified in the table if a 6-inch check dam is used.
2. A check dam requires a stone energy dissipater at its downstreamtoe.
3. Check dams require weep holes at the channel invert. Swales with slopes less than 2 percent will require multiple weep holes (at least three) in each check dam.
4. Dry conveyance swales and treatment swales with slopes greater than 4 percent require special design considerations, such as drop structures, to accommodate greater than 12-inch-high check dams (and therefore a flatter effective slope) in order to ensure non-erosive flows.

| Table P-CNV-02-9 Drawdown and Ponding Design | |
|---|---|
| **Parameter** | **Details** |
| Ponding Depth | Drop structures or check dams can be used to create ponding cells along the length of the swale. The maximum ponding depth in a swale should not exceed 12 inches at the most downstream point. |
| Drawdown | Dry swales should be designed so that the desired Tv is completely filtered within 6 hours or less. This drawdown time can be achieved using the soil media mix specified in Section 6.6 and an underdrain along the bottom of the swale, or native soils with adequate permeability, as verified through testing. |
| Underdrain | Underdrains are provided in dry swales to ensure that they drain properly after storms.<br>• The underdrain should have a minimum diameter of 4 inches (or larger as required by the Tv design flow) and be encased in a 12-inch-deep gravel bed.<br>• Two layers of stone should be used. A choker stone layer consisting of #8 or #78 stone at least 3 inches deep should be installed immediately below the filter media. Below the choker stone layer, the main underdrain layer should be at least 12 inches deep and composed of 1-inch double-washed stone.<br>• The underdrain pipe should be set at least 4 inches above the bottom of the stone layer. |

### 5.6 Pre-Treatment

Dry swales provide pre-treatment at each point of concentrated inflow and along the length of the contributing impervious surface. Refer to P-SUP-06 Pre-Treatment for design details and specifications. Provide pre-treatment for a water quality for dry swales.

Pre-treatment for a *Dry Conveyance Swale* takes the form of a grass filter strip (minimum 10 ft. wide) along the length of the contributing impervious cover. Pre-treatment for a *Dry Treatment Swale* is required at the inflow points along the length of the dry swale to trap coarse sediment particles before they reach the filter bed to prevent premature clogging. Several pre-treatment measures are feasible depending on whether the specific location in the dry swale system will be receiving sheet flow, shallow concentrated flow, or fully concentrated flow:

***Initial Sediment Forebay*** (channel flow). This grass cell is located at the upper end of the dry swale segment, usually formed with check dams, and should have a 2:1 length-to-width ratio and a storage volume equivalent to at least 15 percent of the total Tv.

***Tree Check Dams*** (channel flow). These are street tree mounds placed within the bottom of a dry swale up to an elevation of 9 to 12 inches above the channel invert. One side has a gravel or river stone bypass to allow storm runoff to percolate through.

***Grass Filter Strip*** (sheet flow). Grass filter strips extend from the edge of the pavement to the bottom of the dry swale at a 5:1 slope or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5 percent (20:1) slope and 3:1 or flatter side slopes on the dry swale (See Figure P-CNV-02-3).

***Gravel Diaphragm*** (sheet flow). A gravel diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff with a 2- to 4-inch drop. The stone must be sized according to the expected rate of discharge (See Figure P-CNV-02-8).

***Pea Gravel Flow Spreader*** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points and should have a 2- to 4-inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the swale (See Figure P-CNV-02-9).

### 5.7 Conveyance and Overflow

The swale should also convey the locally required design storms (usually the 2-year storm at a non-erosive velocity and the 10-year storm within the banks with at least 3 inches of freeboard). The analysis should evaluate the flow profile through the channel at normal depth as well as the flow depth over the tops of the check dams. Refer to P-CNV-01 Grass Channels for design criteria pertaining to maximum velocities and depth of flow.

A dry swale may be designed as an off-line system with a flow splitter or diversion to divert runoff that exceeds the design capacity to an adjacent conveyance system. Alternatively, strategically placed overflow inlets may be placed along the length of the swale to periodically pick up water and reduce the hydraulic loading at the downstream limits.

### 5.8 Filter Media

Dry swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the dry swale. At least 18 inches of soil media should be added above the choker stone layer to create an acceptable filter. The recipe for the soil media is identical to that used for bioretention and is provided in Table P-CNV-02-5 (refer to P-FIL-05 Bioretention for additional soil media specifications). The soil media should be certified by the supplier as meeting the intent of the soil specifications as described in Section 6.6 of Specification P-FIL-05 Bioretention.

### 5.9 Underdrain and Underground Storage Layer

Some Level 2 dry swale designs will not use an underdrain (where soil infiltration rates meet minimum standards. For Level 2 designs with an underdrain, an underground storage layer consisting of a minimum 12 inches of stone should be incorporated below the invert of the underdrain (Refer to P-FIL-05 Bioretention for additional information on the use of an "upturned elbow" to create the infiltration sump). The depth of the storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria. However, the bottom of the storage layer must be at least 2 feet above the seasonally high groundwater table. The storage layer should consist of clean, washed #57 stone or an approved infiltration module.

A dry swale should include observation wells with cleanout pipes at regular frequency along the length of the swale. The wells should be tied into any T's or Y's in the underdrain system and should extend upwards to be flush with surface with a vented cap.

**5.10 Landscaping and Planting Plan**

Designers should choose native grasses, herbaceous plants, or trees that can withstand both wet and dry periods and relatively high-velocity flows for planting within the channel, refer to Appendix G for suggestions on plant species. Salt-tolerant grass species should be chosen for dry swales located along roads. Taller and denser grasses are preferred, although the species is less important than good stabilization and dense vegetative cover. Grass species should have the following characteristics: a deep root system to resist scouring, a high stem density with well-branched top growth, water tolerance, resistance to being flattened by runoff, and an ability to recover growth following inundation. To find a list of plant species suitable for use in dry swales, consult the Virginia Erosion and Sediment Control Handbook.

**5.11 Regional and Special Case Design Adaptations**

| Table P-CNV-02-10 Regional and Special Case Design Adaptations | |
|---|---|
| **Parameter** | **Details** |
| Karst Terrain | Shallow dry swales are an acceptable practice in karst areas. To prevent sinkhole formation and possible groundwater contamination, dry swales should use impermeable liners and underdrains or must be subject to sheet flow only and use an armored level spreader where outfall enters the BMP. Channelized flow through a dry swale is discouraged in karst areas. Therefore, Level 2 dry swale designs that rely on infiltration are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland 2005).<br><br>If a dry swale facility is located in an area of sinkhole formation, standard setbacks to buildings should be increased. |
| Coastal Plain | The flat terrain, low head, and high water table of many coastal plain sites can constrain the application of dry swales (particularly Level 2 designs). Swales perform poorly in extremely flat terrain because they lack enough grade to ensure positive drainage. However, the use of multiple storage cells can help conserve hydraulic head, relying on the underdrain to drain at a minimal slope to the drainage system. In these situations, the following design adaptations apply:<br><br>• The minimum depth to the seasonally high groundwater table from the invert of the system can be 1 foot as long as the dry swale is equipped with a large diameter underdrain (6-inch diameter or more).<br><br>• A minimum underdrain slope of 0.5% should be maintained to ensure positive drainage.<br><br>• The underdrain should be tied into the drainage ditch system.<br><br>• If the surface cover is to be landscaped with plants (as opposed to turf), the mix of plant species selected should reflect coastal plain plant communities and should be more wet-footed and salt-tolerant than those used in typical Piedmont applications.<br><br>While these design criteria permit use of dry swales on a wider range of coastal plain sites, it is important to avoid installing dry swales on marginal sites. Dry swales must have a 1-foot separation between the groundwater table and the invert of the system. Other stormwater practices, such as wet swales, ditch wetland restoration, and smaller linear wetlands, are preferred alternatives for coastal plain sites. |
| Steep Terrain | In areas of steep terrain, dry swales can be implemented with contributing slopes of up to 20% gradient as long as a multiple cell design is used to dissipate erosive energy prior to filtering. This can be accomplished by terracing a series of dry swale cells to manage runoff across or down a slope. The drop in elevation between cells should be limited to 1 foot and armored with river stone or a suitable equivalent. A greater emphasis on properly engineered energy dissipaters and/or drop structures is warranted. |

| Table P-CNV-02-10 Regional and Special Case Design Adaptations | |
|---|---|
| **Parameter** | **Details** |
| Cold Climate and Winter Performance | Dry swales can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is applied within the CDA, dry swales should be planted with salt-tolerant non-woody plant species. Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC 2005). The underdrain pipe should also extend below the frost line and be oversized by one pipe size to reduce the chances of freezing. |
| Linear Highway Sites | Dry swales are a preferred stormwater practice for linear highway sites. The design should be broken into multiple cells with outlets or overflow points to avoid large single areas of flow through the swale. Also, salt-tolerant grass and/or plant species should be selected if salt compounds will be used to de-ice the contributing roadway in the winter. |
| Linear Utility Sites | Dry swales may be a feasible but not preferred stormwater practice suitable to treat runoff within fully vegetated utility rights-of-way or easements, as they may require acquisition of additional land adjacent to the utility corridor. |

## 6.0 Construction Specifications

### 6.1 Typical Details

Figure P-CNV-02-2 through Figure P-CNV-02-9 provide typical schematics for dry swales.

### 6.2 Dry Swale Material Specifications

Table P-CNV-02-11 outlines the standard material specifications for constructing dry swales.

| Table P-CNV-02-11 Dry Swale Material Specifications | |
|---|---|
| **Material** | **Specification** |
| Filter Media Composition | P-FIL-05 Bioretention |
| Filter Media Testing | P-FIL-05 Bioretention |
| Surface Cover | P-FIL-05 Bioretention |
| Pretreatment | P-SUP-06 Pre-Treatment |
| Filter Fabric | P-FIL-05 Bioretention and P-FIL-06 Filtering Practices<br>Designer should choose appropriate filter fabric for the individual applications. For hot spots and certain karst sites only, use an appropriate liner on the bottom. |
| Choking Layer | P-FIL-05 Bioretention<br>Designer should use a choking layer that is laid above the underdrain stone. |

| Table P-CNV-02-11 Dry Swale Material Specifications | |
|---|---|
| **Material** | **Specification** |
| Stone Jacket and/or Storage Layer | P-FIL-05 Bioretention<br><br>9- to 18-inch layer (depending on the desired depth of storage) of 1-inch stone should be double-washed, clean, and free of all fines (e.g., Virginia Department of Transportation [VDOT] #57 stone). |
| Underdrains, Cleanouts, and Observation Wells | P-FIL-05 Bioretention<br><br>Install perforated pipe for the full length of the dry swale cell. Use non-perforated pipe, as needed, to connect with the storm drain system. |
| Vegetation | C-SSM-10 Permanent Seeding and P-FIL-05 Bioretention<br><br>Seeding should be applied in the manner and method specified in P-FIL-05 Bioretention. The plant species should comply with the plant list on the landscape plan for the project. |
| Check Dams | C-SCM-07 Rock Check Dam and P-SUP-06: Pre-Treatment<br><br>Check dams should be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric conforming to local design standards. Wood used for check dams should consist of pressure-treated logs or timbers or water-resistant tree species such as cedar, hemlock, swamp oak, or locust. |
| Erosion Control Fabric | C-SSM-05 Soil Stabilization Blankets and Matting<br><br>Grass channels should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the channel bed and banks. Where flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least two growing seasons. |

### 6.3 Construction Sequence for Dry Swales

***Construction Stage Erosion and Sediment Controls (ESCs):*** Dry swales should be fully protected by silt fence or construction fencing, particularly if they will provide an infiltration function (i.e., have no underdrains). Ideally, dry swale areas should remain outside the limits of disturbance during construction to prevent soil compaction by heavy equipment.

Dry swale locations may be used for small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the ESC plan specifying that the maximum excavation depth of the sediment trap/basin at the construction stage must: (1) be at least 1 foot above the depth of the post-construction dry swale installation; (2) contain an underdrain; and (3) specify the use of proper procedures for conversion from a temporary practice to a permanent one including de-watering, cleanout, and stabilization.


*Dry swale in operation too early in construction sequence.*
*Photo Credit: Hirschman Water & Environment, LLC*

The following is a typical construction sequence to properly install a dry swale, although the steps may be modified to adapt to different site conditions.

***Step 1: Protection during Site Construction:*** As noted above, dry swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical given that swales are a key part of the drainage system at most sites. In these cases, temporary ESCs, such as dikes, silt fences, and other similar measures, should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, erosion control fabric should be used to protect the channel, and excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain. Dry swales that lack underdrains (and rely on filtration) must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction.

***Step 2:*** Grading of the dry swale in preparation of installation of the gravel, underdrain, and soil media should begin only after the entire contributing drainage area has been stabilized by vegetation or runoff has been diverted away from the area. The designer and the installer should have a preconstruction meeting, checking the boundaries of the CDA and the actual inlet elevations to ensure they conform to original design. Because other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage, and paving elevations that can produce hydraulically important differences for the proposed dry swale. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

***Step 3:*** Identify any additional ESCs that may be needed during swale construction, particularly to divert stormwater from the dry swale, until the filter bed and side slopes are fully stabilized.

***Step 4:*** Pre-treatment cells should be excavated first to trap sediments before they reach the planned filter beds.

***Step 5:*** Excavators or backhoes should work from the sides to excavate the dry swale area to the appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the dry swale area.

***Step 6:*** The bottom of the dry swale should be ripped, roto-tilled, or otherwise scarified to promote greater infiltration.

***Step 7:*** Place an acceptable filter fabric on the underground (excavated) sides of the dry swale with a minimum 6-inch overlap. Place the stone needed for storage layer over the filter bed. Perforate the underdrain pipe and check its slope. Add the remaining stone jacket, and then pack #57 stone to 3 inches above the top of the underdrain. Finally, add 3 inches of pea gravel as a filter layer.

***Step 8:*** Obtain the soil media from a qualified vendor and store it on an adjacent impervious area or plastic sheeting. After verifying that the media meets the specifications, add the soil media in 12-inch lifts until the desired top elevation of the dry swale is achieved. Wait a few days to check for settlement and add media as needed.

***Step:*** Install check dams, driveway culverts, and internal pre-treatment features as specified in the plan.

***Step 10:*** Prepare planting holes for specified trees and shrubs, install erosion control fabric where needed, spread seed or lay sod, and install any temporary irrigation.

***Step 11:*** Plant landscaping materials as shown in the landscaping plan and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

***Step 12:*** Conduct a final construction inspection and develop a punch list for facility acceptance. Log the global positioning system (GPS) coordinates for each bioretention facility and submit them for entry into the local BMP tracking database.

### 6.4 Construction Inspection

Inspections are needed during construction to ensure that the dry swale practice is built in accordance with these specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction to ensure that the contractor's interpretation of the plan is consistent with the designer's intent. An example construction phase inspection checklist for dry swales is provided at the end of this specification.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of dry swale installation.

- Check the filter media to confirm that it meets specifications and is installed to the correct depth.
- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the filter beds and their contributing side slopes.
- Inspect check dams and pre-treatment structures to make sure they are properly installed and working effectively.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.
- Upon final acceptance, the GPS coordinates should be logged for all dry swales and submitted for entry into the local BMP maintenance tracking database.

The real test of a dry swale occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows, or fully concentrated flows assumed in the plan occur in the field. Also, inspectors should check that the dry swale surface drains completely within 6 hours after a storm. Minor adjustments are normally needed as a result of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or outfalls, and check dam realignment).

### 6.5 Sample Construction Inspection Checklist for Dry Swales

The following checklist provides a basic outline of the anticipated items for the construction inspection of dry swales. This checklist does not necessarily distinguish between the use of an infiltration sump below an underdrain or an infiltration sump with an "upturned elbow." Similarly, design variations between Level 1 and Level 2 dry swales and different configurations of check dams may not be clearly identified in this checklist. Inspectors should review the plans carefully and adjust these items and the timing of inspection verification as needed to ensure the intent of the design is met. Finally, users of this information may wish to incorporate these items into a Virginia Stormwater Management Program (VSMP) Authority

Construction Checklist format consistent with that used for ESC and BMP construction inspections.

#### 6.5.1 Pre-Construction Meeting

- Pre-construction meeting with the contractor designated to install the dry swale has been conducted.
- The tentative schedule for construction has been identified, and the requirements and schedule for interim inspections and sign-off have been verified.
- Subsurface investigation and soils report support the placement of a dry swale in the proposed location.
- Impervious cover has been constructed/installed, and the area is free of construction equipment, vehicles, material storage, and other equipment.
- All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation, and erosion control measures have been removed.
- Area of the dry swale has not been impacted during construction.
- Stormwater has been diverted around the area of the dry swale, and perimeter erosion control measures to protect the facility during construction have been installed.

### 6.5.2 Excavation

- Compare the dry swale surface and invert design elevations with the actual constructed elevations of the inflow and outlet inverts and adjust design elevations as needed.
- Confirm that the area of dry swale excavation is marked, and the size and location conforms to plan.
- If the excavation area has been used as a sediment trap, verify that the bottom elevation of the proposed stone reservoir is lower than the bottom elevation of the existing trap.
- For Level 2 dry swale, ensure the bottom of the excavation is scarified before placement of stone.
- Subgrade surface is free of rocks, roots, and large voids. Any voids should be refilled with the base aggregate to create a level surface for the placement of aggregates and underdrain (if required).
- No groundwater seepage or standing water is present. Any standing water is dewatered to an acceptable dewatering device.
- Excavation of the dry swale has achieved proper grades, longitudinal slope, and the required geometry and elevations without compacting the bottom of the excavation.
- **Certification of Excavation Inspection**: Inspector certifies the successful completion of the excavation steps listed above.

### 6.5.3 Filter Layer, Underdrain, and Stone Reservoir Placement

- All aggregates, including, as required, the filter layer (choker stone and sand), the stone reservoir layer, or infiltration sump, conform to specifications as certified by quarry.
- Underdrain size and perforations meet the specifications.
- For Level 2 installations, placement of filter layer and initial lift of stone reservoir layer aggregates with underdrain or infiltration sump are spread (not dumped) to avoid aggregate segregation; or
- Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturers' specifications.
- Sides of excavation are covered with geotextile, when required, before placing stone reservoir aggregate; no tears, holes, or excessive wrinkles are present.
- Placement of underdrain, observation wells, and underdrain fittings (e.g., 45-degree wyes, cap at the upstream end) are in accordance with the approved plans.

- Elevations of underdrain and outlet structure are in accordance with approved plans or as adjusted to meet field conditions.
- Remaining lift of stone reservoir layer is placed as needed to achieve the required reservoir depth.
- **Certification of Filter Layer and Underdrain Placement Inspection**: Inspector certifies the successful completion of the filter layer and underdrain placement steps listed above.

### 6.5.4 Dry Swale Soil Media Placement

- Soil media is certified by supplier or contractor as meeting the project specifications.
- Soil media is placed in 12-inch lifts to the design top elevation of the dry swale. Elevation has been verified after settlement (2 to 4 days after initial placement).
- Side slopes of ponding or flow area are feathered back at the required slope (no steeper than 3H:1V).
- Dry swale length, bottom width, side slopes, and longitudinal slope are in accordance with the approved plans.
- **Certification of Soil Media Placement Inspection**: Inspector certifies the successful completion of the soil media steps listed above.

### 6.5.5 Pre-treatment and Check Dam Installation

- Energy dissipators and pre-treatment practices (e.g., forebays, gravel diaphragms) are installed in accordance with the approved plans.
- Riser, overflow weir, or other outflow structure is set to the proper elevation and functional; or
- External bypass structure is built in accordance with the approved plans.
- Appropriate number and spacing of check dams is installed in accordance with the approved plans (verification of energy dissipators at downstream toe, depth keyed into dry swale flow line, and tied back into dry swale side slopes).
- Erosion control matting is applied as required by approved plans or as needed to ensure adequate stabilization.
- All external ESC practices have been removed.
- Follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all dry swale installations on the parcel.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the dry swales, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- All dry swales must include a long-term Maintenance Agreement consistent with the provisions of the VESMP Regulations and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When dry swales are applied on private residential lots, homeowners should be educated by being provided a simple document that explains their purpose and routine maintenance needs.

- A deed restriction, drainage easement, or other mechanism enforceable by the VESMP Authority must be in place to help ensure that dry swales are maintained and not converted or disturbed as well as to pass the knowledge along to any subsequent owners.
- The mechanism should, if possible, grant VESMP Authority access the property for inspection or corrective action.

### 7.2 First Year Maintenance Operations

Initial and subsequent annual inspections trigger maintenance operations such as sediment removal, spot revegetation, and inlet stabilization. The following is a list of several key maintenance inspection points:

**Table P-CNV-02-12 Maintenance Inspection Items**

| Activity | Details |
|---|---|
| Initial Inspections | For the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 0.5 inch of rainfall. |
| Spot Reseeding | Inspectors should look for bare or eroding areas in the contributing drainage area or around the dry swale area and make sure they are immediately stabilized with grass cover. |
| Fertilization | One-time, spot startup fertilization may be needed for initial seed and/or plantings. |
| Watering | Depending on the time of year of initial planting, watering is needed once a week during the first 2 months, and then as needed during the first growing season (April through October) depending on rainfall. |

#### 7.2.1 Maintenance Inspections

Ideally, inspections of dry swales should be conducted in the spring of each year.

- Check to see if 90 percent turf cover or vegetation density has been achieved in the bed and banks of the dry swale.
- Check for sediment buildup at curb cuts, gravel diaphragms, or pavement edges that prevents flow from entering the dry swale, and check for other signs of bypassing.
- Check for any winter- or salt-killed vegetation.
- Check inflow points for clogging or accumulated sand, sediment, and trash and remove it.
- Inspect dry swale side slopes and grass filter strips for evidence of any rill or gully erosion and repair it.
- Check the dry swale for evidence of excessive ponding or concentrated flows and take appropriate remedial action.
- When sediment accumulation is noted, look for any bare soil or sediment sources in the CDA and stabilize them immediately.
- Check for clogged or slow-draining soil media, a crust formed on the top layer, inappropriate soil media, or other causes of insufficient filtering time and restore proper filtration conditions.
- Inspect upstream and downstream of check dams for evidence of undercutting or erosion and remove trash or blockages at weep holes.

Example maintenance inspection checklists for dry swales are included in Chapter 10.

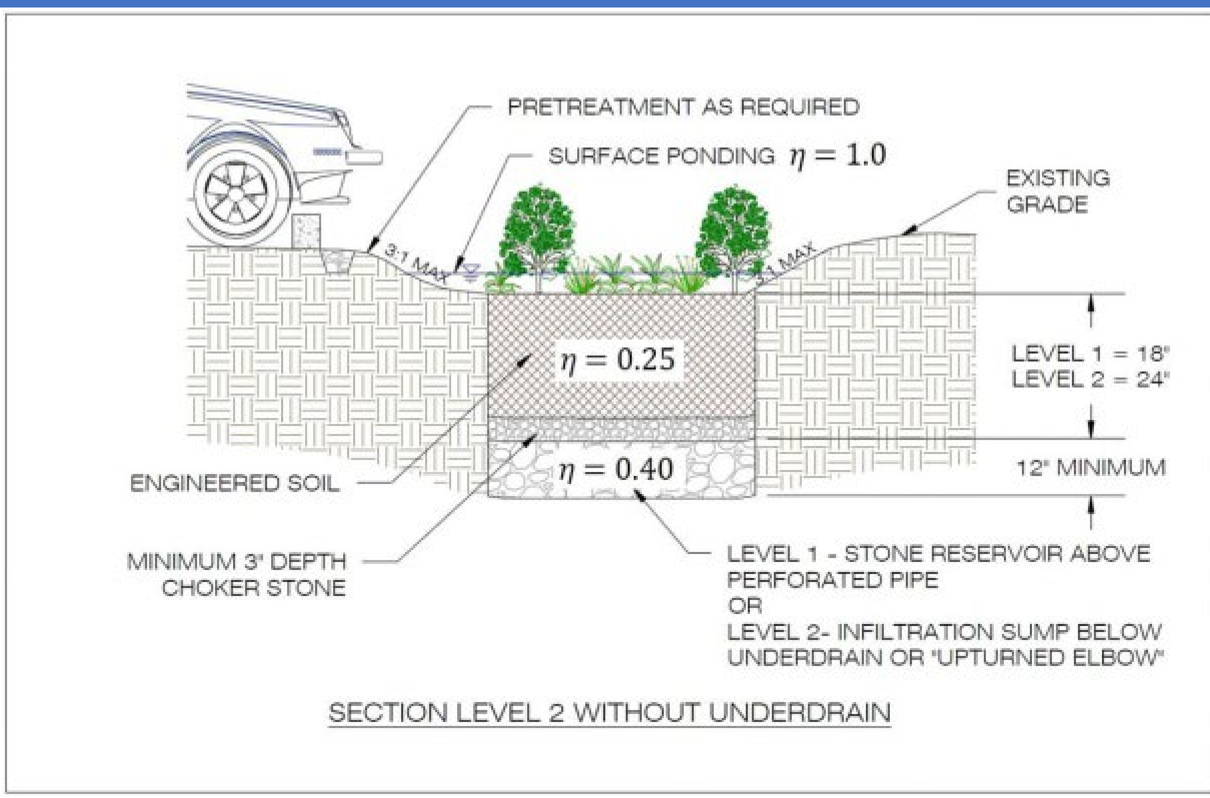
### 7.2.2 Maintenance and Operation

Once established, dry swales have minimal maintenance needs outside of the spring cleanup, regular mowing, and pruning and management of trees and shrubs.

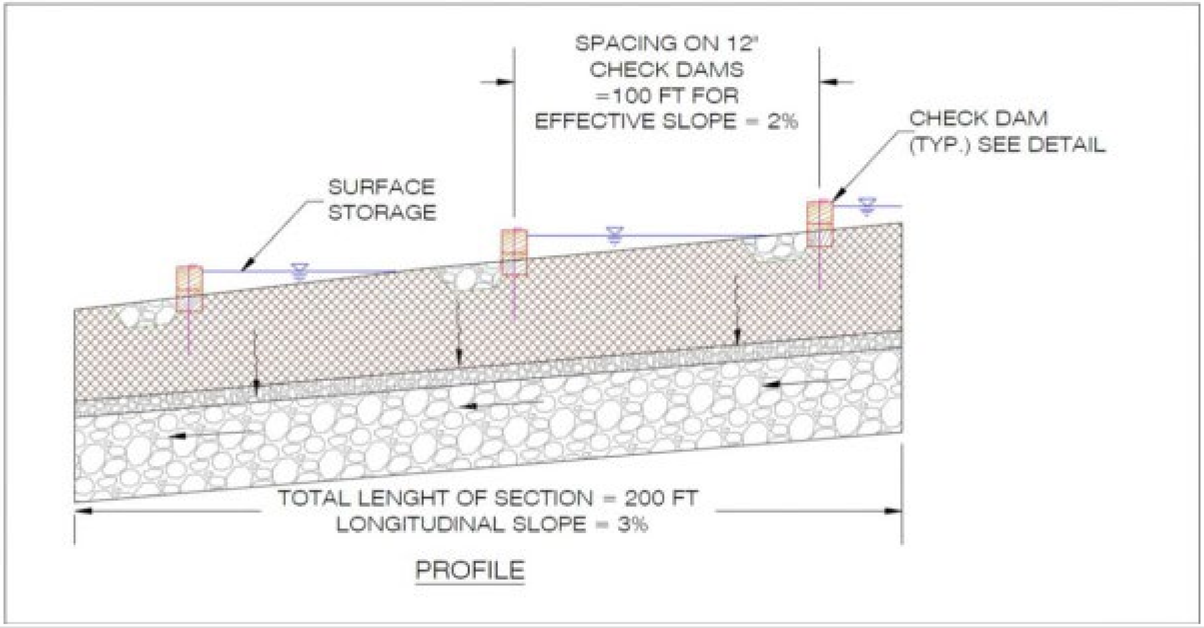
The most common non-routine maintenance problem involves standing water. If water remains on the surface for more than 48 hours after a storm, adjustments to the grading, rehabilitation of the surface infiltration, or underdrain repairs may be needed. The following represents an easiest-to-hardest selection of possible solutions:

- The surface of the filter bed can become clogged with fine sediment over time. This will be evidenced by accumulated sediment, a fine crust that builds up after the first several storm events, or cracking of the surface sediment layer. Remove accumulated sediment and till 2 to 3 inches of sand into the upper 8 to 12 inches of soil.
- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicate standing water, then the underdrain must be clogged and will need to be snaked.
- If evidence indicates that a soil layer is clogged, install sand wicks from 3 inches below the surface to the underdrain layer by excavating or augering (using a tree auger or similar tool) down to the gravel storage zone to create vertical columns, which are then filled with a clean open-graded coarse sand material (coarse sand mix similar to the gradation used for the soil media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- Last resort - remove and replace some or all of the soil media.

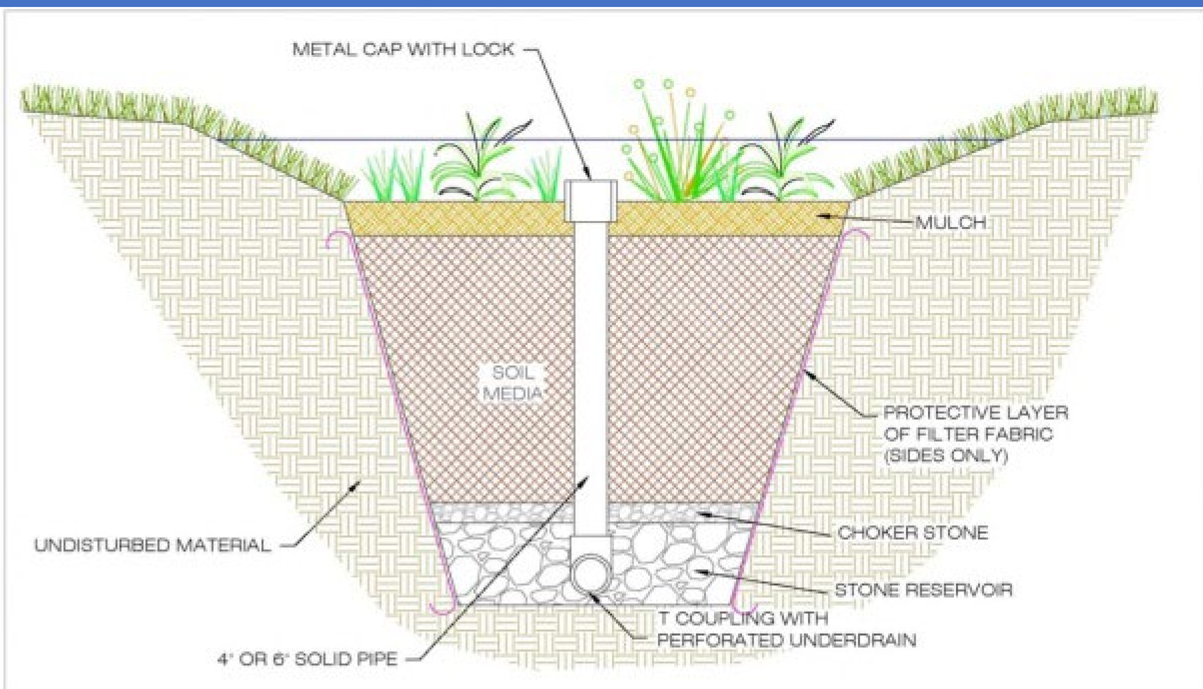
***Figure P-CNV-02-1 Dry Swale Section with Porosity for Volume Computations***



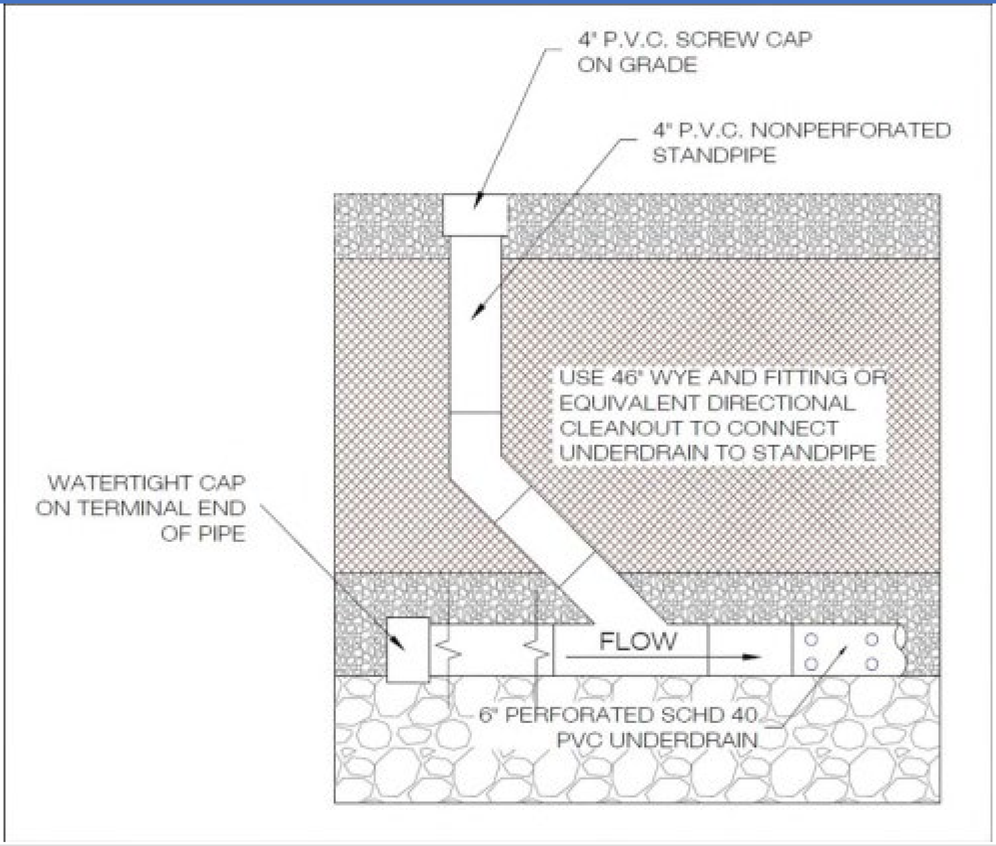
## Figure P-CNV-02-2 Spacing of Check Dams for Surface Storage and Effective Slope




## Figure P-CNV-02-3 Dry Swale Observation Well



## *Figure P-CNV-02-4 Dry Swale Underdrain Cleanout*



## Figure P-CNV-02-5 Typical Details for Level 1 and 2 Dry Swales

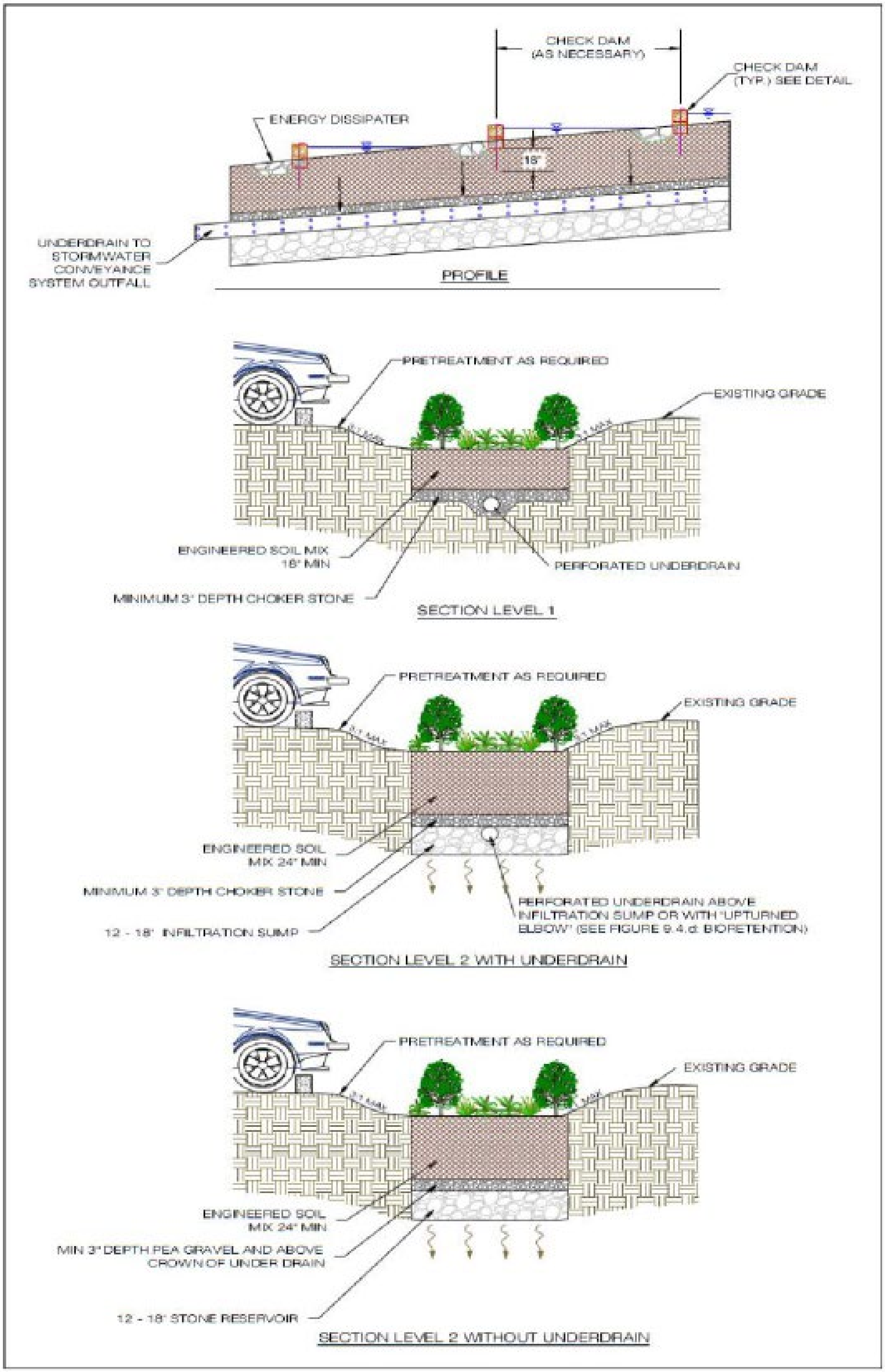


**Figure P-CNV-02-6 Typical Detail for Dry Swale Check Dam**

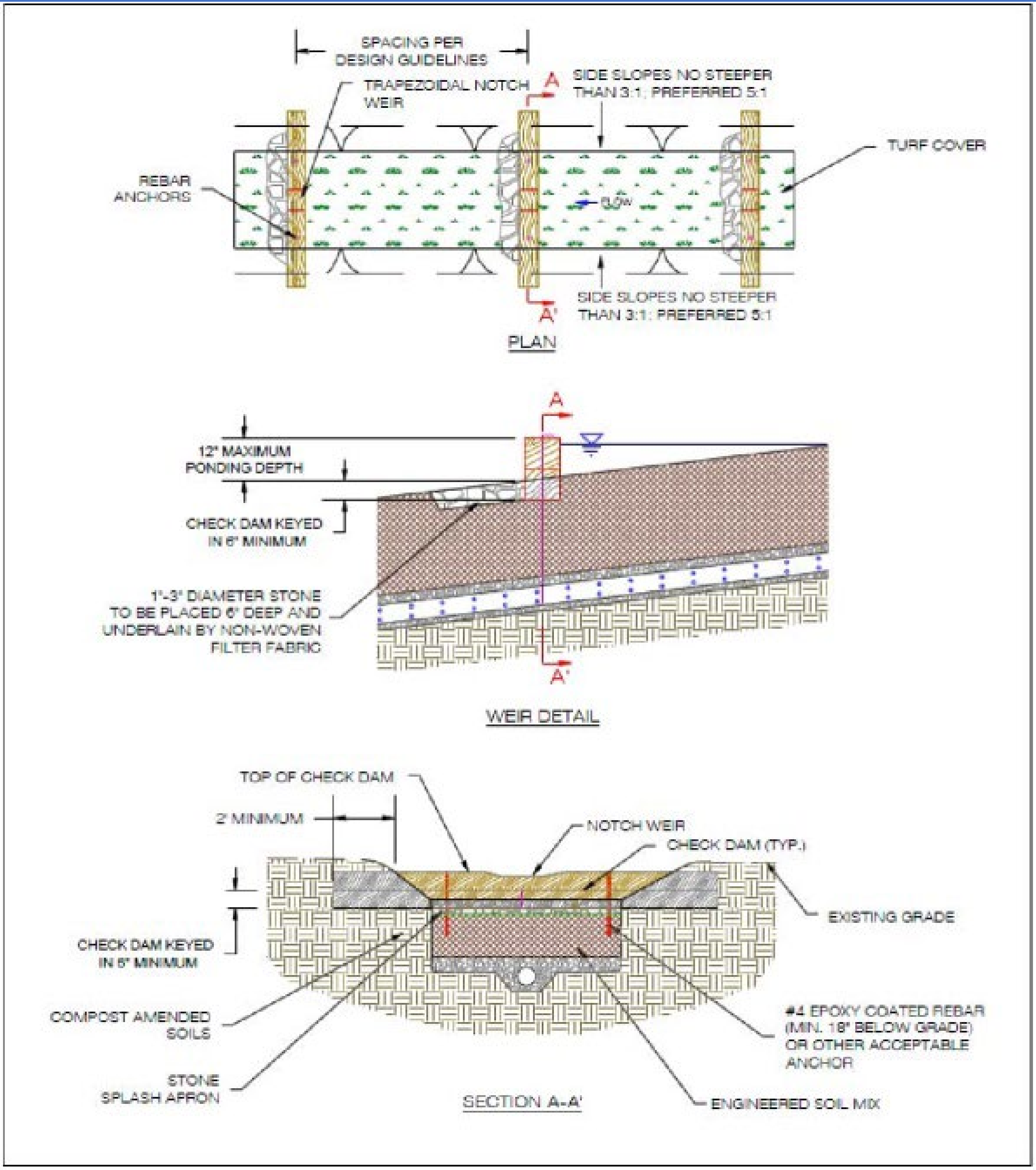


**Figure P-CNV-02-7a Pretreatment I – Grass Filter for Sheet Flow**

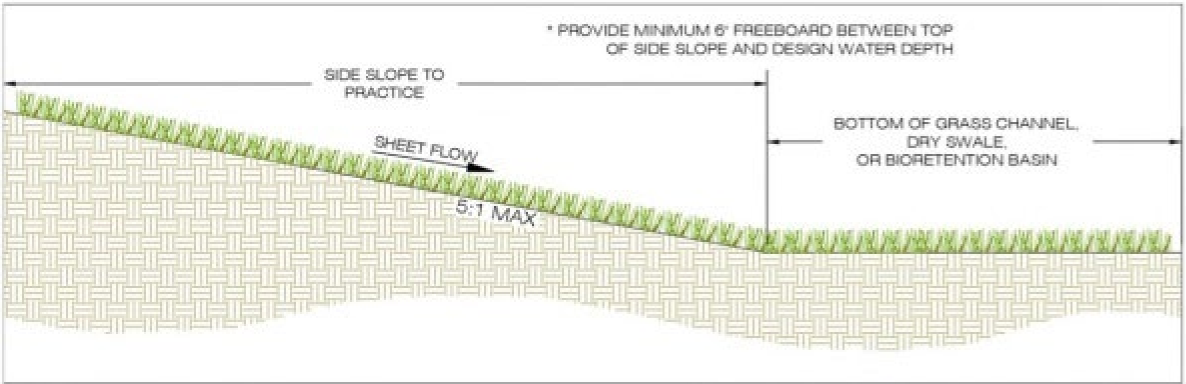



**Figure P-CNV-02-7b Pretreatment II – Grass Filter for Sheet Flow**


**Figure P-CNV-02-8 Pre-treatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious**

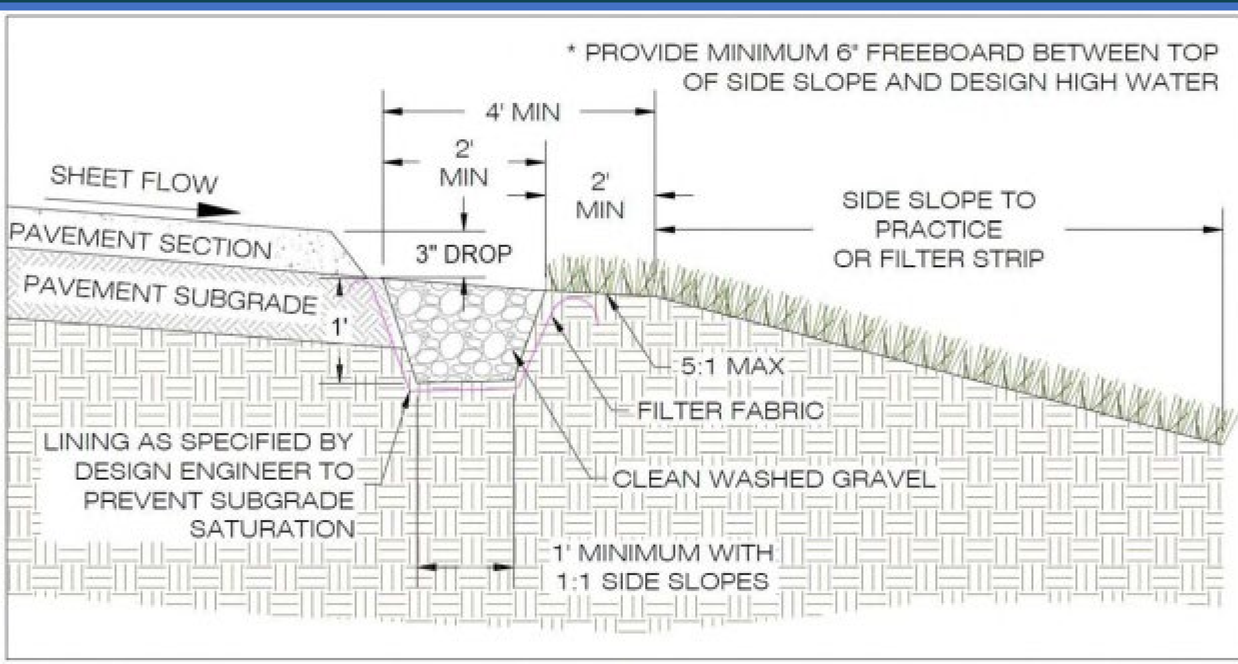
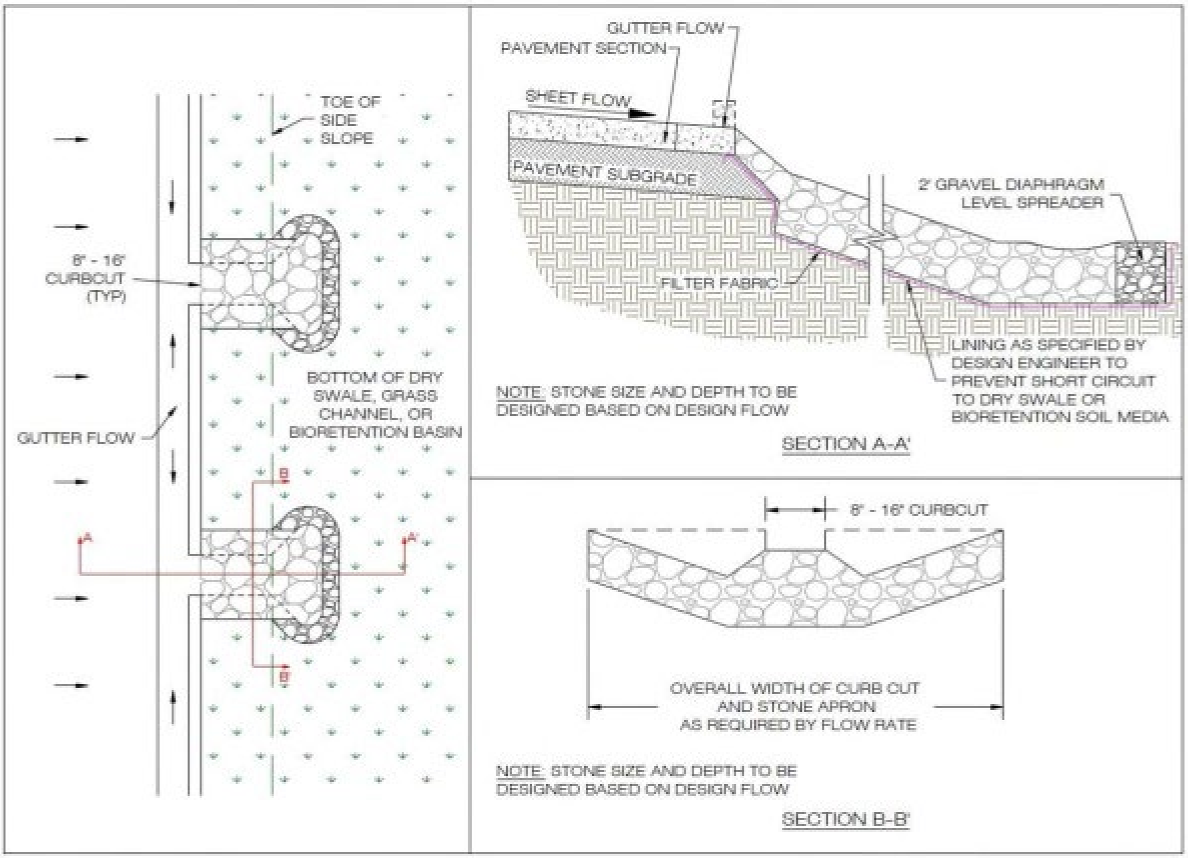


**Figure P-CNV-02-9 Pre-Treatment – Gravel Flow Spreader for Concentrated Flow**




## 8.0 References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# P-CNV-03 Wet Swales

## 1.0 Definition

Wet swales are a cross between a wetland and a swale that can filter and treat runoff within a stormwater conveyance system. Linear on-line or off-line wetland cells are formed within the channel to intercept shallow groundwater or retain runoff and create saturated soil or shallow standing water conditions (typically less than 6 inches deep) to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity.

## 2.0 Purpose and Applicability of Best Management Practice

Wet swales are ideal for placement where the water table is close to the ground surface or where water does not positively drain out of the swale. A wet swale acts as a very long and linear shallow biofiltration or linear wetland system (MPCA 2022). Designers should note that a wet swale does not provide a runoff volume reduction credit and is therefore typically the final element in the roof-to-stream pollutant removal sequence.

Wet swales may be constructed as a form of pre-treatment for larger infiltration best management practices (BMPs) and/or for managing the remaining pollutant removal required after all other upland runoff reduction options have been considered and properly credited.

## 3.0 Planning and Considerations

The feasibility criteria outlined in Table P-CNV-03-1 should be evaluated when designing a wet swale:

**Table P-CNV-03-1 Summary of Feasibility Criteria for Wet Swales**

| Parameter | Details |
|---|---|
| Contributing Drainage Area | The maximum contributing drainage area (CDA) to a wet swale should not exceed 5 acres, preferably less, to avoid excessive flowrates. |
| Space Required | Wet swale footprints typically cover approximately 5% of their CDA depending on the CDA's impervious cover. |
| Site Topography | Site topography constrains wet swales; while some gradient is needed to provide positive drainage through the system, wet swales generally work best on sites with relatively flat slopes (less than 2% gradient).<br><br>A modification of the wet swale is the regenerative stormwater conveyance (RSC). The RSC can be used to bring stormwater down steeper grades through a series of step pools. Refer to BMP P-CNV-04 Regenerative Stormwater Conveyance. |
| Depth to Water Table | In general, it is permissible for wet swales to intersect the water table. However, some source water protection requirements may define a separation distance if there is a sensitive underlying aquifer. |
| Soils | Wet swales work best on the more impermeable Hydrologic Soil Group (HSG) C or D soils. |
| Karst Topography | If wet swales are used in karst areas, an impermeable liner should be installed. |

| Table P-CNV-03-1 Summary of Feasibility Criteria for Wet Swales | |
|---|---|
| **Parameter** | **Details** |
| Hydraulic Capacity | When a wet swale is used as an on-line practice (Level 1 design), it must be designed with enough capacity to convey peak runoff from the 1-, 2-, and 10-year design storms. This means that the surface dimensions are largely determined by the need to pass these larger storm events.<br><br>When a wet swale is used as an off-line practice (Level 2 design), a bypass or diversion structure must be designed to divert the large storm (e.g., when the flowrate and/or volume exceeds the treatment volume [Tv] to an adequate channel or conveyance system). The wet swale is then designed to provide the required volume and meet the velocity and residence time criteria for the Tv.<br><br>Conveyance Velocity. Wet swales should be designed for non-erosive flow velocities within the swale and at the outlet point to reduce downstream erosion. During the 10-year storm, discharge velocity should be kept below 4 feet per second for established vegetated channels. Erosion control matting or rock lining should be specified if higher velocities are anticipated. |
| Hot Spot Land Uses | Wet swales are not recommended to treat stormwater hot spots due to the potential interaction with the water table and the risk that hydrocarbons, trace metals, and other toxic pollutants could migrate into the groundwater. For a list of designated stormwater hot spots, consult BMP P-FIL-04 Infiltration Practices. |
| Highway Runoff | The linear nature of wet swales make them well suited to treat highway or low- and medium-density residential road runoff if there is adequate right-of-way width and distance between driveways. |

## 4.0 Stormwater Performance Summary

While wet swales do not reduce runoff volume, they do provide moderate pollutant removal depending on their design (see Table P-CNV-03-2). Wet swales are particularly well suited for the flat terrain and high water table of the Coastal Plain and can be an excellent choice for pre-treatment.

| Table P-CNV-03-3 Summary of Stormwater Functions Provided by Wet Swales | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Volume Reduction (RR) | 0% | 0% |
| Total Phosphorus (TP) Event Mean Concentration (EMC) Reduction[1] by BMP Treatment Process | 20% | 40% |
| TP Mass Load Removal | 20% | 40% |
| Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process | 25% | 35% |
| TN Mass Load Removal | 25% | 35% |

| Table P-CNV-03-3 Summary of Stormwater Functions Provided by Wet Swales | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Channel Protection | Limited – reduced time of concentration; and partial detention volume can be provided above the treatment volume (*Tv*) within the allowable maximum ponding depth. | |
| Flood Mitigation | Limited | |

1. Change in EMC through the practice.

Sources: CWP and CSN 2008, CWP 2007

## 5.0 Design Criteria

The major design goal for wet swales is to maximize nutrient removal via two levels of design, shown in Table P-CNV-03-3.

| Table P-CNV- 03-4 Wet Swale Design Criteria | |
|---|---|
| **Level 1 Design (RR:0; TP:20; TN:25)** | **Level 2 Design (RR:0; TP:40; TN:35)** |
| Tv = [(1 inch)(Rv)(A)] / 12 – the volume reduced by an upstream RR BMP | Tv = [(1.25 inch)(Rv)(A)] / 12 – the volume reduced by an upstream RR BMP |
| Swale slopes less than 2%[1] | Swale slopes less than 1%[1] |
| On-line design | Off-line swale cells |
| Minimal planting; volunteer vegetation | Wetland planting within swale cells |
| Turf cover in buffer | Trees, shrubs, and/or ground cover within swale cells and buffer |

1. Wet swales are generally recommended only for flat Coastal Plain conditions with a high water table. A linear wetland is always preferred to a wet swale. However, check dams or other design features that lower the effective longitudinal grade of the swale can be applied on steeper sites to comply with these criteria.

### 5.1 Sizing of Wet Swales

Wet swales should be designed to capture and treat the Tv remaining from the upstream runoff reduction practices.

Runoff treatment credit can be taken for any temporary or permanent storage created within each wet swale cell. This includes the permanent wet storage below the normal pool level and up to 12 inches of temporary storage created by check dams or other design features.

Designers must also demonstrate that on-line wet swales also have sufficient capacity beyond the Tv to safely convey the larger design storm events. Refer to the hydraulic design methods outlined in BMP P-CNV-01 Grass Channels.

### 5.2 Swale Pre-treatment and Geometry

The wet swale should follow the general design guidance contained in Sections 5.2 and 5.3 of BMP P-CNV-01 Grass Channels.

### 5.3 Other Design Issues for Wet Swales

- The average normal pool depth (dry weather) throughout the swale should be 6 inches or less.

- The maximum temporary ponding depth in any single wet swale cell should not exceed 12 inches at the most downstream point (e.g., at a check dam or driveway culvert). Nominal additional flow depth is acceptable during storm events to pass the larger storms.
- Check dams should be spaced as needed to maintain the effective longitudinal slope identified for the Level 1 or Level 2 design. A typical plan and profile for the check dams is provided on Figure P-CNV-03-1. Refer to Section 6.4 of BMP P-CNV-01 Grass Channels for additional information on check dams.
- Individual wet swale segments formed by check dams or driveways should generally be at least 25 feet long.
- Wet swale side slopes should be no steeper than 4H:1V to enable wetland plant growth. Flatter slopes are encouraged where adequate space is available to enhance pre-treatment of sheet flows entering the channel.

### 5.4 Planting Wet Swales

Designers should choose grass and wetland plant species that can withstand both wet and dry periods as well as relatively high-velocity flows within the channel. For a list of wetland plant species suitable for use in wet swales, refer to the wetland planting guidance and plant lists provided in BMP P-BAS-01 Constructed Wetlands. If roadway salt will be applied to the contributing drainage area, swales should be planted with salt-tolerant, non-woody plant species such as creeping bent grass or switchgrass (PDEP 2006). Bluegrass should be avoided in swales where salt loading is high (NCDEQ 2020). Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC 2005).

### 5.5 Material Specifications

Consult Section 6.7 of BMP P-CNV-01 Grass Channels for criteria pertaining to suitable materials for check dams and other swale features.

*Wet Swale in Coastal Area*
*Photo Credit: Hirschman Water & Environment, LLC*

| Region | Details |
|---|---|
| Karst Terrain | Wet swales are generally feasible in karst terrain with the installation of an impermeable liner. |
| Coastal Plain | Wet swales work well in areas of high water table and consist of a series of on-line or off-line storage cells. Designers should design cells such that the underlying soils are typically saturated but do not cause standing water between storm events. It may also be advisable to incorporate sand or compost into surface soils to promote a better growing environment. Wet swales should be planted with wet-footed species such as sedges or wet meadows. Wet swales are not recommended in residential areas due to concerns about mosquito breeding. |

## 6.0 Construction Specifications

Consult the construction criteria outlined in Section 8 of both BMP P-CNV-01 Grass Channels and in BMP P-BAS-01 Constructed Wetlands. An example construction phase inspection checklist for wet swales is provided at the end of this specification.

Upon final inspection and acceptance, the global positioning system (GPS) coordinates should be logged for all wet swales and submitted for entry into the local BMP maintenance tracking database.

### 6.1 Typical Details

Figure P-CNV-03-1 shows a typical plan for a wet swale with check dams. Figure P-CNV-03-2 provides a typical profile and section.

**Figure P-CNV-03-1 Wet Swale with Check Dams**

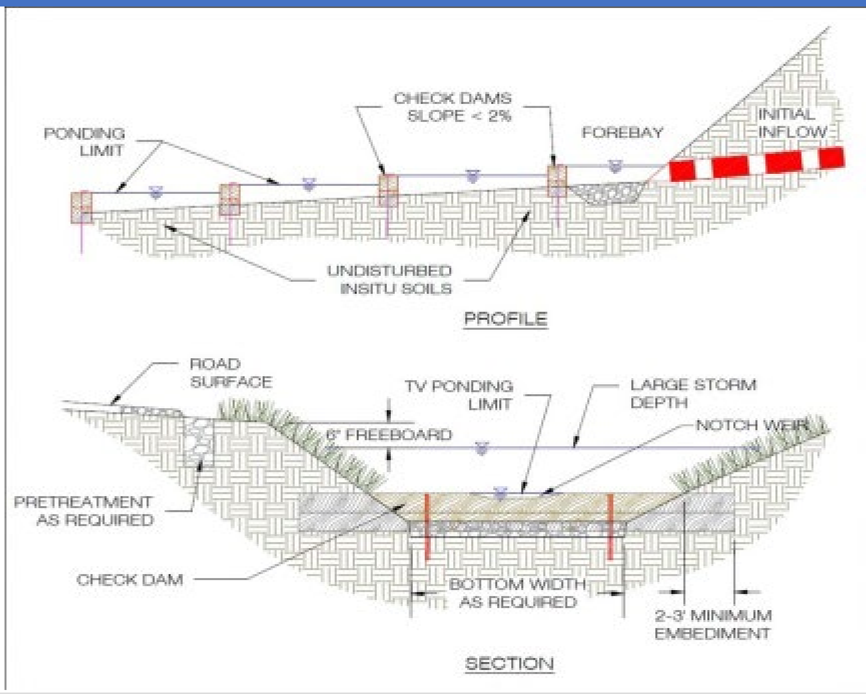
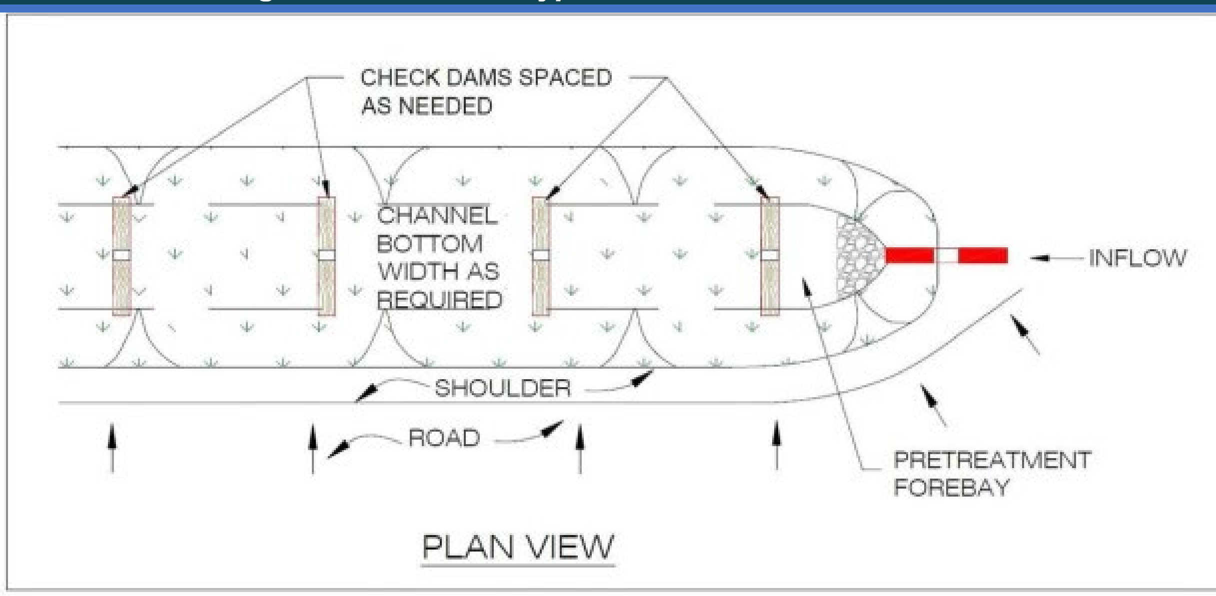



**Figure P-CNV-03-2 Typical Wet Profile and Section**




## 7.0 Operations and Maintenance Considerations

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of wet swales, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All wet swales must include a long-term Maintenance Agreement consistent with the provisions of the VESMP Regulation and must include the recommended maintenance tasks and a copy of an annual inspection checklist.

When wet swales are located on individual private residential lots, homeowners will need to be educated regarding their routine maintenance needs.

A deed restriction, drainage easement, or other mechanism enforceable by the VESMP Authority must be in place to help ensure that wet swales are maintained as well as to pass the knowledge along to any subsequent owners.

The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action. Where wet swales are designed to convey runoff from multiple lots or properties, a drainage easement that ensures the access for purposes of inspections and corrective actions must be provided.

Wet swales have maintenance needs like dry swales, although woody wetland vegetation may need to be removed periodically. Please consult the maintenance criteria outlined in Section 9 of BMP P-CNV-01 Grass Channels, BMP P-CNV-02 Dry Swales, and BMP P-BAS-01 Constructed Wetlands. Example maintenance inspection checklists for wet swales are provided in Chapter 10

### 7.1 Community and Environmental Concerns

The main concerns of adjacent residents are perceptions that wet swales will create nuisance conditions or will be difficult to maintain. Common concerns include the continued ability to mow grass; landscaping preferences; and the risks of unsightly weeds, standing water, and mosquitoes breeding. For these reasons, wet swales are not recommended in residential settings.

### 7.2 Sample Construction Inspection Checklist for Wet Swales

The following checklist provides a basic outline of the anticipated items for the construction inspection of wet swales. Many inspection elements will mirror those of constructed wetlands. Inspectors should review the plans carefully and adjust these items and the timing of inspection verification as needed to ensure the intent of the design and the inspection is met. Finally, users of this information may incorporate these items into a VSMP Authority Construction Checklist format consistent with that used for erosion and sediment control and BMP construction inspections.

#### 7.2.1 Pre-Construction Meeting

- Pre-construction meeting with the contractor designated to install the wet swale practice has been conducted.
- The tentative schedule for construction has been identified, and the requirements and schedule for interim inspections and sign-off have been verified.
- Subsurface investigation and soils report supports the placement of a wet swale practice in the proposed location.
- Impervious cover has been constructed/installed and area is free of construction equipment, vehicles, material storage, and other project components.
- All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation, and erosion control measures have been removed.

- **Certification of Stabilization Inspection:** Inspector certifies that the drainage areas are adequately stabilized in order to convert the drainage conveyance feature (if used for sediment control or diversion) into a wet swale.

#### 7.2.2 Excavation of Wet Swale

- Stormwater has been diverted around the area of the wet swale to a stabilized conveyance, and perimeter erosion control measures to protect the facility during construction have been installed.
- Materials (e.g., wetland soils and plants, erosion control materials such as stone, soil stabilization matting) are available.
- Construction of the wet swale geometry (including bottom width, side slopes, check dams, weir overflow and outlet protection) is in accordance with approved plans.
- Excavation of internal micro-topographic features (e.g., earthen check dams, tree check dams, forebays) is in accordance with approved plans.
- Installation of pre-treatment, including forebays, gravel diaphragms, energy dissipators, is in accordance with the approved plans.
- Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturers specifications.
- Placement of wetland soils and amendments is in accordance with approved plans.
- **Certification of Excavation Inspection:** Inspector certifies that the excavation has achieved all the appropriate grades, grade transitions, and wet swale geometry as shown on the approved plans.

#### 7.2.3 Wetland Plantings and Stabilization

- Exposed soils on swale bottom and side slopes are stabilized with seed mixtures, stabilization matting, and mulch in accordance with approved plans.
- External bypass structure is built in accordance with the approved plans.
- Appropriate number and spacing of plants are installed and protected in accordance with the approved plans.
- All erosion and sediment control practices have been removed.
- Follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all wet swale installations on the parcel.

## 8.0 References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# P-CNV-04 Regenerative Stormwater Conveyance

***Figure P-CNV-04-1 Newly constructed regenerative stormwater conveyance Chesterfield County Complex***

*Source: Chesterfield County*

## 1.0 Definition

Regenerative stormwater conveyances (RSCs) treat and convey stormwater through a combination of sand, wood chips, native vegetation, riffles (with either cobble rocks or boulders), and shallow pools. RSCs are designed to convey water while minimizing the effects of erosion.

## 2.0 Purpose and Applicability of Best Management Practice

RSC systems are best management practices (BMPs) designed to restore incised and eroded channels, ditches, outfalls, ephemeral streams, and in certain cases, perennial streams. These BMPs are constructed with a series of shallow pools, riffles, cascades, weirs, and outfalls that dissipate stormwater runoff energy and allow for temporary ponding, internal storage, and infiltration. The temporary ponding area of an RSC provides settling time for total suspended solids. The wood chip/sand layer provides filtration as well as an environment conducive to the growth of microorganisms that degrade hydrocarbons and organic material. Both woody and herbaceous plants in the ponding area provide vegetative uptake of runoff and pollutants, and also serve to stabilize the surrounding soils.

RSC systems are usually used to retrofit or repair an existing channel. They can be designed to receive stormwater runoff from up to 50 acres, usually highly impervious. They can also be designed for new construction projects and roadway designs when site conditions allow. RSC system can receive relatively high volume and rates of runoff, as they must be sized for safe passage of the 100-year storm event. Designers should consider the importance of native herbaceous and woody vegetation in the function of an RSC system and ensure that the design can support the necessary landscaping.

### 2.1 Feasibility/Limitations

The following feasibility criteria should be evaluated when RSCs are considered as the final practice in a treatment train. Many of these items will be influenced by the type of RSCs being considered (refer to Design Applications at the end of this section).

**Table P-CNV-04-1 Feasibility Criteria**

| Parameter | Details |
|---|---|
| Drainage Area | 50 acres or less |
| Depth to Water Table and Bedrock | Shallow ponding areas should include storage volume beyond the seasonally high groundwater table to allow for temporary ponding in a majority of the pools and storage of the water quality volume. |
| Site Slope | RSCs can be used on moderate to steep slopes. However, longitudinal slopes of 5% or less are recommended. |
| Karst Terrain | RSC systems have largely been used in coastal plain settings but could be adapted to karst with certain design considerations. While RSC produces shallower ponding than conventional stormwater practices (e.g., ponds and wetlands), designs that infiltrate a lot of water through the sand/woodchip bed into underlying groundwater are not recommended in any area with a moderate or high risk of sinkhole formation (Hyland 2005). On the other hand, RSC designs that meet a 3-foot separation distance to karst bedrock features and/or contain an impermeable bottom liner may work well. However, because RSCs are placed within existing drainage systems, it may be difficult to avoid proximity to bedrock in some places. In general, smaller-scale RSC systems are advisable in karst areas, and geotechnical studies should be conducted to ascertain structural suitability. |
| Soils | No soil restrictions. |

| Table P-CNV-04-1 Feasibility Criteria | |
|---|---|
| **Parameter** | **Details** |
| Tailwater Conditions | The flow depth in the receiving channel should be considered when determining pool elevations and discharge rates from the RSC. Design tailwater condition elevation will be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a high tide elevation evaluation will accompany the tailwater condition evaluation. |
| Tidal Impacts | The designer must investigate the receiving reach and design the RSC so that it discharges into a pool segment of the receiving stream or to tidal water. For projects that discharge to tidal waters, the RSC should discharge to mean lower low water to ensure the long-term resiliency of the BMP during different tidal ranges and storm events. |
| Perennial Streams | RSCs are located within perennial streams only where the practice is being used to restore eroded and incised streams and will require Section 401 and Section 404 permits from the appropriate state or federal regulatory agencies. |

| Table P-CNV-04-2 RSC Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and other such structures | 25 feet horizontal | Closer offsets may be considered on a case-by- case basis. |
| Property lines | 10 feet horizontal | |
| Septic system drain fields | 50 feet horizontal | |
| Private water wells | 50 feet horizontal | |
| Proximity to utilities | Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. Approval from the applicable utility company or agency is required if utility lines will run below or through the RSC system. Conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered as necessary to avoid impacts to existing service. | |
| * Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the top of bank of the RSC pools and riffle channel sections. | | |

## 3.0 Planning and Considerations

| Table P-CNV-04-3 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Details** |
| Community Factors | RSC systems can be designed as safe and aesthetically pleasing practices which, when incorporated into open space areas, can increase the natural value of a space. |
| Hot Spots | RSC systems should not be used for hot spot runoff. |

| Table P-CNV-04-3 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Details** |
| Existing Forests | Designers can expect a great deal of opposition if they do not make a concerted effort to save mature trees during RSC design and construction.<br>Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Wright et al. 2007). |
| Stream Warming Risk | RSC systems may provide for temperature reduction and reduction in thermal impacts. |
| Trout Streams | The ponding and settling functions provided by RSC systems allow for a reduction of the thermal impacts and pollutant loads of runoff from highly urbanized areas. |
| Cold Climate and Winter Performance | Salt and sand materials are applied to roads in Virginia during winter conditions. These can clog the sand/woodchip bed of RSC systems if the proper design approach is not used, particularly for practices that treat road and highway runoff. In these cases, pre-treatment cells or separate upgradient sediment storage areas should be employed to try to keep as many of these materials as possible off of the main RSC conveyance system. |
| Safety Risk | Ensure that runoff through the RSC system is conveyed in a safe, non-erosive manner to minimize damage to existing structures and facilities. |

## 4.0 Stormwater Performance Summary

| Table P-CNV-04-4 Summary of Stormwater Functions Provided by RSCs | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Volume Reduction (RR) | 0% | 0% |
| Total Phosphorus (TP) EMC Reduction[2] by BMP Treatment Process | 20% | 40% |
| TP Mass Load Removal[1] | 20% | 40% |
| Total Nitrogen (TN) Event Mean Concentration (EMC) Reduction[2] by BMP Treatment Process | 25% | 35% |
| TN Mass Load Removal[1] | 25% | 35% |
| Channel Protection | Yes; storage volume can be provided within pools to accommodate the full channel protection volume (CPv) | |
| Flood Mitigation | Yes; Flood protection storage can be provided within pools | |
| Target Water Quality Volume | $T_v$ | $1.5 \times T_v$<br>(See Section 5.1 for $T_v$ calculation) |

| Table P-CNV-04-4 Summary of Stormwater Functions Provided by RSCs | | |
|---|---|---|
| Stormwater Function | Level 1 Design | Level 2 Design |

1. Change in EMC through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate.
2. Pollutant removal referenced from Georgia Stormwater Management Manual 2016 https://cdn.atlantaregional.org/wp-content/uploads/gsmm-2016-final.pdfhttps://www.aacounty.org/public-works/bwpr/watershed-restoration/step-pool-stormwater-conveyance-systems-spscs

For additional information about the designand implementation of RSC systems, visit Anne Arundel County:

## 5.0 Design Criteria

RSC systems are best used to restore ecological functions to an existing eroded ditch, outfall, channel, or ephemeral stream. RSC systems are designed for intermittent flow and must be allowed to drain and reaerate between rainfall events.

An RSC consists of the following:

- A sequence of pools, riffles, and cascades to assist in treating, detaining, and conveying storm flow;
- An organic/mulch layer to protect planting media;
- A grade control structure and settling pool should be used if the slope of the channel is greater than 5 percent; and
- A pre-treatment sediment forebay located at the point of inflow to the RSC is required to keep sediment and large debris out of the practice. Refer to P-SUP-06 Pre-Treatment for design information.

Refer to Anne Arundel County Design Guidelines for Step Pool Stormwater Conveyance (SPSC) Systems May 2022 for additional recommendations and general guidelines for the design and construction of RSCs.

https://www.aacounty.org/departments/public-works/wprp/restoration/step-pool-conveyance-systems/aaco-spsc-guidelines.pdf.

### 5.1 Overall Sizing

1. Calculate the Target Water Quality Volume

   Calculate the water quality treatment volume formula using the following formula:

$$T_v = \frac{1.2\ in \times (R_v) \times A \times 43560 \frac{ft^2}{acre}}{12\ \frac{in}{ft}}$$

   Where:

   Tv = water quality volume ($ft^3$)

   Rv = volumetric runoff coefficient. Refer to Appendix A Hydrologic and Hydraulic Methods and Computations

   A = onsite drainage area of the RSC (acres)

2. Determine the storage volume of the practice and the pre-treatment volume

   The actual volume provided in the RSC is calculated using the following formula:

$$VP_{Total} = VP_{Sand} + \sum VP_{Pools}$$

Where:

$VP_{Total}$ = Total volume provided

$VP_{Sand}$ = Volume provided in the sand layer

$VP_{Pools}$ = Volume provided in the pools throughout the RSC system

To determine the volume provided for the sand layer in the RSC, use the following equation:

$$VP_{SAND} = (VSB)^* (N)$$

Where:

$VP_{SAND}$ = Volume provided in sand layer

VSB = Volume of sand bed

N = Porosity (0.4)

To determine the volume provided for the shallow pools in the RSC, use the following equation:

$$VP_{POOLS} = (V_{POOL\_1}) + (V_{POOL\_2}) + (V_{POOL\_3}) + \ldots$$

Where:

$VP_{POOLS}$ = Volume provided in the pools throughout the RSC system

$V_{POOL}$ = Volume of a single storage pool

3. Verify total volume provided by the practice is at least equal to the Tv(target)

   When the VP ≥ Tv(target) then the water quality treatment requirements are met for this practice. When the VP < Tv(target), then the design must be adjusted or another BMP must be considered and designed

4. Design grade control structure, pools, and cascades based on 100-year storm event.

   Check velocities and use appropriate stone to prevent erosion and head cutting.

### 5.2 Design Geometry

- Recommended total length of grade control structures and pools is less than 10 feet.
- The invert of the upstream elevation of the grade control structure should be 1 foot higher than the elevation of the downstream grade control structure.
- The width of the grade control structure should be 8 to 20 times the depth of the grade control structure. Ten feet is the preferred width.

  Use the following equation to determine the length of the grade control structure for an RSC:

$$L_{GCS} = L_{pool} = \frac{L_{RSC\ Path}}{\frac{\Delta E}{2}}$$

Where:

LGCS = Length of grade control structure

$L_{pool}$ = Length of pool

$L_{RSC\ Path}$ = Length of the RSC flow path

ΔE = Change in Elevation

- Four inches should be the maximum depth of flow going over the grade control structure.

- Cascades should have a maximum slope of 2H:1V, a maximum vertical drop of 5 feet, and should be followed by three pools instead of the usual one. Pools should be wider than the width of the grade control structure.
- Pool slopes should be no steeper than 3:1.
- The sand layer should be a mixture of sand and wood chips with a ratio of 4:1. This layer should run along the length of the RSC system. To stabilize the sand layer, 1 foot of bank-run gravel should be placed below the sand layer.
- A layer of hardwood mulch 3 to 4 inches thick should be placed on top of the sand layer to stabilize the grade control structures. The maximum width of the sand bed is 14 feet.
- The velocity of the water going through the pool should be less than 4 ft/s.
- Footer boulders should be inserted 6 inches lower than the invert of the pool.
- The RSC cross section (riffles and pools) must be sized to convey the peak flow for the 100-year storm event without overtopping of banks.
- Flow velocity during the 100-year storm event going through the RSC should be lower than the maximum allowable velocity for the cobble size selected, use Table P-CNV-04-5 to size the riffle cobble stones based on the velocity of flow.
- If the native soils are not suitable for planting, then an engineered soil mix or compost amendments should be provided. Refer to BMP P-FIL-08 Soil Compost Amendment for requirements and specifications of planting soils.

Open channel design through the riffle section of the RSC should be based on Manning's Equation for open channel flow:

$$Q = A \times 1.49/n \times R^{2/3} \times S^{1/2}$$

Where:

Q = Flow in the open channel (cfs)

A = Cross-section area of the channel ($ft^2$)

R = A/wetted perimeter (ft)

S = Channel slope (ft/ft)

n = Channel roughness coefficient

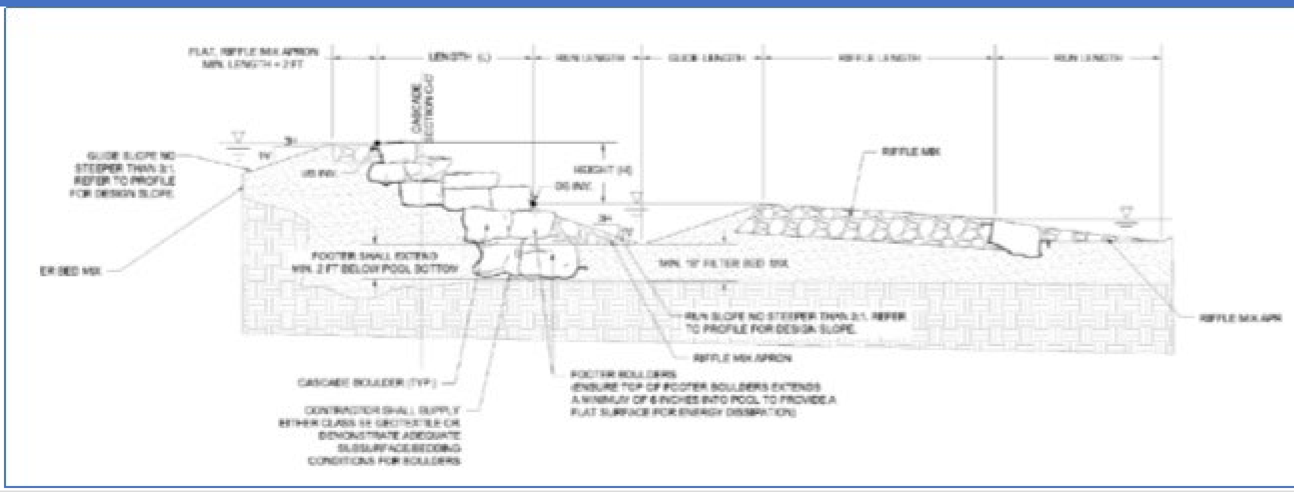
**Table P-CNV-04-5 Riffle Cobble Diameter Based on Flow Velocity**

| Cobble Diameter (inches) | Allowable Velocity (ft/s) |
|---|---|
| 4 | 5.8 |
| 5 | 6.4 |
| 6 | 6.9 |
| 7 | 7.4 |
| 8 | 7.9 |
| 9 (VDOT Class A1) | 8.4 |
| 10 | 8.8 |
| 11 | 9.2 |

| Table P-CNV-04-5 Riffle Cobble Diameter Based on Flow Velocity | |
|---|---|
| **Cobble Diameter (inches)** | **Allowable Velocity (ft/s)** |
| 13 (VDOT Class I) | 9.6 |
| 15 (VDOT Class II) | 10.4 |

VDOT = Virginia Department of Transportation

***Figure P-CNV-04-2 Typical RSC Profile***

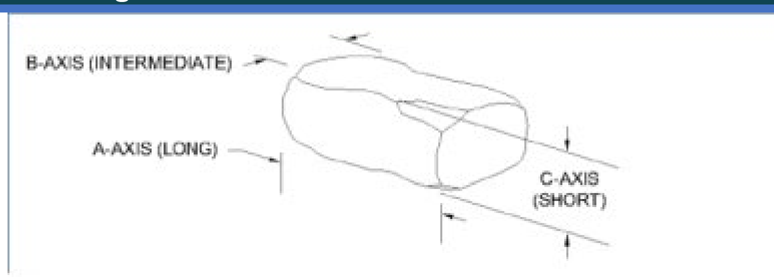


*Source: Anne Arundel County Bureau of Watershed Protection and Restoration 2022*

### 5.3 Grade Control Structure Boulders

All boulders should be imbricated in shape to allow for maximum interlocking. Boulders should be placed with the C axis vertical and the B axis parallel to the direction of flow.

***Figure P-CNV-04-3 Boulder Section View***




*Source: Anne Arundel County Bureau of Watershed Protection and Restoration 2022*

Boulder dimensions will meet or exceed the requirements for Type 1 rip rap. The minimum boulder dimension varies based on use in the project. Top-level boulders used in cascade weirs may be thinner along the C axis than those used for cascade footers. A wide range of boulder sizes is acceptable and encouraged. The contractor should have flexibility to select stone that can be placed to match the design section, provided the median boulder size is at least 30 inches along the A axis.

The designer will note on the plans that the contractor is responsible for selecting boulder material that is appropriately sized to allow for economical construction of structures based on minimum dimensions dictated on the plans.

**Table P-CNV-04-6 Grade Control Structure Boulders**

| Boulder Location | A axis (in) | B axis (in) | C axis (in) |
|---|---|---|---|
| Riffle and Cascade Weir (surface) | 24 to 36* | 24 to 36 | 12 to 24 |
| Cascade Footer Boulders (subsurface) | 24 to 36 | 24 to 36 | 12 to 24 |

* Median A axis for each structure must equal a minimum of 30 inches.

Source: Anne Arundel County Bureau of Watershed Protection and Restoration 2022

The designer will note on the design plans that the edges of the boulders should be placed as tightly against one another as possible, creating a continuous structure. All voids between boulders will be chinked with cobble or boulder fragments from upstream of the structure to fill voids and promote surface flow over the boulders.

Filter fabric will be placed under all layers of boulders in cascade weirs. In riffle weirs, filter fabric is not required under boulders provided adequate subsurface bedding conditions and construction of a low-profile run. Note: filter fabric will not be placed under pools or riffle mix.

### 5.4 Filter Bed Media

All RSC projects require a sand and wood chip filter bed regardless of whether the project is presented as a stormwater filtration device for environmental site design (ESD) or retrofit credit. The sand will meet the American Association of State Highway and Transportation Officials (AASHTO)-M-6 or ASTM-C-33 standard,

0.02 inch to 0.04 inch in size. Sand substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No "rock dust" can be substituted for sand. The wood chips should be made from hardwood trees, recently chipped (green), and un- composted. Wood chips are typically mixed with the sand onsite, approximately 20 percent by volume, to increase the organic content of the media in support of denitrification. The designer and contractor will note that, due to compaction upon installation, the wood chips are not to be considered as a "fill" material when quantifying volume of material needed to fill the channel. The 20 percent wood chip is considered a separate, supplementary volume. The minimum depth of the filter bed below the invert of all project features will be 18 inches with a minimum width of 4 feet as shown in the profile and section views on Figure P-CNV-04-2. For projects located in extremely incised or eroded gullies, where the depth of fill far exceeds the required filter volume, designers may specify the use of common borrow fill material for subgrade fill provided a continuous filter bed meeting the volume and minimum depth requirements is installed above.

Note: Sand and wood chips are not mixed prior to installation. The wood chips are installed in layers during construction to provide clean and efficient access. As the site is being worked and graded, the sand and wood chips will become well incorporated. Wood chip hot spots and clean sand areas are desired.

### 5.5 Pools

Pools are low-energy slope areas designed to impound water and minimize velocity. Standard dimensions for pools are closely related to the dimensions of the upstream riffle or cascade weir structure that discharges into the pool. The designer should note the following:

- Pools should be constructed with minimum side slopes of 3H:1V.

- For pools downstream of riffle weirs, the minimum length of pool will be equal to the length of the upstream riffle weir.
- The maximum pool depth will range from 1 to 3 feet. The designer may modify depth depending on site- specific goals and constraints or to incorporate diversity of depth.
- Pools immediately downstream of cascade weirs should have a minimum length equal to the greater of: (a) the length of the calculated standard 1-foot riffle weir, or (b) the length of the cascade weir that precedes it. At low design flowrates, and with shorter cascade weir heights, the standard 1-foot riffle weir is generally longer due to a comparatively lower slope. However, as cascade height and design flowrate increase, cascade weirs may extend longer than the standard 1-foot riffle weir length. This guideline creates a length of pool downstream of cascades that is conservative in most circumstances.
- The top width of pool at its widest point will be equal to or greater than the design depth top width of the upstream riffle or cascade weir. The top width of the pool is measured at the elevation backwatered by the downstream structure invert (low-flow water surface elevation).
- For the first outfall pool (i.e., entrance pool), designers should size a forebay using P-SUP-06 Pre-Treatment and compare the width and length to those of the calculated standard 1-foot riffle weir. The designer will use the more conservative sizing. The minimum depth for the first pool is 1.5 feet. Designers should note that ensuring pools meet or exceed the requirement for minimum width is critical to reducing velocity and potential for scour. Wider pools increase the available surface storage and reduce the need for imported fill. Should the proposed structures have a top width that is narrower than the existing drainage channel, the designer is advised to maximize pool width within the existing channel footprint while considering impacts to natural resources and any surrounding constraints.

Downstream of cascade weirs, designers should evaluate the potential for scour using equation 11 below. The equation is a modified version of the Veronese equation to estimate the potential depth of scour.

*Equation 11: Veronese equation (United States Department of Argriculture, 2007) modified for SPSC*

$$p_d = K * H^{0.225} * \left(\frac{Q}{T_W}\right)^{0.54} - y$$

Where:

$p_d$ = Calculated maximum scour depth, ft

K = 1.32 (coefficient for U.S. units)

H = Height of upstream structure, ft

Q = Design flow, cfs (typically $Q_{100}$)

$T_W$ = Top width of the upstream structure, ft

y = Design flow depth within the downstream structure, ft

The resulting scour depth (pd) represents depth from the top of pool elevation (low-flow water surface) to the bottom of the conceptual scour hole. Footer boulders for cascade weirs should extend a minimum of 2 feet below the pool bottom and at least 1 foot below the calculated maximum scour depth elevation. Should the calculated pd exceed 5 feet, the designer should consider modifying geometry (e.g., reduce height or increase top width) to reduce the required depth of footers.

**5.6 Required Geotechnical Testing**

Soil explorations should be conducted within the footprint of the RSC. Soil boring data are needed to: (1) determine the physical characteristics of the excavated material to determine its adequacy as structural fill or for another use, (2) determine the depth to groundwater and bedrock, and (3) evaluate potential infiltration losses. Guidance on soil explorations in general is provided in Appendix C Soil Characterization and Infiltration Testing.

### 5.7 Sediment Forebay

Pre-treatment is vital to the successful operation of filtration BMPs, as the media can quickly become clogged from high sediment loads if otherwise left without pre-treatment. Sediment forebays should be provided at inflow to the RSC. Refer to P-SUP-06 Pre-Treatment for additional guidance on forebays.

### 5.8 Landscaping and Planting Plan

A landscaping plan is required for all RSC designs and should be jointly developed by the engineer, a plant ecologist or natural resources specialist, or experienced landscape architect. The plan should outline a detailed schedule for the care, maintenance, and possible reinforcement of vegetation in the RSC pools and buffer for up to 10 years after the original planting because many plants will adapt to the hydrology and may require thinning or additional plantings. A selection of trees, shrubs, and herbaceous materials, in addition to planting densities and planting zones, should be provided in the construction plan set. Reference Appendix G for plant selection guidance. Note that designers should be sure to consult any locality planting standards and requirements when developing a planting plan.

For additional guidance on planting trees and shrubs in RSCs and stream buffers, consult the following sources:

- Cappiella et al. 2006;
- Virginia Department of Recreation and Conservation's (DCR's) Riparian Buffer Modification & Mitigation Guidance Manual available online at: http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/ripbuffmanual.shtml ; and
- Anne Arundel County Design Guidelines for Step Pool Stormwater Conveyance (SPSC) Systems May 2022 https://www.aacounty.org/departments/public-works/wprp/restoration/step-pool-conveyance-systems/aaco-spsc-guidelines.pdf.

### 5.9 Maintenance Features

The following design criteria will help to avoid significant maintenance problems pertaining to RSCs:

- Good access is needed so crews can remove sediments, make repairs, and preserve treatment capacity.
- Maintenance access must be provided to the forebay, riffles, and pool areas.
- Access roads must be constructed of load-bearing materials, have a minimum width of 12 feet, and possess a maximum profile grade of 15 percent.
- Turnaround areas may also be needed depending on the size and configuration of the RSC.

## 6.0 Construction Specifications

**Table P-CNV-04-7 RSC Materials Specifications**

| Component | Specification |
|---|---|
| Grass and Landscaping | BMP C-SSM-10 Permanent Seeding<br>Appendix G Plant Selection |
| Rip Rap and Outlet Protection | BMP C-ECM-15 Outlet Protection<br>BMP C-ECM-13 Riprap |

| Table P-CNV-04-7 RSC Materials Specifications | |
|---|---|
| **Component** | **Specification** |
| Sediment Forebay | P-SUP-06 Pre-Treatment |
| Erosion Control Blankets | C-SSM-05 Soil Stabilization Blankets and Matting<br>RSC banks should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the banks. |

### 6.1 Construction Inspection

Construction inspections are critical to ensuring that RSC systems are properly constructed and established. Multiple site visits and inspections are recommended during the following stages of the RSC process:

- Pre-construction meeting;
- Initial site preparation (including installation of project erosion and sediment controls);
- Excavation/Grading (e.g., interim/final elevations);
- RSC installation (e.g., grade control cobble and boulders, pools, media, and staking of planting zones);
- Planting phase (with an experienced landscape architect or ecologist); and
- Final inspection (develop a punch list for facility acceptance).

Upon final inspection and acceptance, the global positioning system (GPS) coordinates should be logged for all RSCs and submitted for entry into the local BMP maintenance tracking database.

### 6.2 Construction Sequencing and Erosion and Sediment Control Plan Considerations

- The designer and contractor will consider a temporary diversion pipe, with supplemental sump pumps, to assist with site dewatering during construction. Additional details are provided in the Virginia Stream Restoration Manual and BMP C-ENV-08 Pump Around Diversion.
- All access roads will be constructed with a minimum 6-inch layer of wood chips and replenished throughout construction. The designer should be familiar with site-specific conditions and consider timber matting as necessary. Refer to BMP C-SCM-02 Construction Road Stabilization.
- The designer should include an access path of at least 12' in width along the overbank area to afford maintenance access during and after construction.
- Where adjacent mature forests or other high-quality resources are to be protected, it is recommended that designers specify the use of the existing channel as the primary access road to minimize disturbance. There are other benefits to using the existing channel as the access road including beneficial use of sand fill for access during construction that will remain in place as the filter bed and affording the delivery of construction materials directly to their installed position. The designer should further note the following when using the channel for access:
    - When feasible, construction is typically sequenced with channel fill occurring from upstream to downstream, and subsequent completion of riffle or cascade weirs and pools occurring from downstream to upstream. Note: within this sequence, it is recommended that structure materials (i.e., riffle mix and boulders) be placed directly within the channel access path so it can be tracked in repeatedly by construction equipment before the structures are finalized. Experience has shown that this provides for a more robust, well integrated system that is less prone to movement and piping.

- All projects should include specification of a standard pump-around practice in accordance with C-ENV-08 Pump Around Diversion to ensure the site remains dewatered during construction.
- The designer will include tree protection for specimen trees to be saved during construction in accordance with C-SSM-01 Tree Preservation and Protection.
- It is common practice for delivery of RSC materials to occur directly in place and within the channel. The designer will provide accessibility to the channel by trucks and other equipment when choosing site entrance and access paths. The maximum slope of ramps and access roads is 15 percent.

> The designer should evaluate the condition of the proposed outfall channel when phasing construction. When practical, the designer should consider installation of the RSC prior to site-wide construction (if adequate upstream ESC has been provided).
>
> By installing the RSC in advance, the channel bed and banks will be prepared to accept the post-development discharge. Otherwise, releasing concentrated discharge to an unstable outfall channel may accelerate degradation during construction and generate additional erosion.

- No “biodegradable” plastic mesh matting will be used within the limits of disturbance.
- For sites in which an RSC is installed as part of a development or re-development project:
  - Under no circumstance can the RSC system be used as a sediment control device during construction unless:
    - All water should be treated by an approved erosion and sediment control (ESC) practice before reaching the RSC.
    - Upstream controls, such as diversion pipes and pump-arounds, are required during construction so as not to contaminate the RSC system.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the RSC BMP, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- Restrictive covenants or other mechanisms enforceable by the VESMP Authority should be in place to help ensure that RSCs are maintained as well as to pass the knowledge along to any subsequent property owners.
- Access to stormwater RSCs should be covered by a drainage easement to allow access by the VESMP Authority to conduct inspections and perform maintenance when necessary.
- All RSCs should include a long-term Maintenance Agreement consistent with the provisions of the Virginia Erosion and Stormwater Management Regulation and should include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The Maintenance Agreement should also include contact information for owners to obtain local or state assistance to solve common nuisance problems such as mosquito control, geese, invasive plants, vegetative management, and beaver removal.

### 7.2 P-CNV-04-8 RSC Maintenance Schedule

| Table P-CNV-04-8 RSC Maintenance Schedule | |
|---|---|
| **Activity** | **Schedule** |
| Inspect two times after establishment for first 6 months after storms that exceed 0.5 inch of rain.<br>Repair any erosion, rills, or gullies that may form in the practice. Conduct any needed repairs or stabilization.<br>Repair areas with bare or dead grass in the contributing drainage area or around the RSC.<br>Watering and spot fertilization may be necessary during first 2 months to establish vegetation.<br>Remove and replace dead, damaged, or diseased plants. | Upon establishment |
| Prune and weed vegetation.<br>Remove trash, sediment, and debris. | Four times per year |
| Add additional plants to maintain needed vegetation density.<br>Remove and replace any dead, damaged, or diseased plants. Repair any eroded areas. | As needed |
| Make sure weirs, riffles, and pools are in structurally good condition and that the practice has stable water levels.<br>Prune trees and shrubs (when they are dormant). Remove any invasive species.<br>Remove any sediment accumulation in pretreatment area and inflow points. | Annually |
| Remove accumulated sediment in pools.<br>Repair damage to weirs, riffles, pools, or other structural components. | Once every 2 to 3 years |

## 8.0 References

Aecom, Atlanta Regional Commission, Center for Watershed Protection, Center Forward, Georgia Environmental Protection Division, Mandel Design. 2016. Georgia Stormwater Management Manual, Volumes 1 & 2.

# P-FIL-01 Rooftop Disconnection

## 1.0 Definition

Impervious areas that immediately drain to a stormwater conveyance system or other impervious surface are "connected impervious" areas and produce stormwater that flows untreated to surface water bodies. Disconnection occurs when impervious surfaces are redirected and dispersed into sheet flow across an expanse of turf grass or natural vegetation. Directing runoff from impervious areas onto vegetated areas as sheet flow will increase infiltration, resulting in a direct reduction in runoff and corresponding storage volume requirements.

## 2.0 Purpose and Applicability of Best Management Practice

By disconnecting direct rooftop or impervious surface runoff, the flow is redirected to designated pervious areas, which will reduce runoff volumes and rates.

### 2.1 Benefits

- Sending runoff to pervious areas and implementing low-impact practices help to increase overland flow time and reduce peak flows (New York Department of Environmental Conservation [NYDEC] 2015).
- Vegetated and pervious areas can filter and infiltrate runoff, thus increasing water quality.

### 2.2 Feasibility/Limitations

- Redirected rooftop runoff may increase a property owner’s maintenance burden.
- Alternative rooftop runoff mitigations may be costly.
- Local law may prohibit or limit rooftop disconnection.

Two kinds of disconnection are allowed (see Figure P-FIL-01-1 and Figure P-FIL-02-2):

1. Simple Disconnection: Impervious surfaces are dissipated and dispersed as sheet flow over a 40-foot-long flow path before it reaches a natural or manmade stormwater conveyance system.
2. Disconnection leads to alternate runoff reduction practice(s) adjacent to the roof or small residential impervious area.

**Alternative Disconnection Practices.** Alternative disconnection practices are structural practices that provide runoff reduction rates equivalent to those seen with simple disconnection. Alternative practices are needed when the simple disconnection criteria cannot be met. Alternate disconnection practices are used only when the flow length or slope criteria cannot be met. Alternative disconnection provides the same runoff reduction rates as those seen with simple disconnection. Alternative practices intercept impervious runoff at the source before the receiving stormwater conveyance system or other impervious surface. One practice may treat more than one downspout if the practice is within 40 feet of closest downspout. Infiltration practices should only be used where there are suitable soils and applicable setbacks allow. Larger-scale (e.g., commercial) applications that use disconnection and/or sheet flow for runoff reduction credit for small impervious areas should consult best management practice (BMP) specification BMP P-FIL-07, Sheet Flow to Vegetative Filter Strip/Open Space.

## Figure P-FIL-01-1 Roof Disconnection with Alternate Runoff Reduction Practices

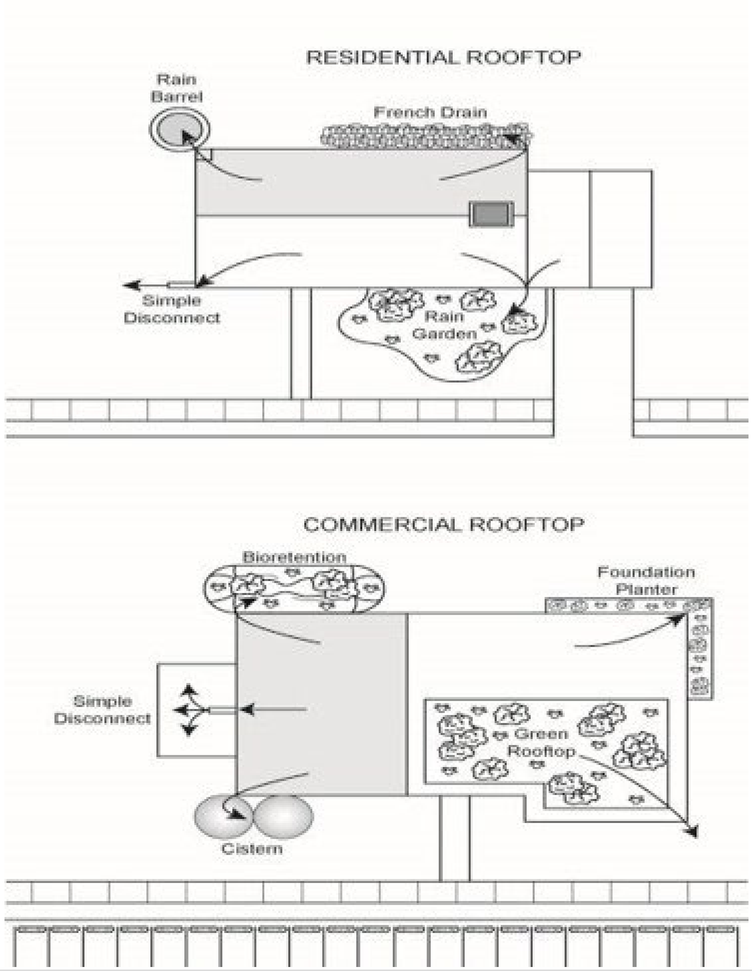
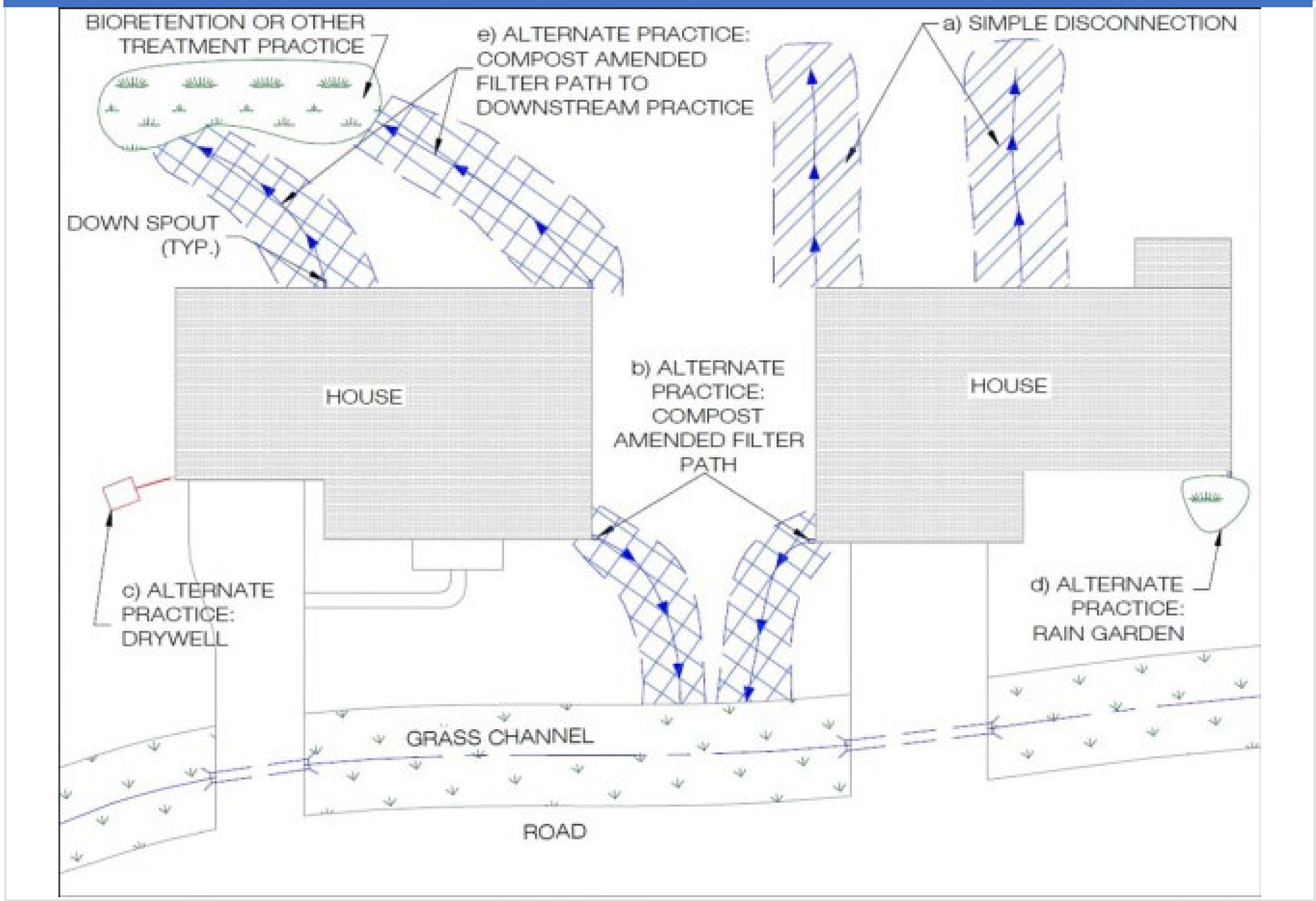


**Figure P-FIL-01-2 Residential Rooftop Treatment – Plan View**




a) *Simple Disconnection*

b) *Disconnection – Alternate Practice: Compost-Amended Filter Path*

c) *Disconnection – Alternate Practice: Dry Well (micro-infiltration)*

d) *Disconnection – Alternate Practice: Rain Garden*

e) *Disconnection – Alternate Practice: Compost-Amended Filter Path to Downstream Practice – Bioretention*

## 3.0 Planning and Considerations

The following considerations are adapted from the State of New York (NYDEC 2015) and apply to simple disconnections:

- Disconnections are encouraged on uncompacted, permeable soils (Hydrologic Soil Groups [HSGs] A and B) Runoff from disconnected rooftops must be directed to a designated area that is appropriately graded for storage and infiltration of the runoff, revegetated and protected from other uses, and designed for conveyance in a non-erosive manner within the site boundary. Use splash pads or level spreaders as necessary to distribute runoff to designated areas with infiltration capacity. Yards without positive drainage should not be used for simple disconnection.
- Use an appropriate pre-treatment measure as necessary to dissipate and disperse runoff to designated flow paths.

- In less permeable soils (HSGs C and D or previously impacted HSGs A and B), permeability and water table depth should be evaluated to determine whether a soil enhancement is needed for the designated flow path. In some cases, soil restoration by deep tilling, decompaction, and compost amendment are needed. Downstream flow path area limits should be perpendicular to contours. With converging contours, the downstream flow path width cannot be less than half of the upstream width.
- Runoff must be directed to a designated flow path that is appropriately graded, revegetated, and protected from other uses. The flow path should be designed in a non-erosive manner using appropriate construction BMPs.
- Simple disconnection is generally not advisable for residential lots smaller than 6,000 square feet in area, although it may be possible to employ one of the alternate disconnection runoff reduction practices on these lots (e.g., cistern, infiltration).

## 4.0 Stormwater Performance Summary

With proper design and maintenance, the simple rooftop disconnection options can provide relatively high runoff reduction rates, although they are not credited with nutrient event mean concentration (EMC) reduction (see Table P-FIL-01-1). If an alternate disconnection runoff reduction practice that does achieve EMC reduction in addition to volume reduction is employed to achieve rooftop disconnection, the higher total removal credit for that practice can be used for the contributing drainage area of the rooftop. In some cases, the designer may use one of the alternate disconnection practices identified in this specification to provide both runoff reduction and nutrient removal regardless of space constraints.

The runoff reduction achieved by rooftop disconnections can help reduce the overall channel protection and flood control volume for the site. Designers can use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a curve number adjustment for each design storm for the contributing drainage area based on the degree of runoff reduction achieved.

**Table P-FIL-01-1 Summary of Stormwater Functions Provided by Rooftop Disconnection**

| Function Provided by Simple Rooftop Disconnection | HSG Soils A and B | HSG Soils C and D |
|---|---|---|
| Annual Runoff Reduction Volume | 50% | 25% |
| Total Phosphorus EMC Reduction by BMP Treatment Process | 0 | 0 |
| Total Phosphorus Mass Load Removal | 50% | 25% |
| Total Nitrogen EMC Reduction by BMP Treatment Process | 0 | 0 |
| Total Nitrogen Mass Load Removal | 50% | 25% |
| Channel and Flood Protection | Partial: Designers can use the VRRM Compliance spreadsheet to adjust curve number for each design storm for the contributing drainage area (CDA) based on the annual runoff reduction achieved. | |

| Table P-FIL-01-1 Summary of Stormwater Functions Provided by Rooftop Disconnection | | |
|---|---|---|
| Function Provided by Simple Rooftop Disconnection | HSG Soils A and B | HSG Soils C and D |

**Notes:**

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.

1. When simple disconnection is not possible, alternative practices can be implemented, but no additional runoff reduction is provided beyond 50% unless the design is in accordance with other approved BMP specifications.
2. Designers should consult the applicable specification for alternative practice design standards.
3. Compost amendments are not credited with additional volume reduction on HSG A and B soils. Primary use is to improve the volume reduction performance of disconnection in C and D soils.

## 5.0 Design Criteria

### 5.1 Simple Rooftop Disconnection

Table P-FIL-01-2 provides the primary design criteria for simple rooftop disconnection. Figure P-FIL-01-3 and Figure P-FIL-01-4 illustrate the application of simple disconnection. These figures also illustrate the alternate disconnection practice of a compost-amended filter path when applied in HSG C or D soils as well as the option of discharging to a downstream practice.

The following provides the general design criteria for simple disconnection:

- Flow from the downspout should be spread over a minimum 10-foot-wide disconnection flow path extending downgradient from the structure and should be at least 40 feet long.
- Where it is determined that the disconnection can be safely spread across a yard area meeting the minimum dimensions (i.e., the flow will remain sufficiently spread beyond the level spreader and will not create nuisance conditions), a defined flow path cross-section need not be constructed.
- Simple disconnection can be used on any post-construction HSG. However, the erodibility of soils, slope, and both existing and planned vegetative cover must be considered to ensure no erosion is created from concentrated flows.
- Provide pre-treatment that dissipates and disperses flows. A pea gravel or river stone diaphragm or other accepted flow-spreading device should be installed at the downspout outlet to distribute flows evenly across the flow path.

| Table P-FIL-01-2 Simple Rooftop Disconnection Design Criteria | |
|---|---|
| Design Factor | Simple Disconnection |
| Maximum impervious (rooftop or residential impervious) area treated | 1,000 square feet per disconnection |
| Disconnection Geometry | Width ≥ 10 feet; Length equal to longest flow path, but no less than 40 feet [1] |
| Disconnection slope | < 5% with turf reinforcement [2] |
| Type of Pretreatment | External (e.g., leaf screens, gravel diaphragm dissipation and dispersion) |

| Table P-FIL-01-2 Simple Rooftop Disconnection Design Criteria | |
|---|---|
| Design Factor | Simple Disconnection |

**Notes:**

1. An alternate disconnection runoff reduction practice must be used when the disconnection length is less than 40 feet.
2. Turf reinforcement may include EC-3 or other appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flowrates anticipated at each individual application and acceptable to the plan-approving authority.
1. For alternate disconnection runoff reduction practices, see the applicable specification for design criteria. See Table P-FIL-01-1 for eligible practices and associated specification numbers.
2. Note that the downspout extension of 5 feet is intended for simple foundations. Any dry well or rock trench adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (e.g., foundation drains) or avoided altogether.

### 5.2 Alternate Disconnection: Soil Compost-Amended Filter Path

The incorporation of compost amendments should conform to BMP P-FIL-08, Soil Compost Amendment, and include the following design elements:

- Flow from the downspout should be spread over a 10-foot-wide flow path extending downgradient from the structure.
- The compost-amended filter path should be 10 feet wide and at least 20 feet long within the longer disconnection flow path.
- A pea gravel or river stone diaphragm or other accepted flow-spreading device should be installed at the downspout outlet to distribute flows evenly across the filter path.
- The compost-amended filter path should have adequate "freeboard" so that flow remains within the amended soil strip and is not diverted away from the strip. In general, this means that the strip should be lower than the surrounding land area to keep flow within the filter path. Similarly, the flow area of the filter path (as well as the larger disconnection flow path) should be level to discourage concentration of the flow.

***Figure P-FIL-01-3 Disconnection: Alternate Practice Soil Compost Amended Filter Path Cross-Section***

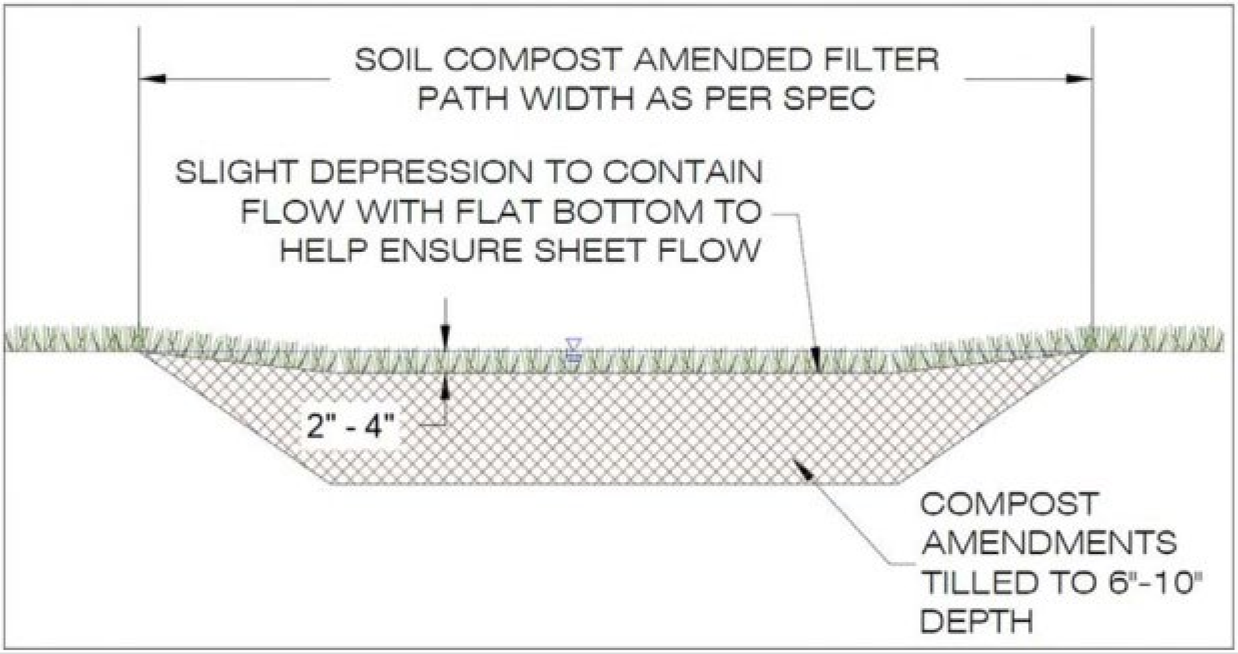



***Figure P-FIL-01-4 Disconnection: Alternate Practice: Compost Amended Filter Path to Downstream Bioretention Section View***

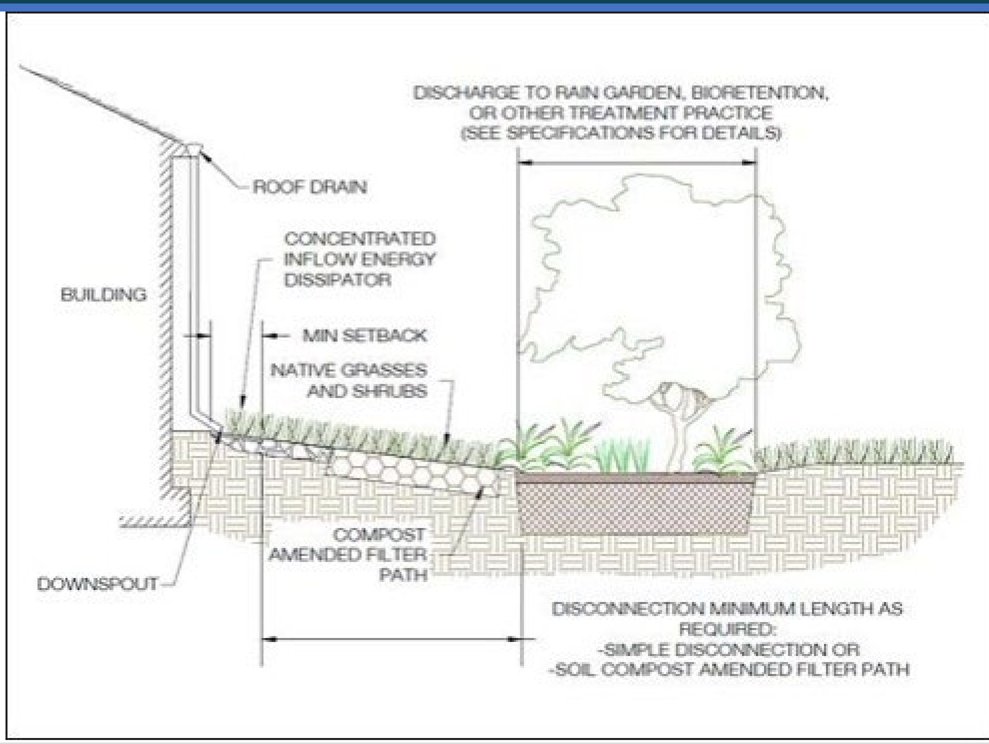
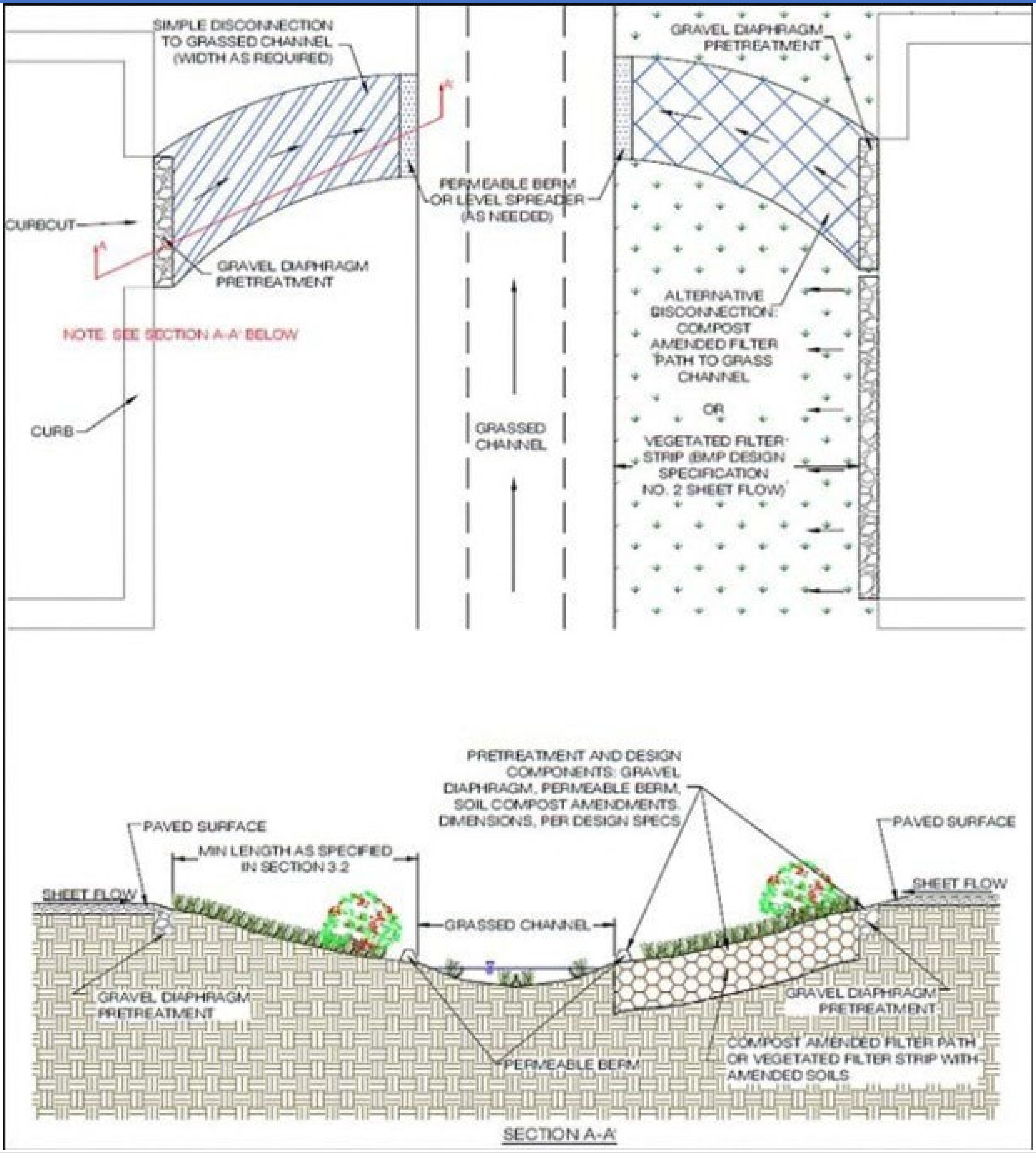


**Figure P-FIL-01-5 Disconnection: Alternate Practice Amended Filter Path to Downstream Grass Channel (or other treatment)**




### 5.3 Alternate Disconnection: Micro-Infiltration

Table P-FIL-01-3 provides the primary design criteria for using micro-infiltration as an alternative disconnection practice. Micro-infiltration alternatives include dry wells and rock trenches.

The following general design criteria must be met for micro-infiltration:

- Soils must have an infiltration rate of 0.5 inch per hour or greater.

- As general rule, approximately 18 cubic feet of stone per 100 square feet of rooftop area is needed to provide storage for 1-inch volume of runoff. If a hollow manufactured tank-style chamber is used, approximately
- cubic feet of storage per 100 square feet of rooftop area is needed for capturing the 1-inch volume of runoff.
- Provide a flat bottom to promote infiltration. Provide non-woven geotextile fabric as a separation barrier with the native soil.
- Provide pre-treatment that screens and filters debris.
- Provide an elevated overflow to pop-up emitter or similar device.
- Chamber systems require a cleanout port. The pop-up emitter can be used as a cleanout.
- The use of micro-infiltration adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's waterproofing system (e.g., foundation drains) or avoided altogether.

**Table P-FIL-01-3 Micro-Infiltration Design Criteria**

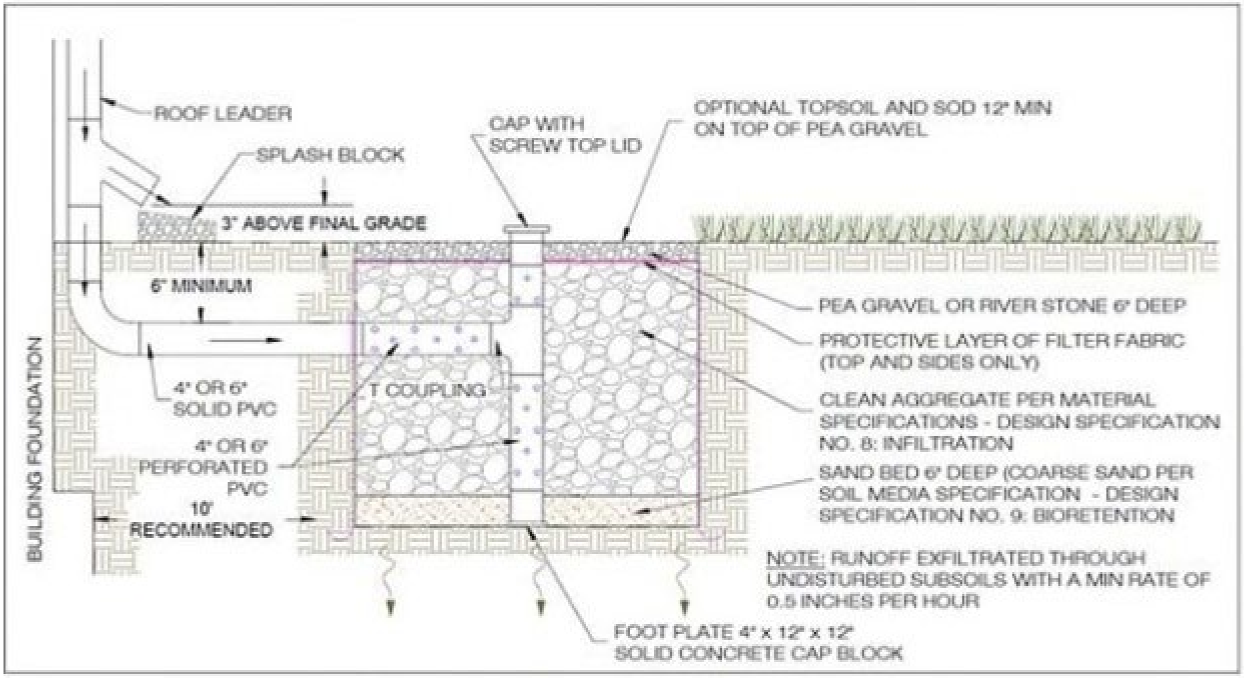
| Design Factor | Micro-Infiltration Design |
|---|---|
| Roof Area Treated | 250 to 2,500 square feet |
| Typical Practices | Dry Well and Rock Trench |
| Recommended Maximum Depth | 3 feet |
| Runoff Reduction Sizing | See BMP P-FIL-04, Infiltration Practices |
| Minimum Soil Infiltration Rate | 0.5 inch/hour |
| Observation Well | No |
| Type of Pretreatment | External (e.g., leaf screens, grass strip) |
| UIC Permit Needed | No |
| Required Soil Test | One soil profile and one infiltration test per practice |
| Building Setbacks | 10 feet [1] |

**Note:**

1. Note that the building setback of 10 feet is intended for simple foundations. Any dry well or French drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's waterproofing system (e.g., foundation drains) or avoided altogether.

In general, micro-infiltration areas will require a surface area up to 3% of the contributing roof area. An onsite soil test is needed to determine whether soils are suitable for infiltration. It is recommended that the micro-infiltration facility be in an expanded right-of-way or stormwater easement so that it can be easily accessed for maintenance.

**Figure P-FIL-01-6 Disconnection: Alternate Practice Dry Well (Micro Infiltration)**




### 5.4 Alternate Disconnection: Micro-Bioretention

Depending on site soil properties, roof runoff may be filtered through a shallow bioretention area. The design for this option should meet the requirements of micro-bioretention (rain garden) or urban bioretention (stormwater planters) as described in BMP P-FIL-05, Bioretention, and summarized in Table P-FIL-01-4.

For some residential applications, front, side, and/or rear yard bioretention may be an attractive option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium-density residential lots in a depressed area (6 to 12 inches) between the home and the primary stormwater conveyance system (e.g., roadside ditch or pipe system). The micro-bioretention or rain garden connects to the drainage system with an underdrain if needed; (connection to the drainage system must comply with the appropriate connection requirements). The concept is to take advantage of the drop from the roof leader to the conveyance system by creating a 10-foot-wide (minimum) bioretention corridor from the roof to the street with a shallow (6- to 12-inch deep) temporary ponding area. The bioretention corridor must have a minimum effective flow length of at least 20 feet. The ponding area may have a turf or landscape cover depending on homeowner preference. The advantage of using micro-bioretention over a soil compost-amended filter path is the additional pollutant removal credit provided by bioretention. The following general design criteria identify design requirements for bioretention planters:

- No infiltration test is needed.
- Minimum soil medium depth is 18 inches with 6-inch gravel sump and under drain.
- Planter wall maximum height is 3 feet. Wall should have stable footings and internal drainage.

**Table P-FIL-01-4 Micro-Bioretention Design Criteria**

| Design Factor | Micro Bioretention (i.e., Rain Garden) |
|---|---|
| Impervious Area Treated [1] | 2,500 square feet |
| Type of Inflow | Sheet flow or roof leader downspout |

| Table P-FIL-01-4 Micro-Bioretention Design Criteria | |
|---|---|
| **Design Factor** | **Micro Bioretention (i.e., Rain Garden)** |
| Runoff Reduction Sizing [1] | Surface Area = 5% of roof area (Level 1); 6% of roof area (Level 2) |
| Minimum Soil Infiltration Rate | 0.5 inch/hour; 1 inch/hour to remove underdrain requirement |
| Observation Well/Cleanout Pipes | No |
| Type of Pretreatment | Leaf screens, gravel diaphragm |
| Underdrain and Gravel Layer | Level 1: Yes |
| Minimum Filter Media Depth | 18 inches (Level 1) |
| Media Source | Mixed on site |
| Required Soil Borings | One soil profile and one infiltration test, only when an underdrain is not used |
| Building Setbacks | 10 feet [2] |

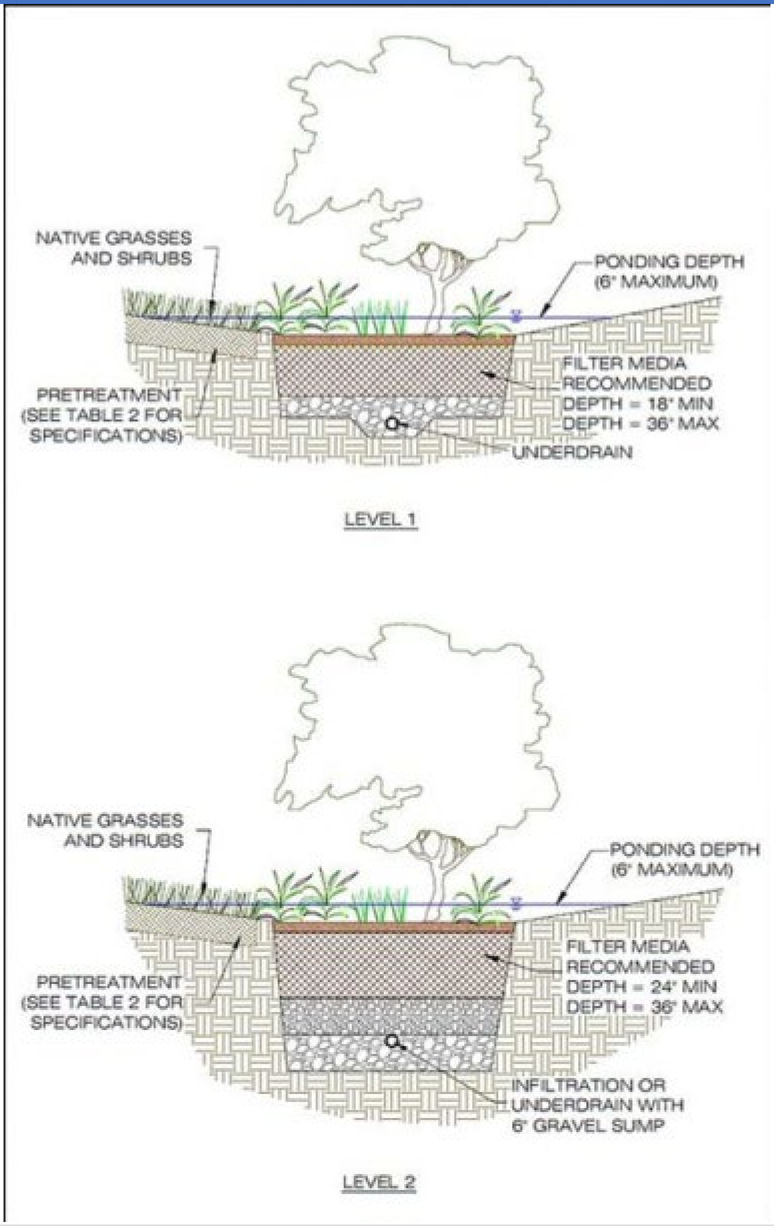
**Notes:**

1. Refer to BMP P-FIL-05, Bioretention, for Level 1 and Level 2 Design Criteria and sizing criteria for individual and multiple downspout applications.
2. Note that the building setback of 10 feet is intended for simple foundations. Any micro-bioretention practice located adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's waterproofing system (e.g., foundation drains) or avoided altogether.

The rain garden medium is 18 to 24 inches deep and is located atop a 12- to 24-inch-deep stone reservoir (as required by the Micro-Bioretention design criteria provided in BMP P-FIL-05. A perforated underdrain is installed above the stone reservoir to promote storage and recharge, even on poorly draining soils. In urban settings, the underdrain is directly connected into the storm drainpipe running underneath the street or in the street right-of- way. A trench needs to be excavated during construction to connect the underdrain to the street storm drain system. Appropriate approvals are required for making any connections to a common or public drainage system.

Construction of the remainder of the bioretention system is deferred until after the lot has been stabilized. The designer can reduce the risk of homeowner conversion by specifying the choice of either turf or landscaping as selected by the homeowner. However, the use of Virginia native plants adapted to regional conditions for rain gardens (provided in Appendix G) is recommended. Rain gardens require regular mowing and/or landscape maintenance to perform effectively. It is recommended that the practice be in an expanded right-of-way or stormwater easement so that it can be easily and legally accessed if it fails to drain properly.

**Figure P-FIL-01-7 Disconnection: Alternate Practice Rain Garden (Micro Bioretention) Level 1 and 2**



| Table P-FIL-01-5 Regional and Special Case Design Adaptations | |
|---|---|
| **Case** | **Adaptation** |
| Karst Terrain | Rooftop disconnection is strongly recommended in karst areas for most residential lots larger than 6,000 square feet, particularly if it can be combined with a secondary micro-practice to increase small-scale runoff volume reduction. The discharge point from the disconnection should extend at least 15 feet from any building foundations. Rooftop disconnection is also recommended for commercial sites that are not likely to be stormwater hotspots. |
| Coastal Plain Terrain | Disconnection is strongly recommended in the coastal plain for rooftops or other impervious areas on most residential lots larger than 6,000 square feet. Because this practice is especially suited to the coastal plain, the VSMP Authority and/or VESMP Authority may encourage the use of an alternate disconnection practice, particularly if it can be combined with a secondary micro-practice to increase small-scale runoff volume reduction while reducing the overall footprint of simple disconnection. The disconnection corridor should have a minimum slope of 1% in the first 10 feet and a minimum 2 feet of vertical separation from the water table. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence for Simple Impervious Disconnection

Impervious cover disconnection will be installed after all impervious areas have been constructed and adjacent pervious areas have been stabilized. This usually includes the construction of the individual residences and driveways and the stabilization of the yards. The design of the practices may require adjustments to fit exact driveway locations, structure rooflines, and downspout locations. The VESMP Authority should enact provisions such as the Erosion Control Program “Agreements in Lieu of Plans” to include all the appropriate parties (e.g., site operator, home builder, and homeowner) to ensure that the residential disconnection practices are installed and stabilized in accordance with the approved plans.

To the extent practicable, the construction of alternate disconnection practices should follow the construction guidance, checklists, and inspections outlined for the micro-scale versions of the individual runoff reduction practices (soil amendments, micro-infiltration, micro-bioretention, rainwater harvesting, and urban planters).

The following are general procedures for implementing simple and, when applicable, alternate disconnection practices:

- Before construction begins, identify the general boundaries of the disconnection practice on the site/plot plan and clearly mark them on the site.
- Minimize construction traffic (e.g., staging of materials, contractor parking), especially during foundation construction.
- Stockpile existing topsoil if it is stripped in preparation for foundation construction.
- Achieve any grading to establish filter or flow paths with lightweight equipment.
- Divert downspouts until the filter path is completely stabilized. It may be appropriate to use stabilization matting (e.g., EC-3 or an equivalent) regardless of slope to encourage thick turf cover growth.

### 6.2 Construction Inspection

Construction inspection is critical to ensure that the minimal slope away from the structure is maintained.

Disconnection practices should be constructed after most of the site work has been completed and the house or building structure has been enclosed. Therefore, especially in residential developments, the disconnection practice may be constructed by the builder and/or the residential landscape contractor responsible for the final lot grading and stabilization. The specific locations of the practices may change because of the actual downspout or driveway locations. It is important that the site designer and contractor be able to adapt the original design of the disconnection to the new location and achieve the same overall performance goals in terms of geometry, volume, and impervious areas treated.

The as-built survey or certification should document that the disconnection practices have: (1) been installed either consistent with the plan or as adapted to fit the specific site conditions; and (2) been accepted by the homeowners.

Global Positioning System coordinates should be logged for any of these practices upon facility acceptance and submitted for entry into the local BMP maintenance tracking database.

An example construction phase inspection checklist for simple disconnection is provided in Appendix H. Construction inspection recommendations for alternate disconnection practices are provided in the BMP specifications for those practices in the same appendix.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation requires long-term responsibility for maintenance and operation of stormwater management facilities (9VAC25-875-535). The requirements must be set forth in an instrument recorded in the local land records prior to permit termination and include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

### 7.2 Maintenance Inspections

Long-term inspections of simple and alternate disconnection practices can be accomplished through a property owner inspection program developed by the VESMP Authority.

Maintenance of a simple disconnection flow path typically involves traditional lawn or landscaping maintenance. In some cases, runoff from a simple disconnection may be directed to a more natural, undisturbed setting (e.g., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected), thereby reducing or even eliminating the need for maintenance. If the simple disconnection flow path is directed toward a turf area, it should be regularly mowed at a tall grass setting and kept to a height of no more than 6 inches.

Inspections should ensure that:

1. Flows through the disconnection filter or flow path are not channelizing or short-circuiting.
2. Debris and sediment do not build up at the top of the flow path.
3. Foot or vehicular traffic does not compromise the gravel diaphragm or energy dissipater.
4. Scour and erosion do not occur within the flow path.
5. Sediments and decomposed leaves or debris are cleaned out of the energy dissipater.
6. Vegetative density exceeds a 90% cover in the filter or flow path and is being regularly mowed to a height of 6 inches or less (Virginia Cooperative Extension 2019; Massachusetts Department of Environmental Protection 2008).
7. In karst areas, subsidence does not occur at the point of discharge or downstream along the flow path.

An example maintenance inspection checklist for Simple Rooftop Disconnection is provided in Appendix H. Maintenance checklists for the alternate micro-scale practices are provided with their respective maintenance checklists in the same appendix.

## 8.0 References


CWP. 2007. National Pollutant Removal Performance Database Version 3.0. Center for Watershed Protection, Ellicott City, Maryland.

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# P-FIL-02 Vegetated Roof

## 1.0 Definition

A vegetated roof, or green roof, are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing medium that is designed to support low-growing plant growth.

## 2.0 Purpose and Applicability of Best Management Practice

Vegetated roofs capture and temporarily store stormwater runoff in the growing medium before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads otherwise generated by rooftops. Vegetated roofs are typically not designed to retain stormwater from larger storms.

Vegetated roofs present an above-ground management alternative when onsite space for stormwater practices is limited. They can be installed on flat roofs or on roofs with slopes up to 30% with special strapping and erosion control devices (Peck and Kuhn 2003; New York Department of Environmental Conservation [NYDEC] 2015).

Vegetated roofs typically contain a layered system of roofing. The roofs are designed so that water drains vertically through the medium and then horizontally along a waterproofing layer toward the outlet. There are two types of vegetated roof systems:

- **Intensive vegetated roofs** have a growing medium layer that ranges from 6 inches to 4 feet thick, which is planted with a wide variety of plants including trees.
- **Extensive vegetated roofs** have a much shallower growing medium layer (4 to 6 inches), which is planted with carefully selected drought-tolerant vegetation. Extensive vegetated roofs are much

lighter and less expensive than intensive vegetated roofs and are recommended for use on buildings on most development and redevelopment sites.

Note: This specification is intended for situations for which the primary design objective of the vegetated roof is stormwater management and, unless specified otherwise, addresses extensive roof systems.

Vegetated roofs are generally designed to have minimal maintenance requirements. Plant species are selected such that the vegetated roof will require minimal irrigation or fertilization after vegetation is initially established.

Vegetated roofs are ideal for use on commercial, institutional, municipal, and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites. Vegetated roofs can be used on a variety of rooftops including:

- Non-residential buildings (e.g., commercial, industrial, institutional, and transportation uses);
- Multi-family residential buildings (e.g., condominiums or apartments); and
- Mixed-use buildings.

Generally, extensive green roofs can be built on flat or sloped roofs, whereas intensive systems are built on flat or tiered roofs (NYDEC 2015). Local regulations may also permit the use of vegetated roofs on single-family residential roofs; however, the designer should verify any requirements or limitations in the local zoning or building codes.

## 3.0 Planning and Considerations

**Table P-FIL-05-1 Common Site Constraints**

| Site Feature | Constraint |
|---|---|
| Structural Capacity of the Roof | When designing a vegetated roof, designers must not only consider the stormwater storage capacity of the vegetated roof, but also its structural capacity to support the weight of the additional water. A conventional rooftop typically must be designed to support an additional 15 to 30 pounds per square foot for an extensive vegetated roof. As a result, a structural engineer, architect, or other qualified professional should be involved with all vegetated roof designs to ensure that the building has enough structural capacity to support a vegetated roof. |
| Roof Pitch | Treatment volume (Tv) is maximized on relatively flat roofs (a pitch of 1% to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing medium. Vegetated roofs can be installed on rooftops with slopes up to 25%; however, a qualified designer should be consulted regarding any vegetated roof proposed for a 2/12 pitch or greater. Further, the drainage system must be carefully designed in conjunction with any baffles, grids, or strips that may be used to prevent slippage of the medium on a sloped roof. The effective Tv of the roof system diminishes on rooftops with steep pitches (Van Woert et al. 2005). |

| Table P-FIL-05-1 Common Site Constraints | |
|---|---|
| **Site Feature** | **Constraint** |
| Roof Access | Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (Northern Virginia Regional Commission [NVRC] 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane) and how construction materials will be stockpiled in the confined space. |
| Roof Type | Vegetated roofs can be applied to most roof surfaces, although concrete roof decks are preferred. Certain roof materials, such as fiberglass shingles, exposed treated wood, and uncoated galvanized metal, may not be appropriate for vegetated rooftops due to pollutant leaching through the medium (Clark et al. 2008). |
| Setbacks | The design of vegetated roofs must be in accordance with the American National Standards Institute (ANSI)/Single Ply Roofing Industry (SPRI)'s VF-1 External Fire Design Standard for minimum criteria for fire breaks and setback dimensions for all roof penetrations such as mechanical sheds, penthouses, ducts, pipes, and skylights as well as rooftop electrical, heating, ventilation, and air conditioning (HVAC), and other mechanical systems. |
| Retrofitting Vegetated Roofs | Retrofitting of existing rooftops would appear to be an attractive option for redevelopment. However, the following key feasibility factors must be considered when evaluating a retrofit:<br>• The structural capacity of the existing rooftop area. This includes a balance between the structural weight tolerances and the required resistance to wind uplift. The designer should refer to the ANSI/SPRI RP-14 Wind Design Standard for Vegetated Roofing Systems;<br>• The age and accessibility of the existing roof.<br>• The capability of the building owner(s) to maintain the roof.<br>Options for vegetated roof retrofits are described in Profile Sheet RR-3 of Schueler et al. (2007). |
| Local Building Codes | Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the vegetated roof design should comply with the Virginia Uniform Statewide Building Code with respect to roof drains and emergency overflow devices. |

| Table P-FIL-05-1 Common Site Constraints | |
|---|---|
| **Site Feature** | **Constraint** |
| Construction Cost | When viewed strictly as stormwater treatment systems, vegetated roofs can cost between $12 and $25 per square foot, ranking them among the costliest stormwater practices available (Moran et al. 2005; Schueler et al. 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency and increased roof longevity due, in part, to the insulating feature of the planting medium (see Risks of Roof Leaks below). These cost saving and energy efficiency benefits could make vegetative roofs a more attractive investment, and some communities offer density bonuses or other incentives for installing vegetated roofs. |
| Risks of Roof Leaks | Well designed and installed vegetated roofs should have fewer problems with roof leaks than traditional roofs due to the protective layer provided by the vegetated roof: ultraviolet light blockage, less temperature-induced expansion and contraction of waterproofing material seams, and projectile blockage. For a discussion on how to properly manage risk in vegetated roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009). |

## 4.0 Stormwater Performance Summary

The overall stormwater functions of vegetated roofs are summarized in Table P-FIL-05-2.

| Table P-FIL-05-2 Summary of Stormwater Functions Provided by Vegetated Roofs | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Reduction Volume | 45% | 60% |
| Total Phosphorus Event Mean Concentration (EMC) Reduction[1] by Best Management Practice (BMP) Treatment Process | 0 | 0 |
| Total Phosphorus Mass Load Removal | 45% | 60% |
| Total Nitrogen EMC Reduction[1] by BMP Treatment Process | 0 | 0 |
| Total Nitrogen Mass Load Removal | 45% | 60% |
| Channel Protection and Flood Mitigation[2] | Use the following Curve Numbers for Design Storm events: 1-year storm = 64; 2-year storm = 66; 10-year storm = 72; 100-year storm = 75 | |

**Notes:**

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008;CWP 2007.

1. Moran et al. (2004) and Clark et al. (2008) indicate no nutrient reduction or even negative nutrient reduction (due to leaching from the medium) in early stages of vegetated roof development.
2. See Miller 2008, NVRC 2007, and Maryland Department of Environment 2008.

## 5.0 Design Criteria

The design goals of vegetated roofs are to hold water for runoff storage, support plant life, minimize total suspended solids and nutrients export, maintain high permeability, and maintain minimum weight (North Carolina Department of Environmental Quality [NCDEQ] 2017).

To this end, designers may choose the baseline design (Level 1) or an enhanced design (Level 2) that maximizes nutrient and runoff reduction. In general, most intensive vegetated roof designs will automatically qualify as Level 2. Table P-FIL-05-3 lists the design criteria for Level 1 and 2 designs.

| Table P-FIL-05-3 Vegetated Roof Design Guidance | |
|---|---|
| **Level 1 Design** | **Level 2 Design** |
| **Runoff Reduction: 45; Total Phosphorous: 0; Total Nitrogen: 0** | **Runoff Reduction: 60; Total Phosphorous: 0; Total Nitrogen: 0** |
| Tv = 1.0 (Rv)[1] (A)/12 | Tv = 1.1 (Rv)1 (A)/12 |
| Depth of media up to 4 inches | Medium depth 4 to 8 inches |
| Drainage System | 2-inch stone drainage layer |
| No more than 20% organic matter in media | No more than 10% organic matter in media |
| All designs must conform to ASTM International (ASTM) Green (Vegetated) Roof Standards (2005). | |

**Note:**

1. Rv represents the runoff coefficient for a conventional roof, which will usually be 0.95. The runoff reduction rate applied to the vegetated roof is for "capturing" the treatment volume (Tv) compared to what a conventional roof would produce as runoff.

### 5.1 Overall Sizing

The required size or depth of a vegetated roof will depend on the porosity and hydraulic conductivity of the growing medium and the underlying drainage materials. Site designers and planners should consult with vegetated roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, the following equation can be used to determine the required water quality treatment storage volume retained by a vegetated roof:

***Equation P-FIL-02-1***

$$\text{Vegetated Roof Volume} = (RA*D*n)/12$$

Where:

RA Storage Volume = roof area storage volume provided in the media (cubic feet).

RA = vegetated roof area (square feet).

D = media depth (inches).

*n* = media porosity (usually 0.25, but consult manufacturer specifications).

The resulting RA storage volume can then be compared to the required Tv for the entire rooftop area (including all non-vegetated areas) to determine whether it meets or exceeds the required Tv for Level 1 or Level 2 design, as shown in Table P-FIL-05-3. Vegetated roofs are not typically designed to capture runoff from other areas of the roof and are considered Level 1 or Level 2 based on the Tv storage volume for the rainfall depth landing on the portion of roof being designed.

### 5.2 Pre-treatment

Pre-treatment is not needed for vegetated roofs.

### 5.3 Elements of a Vegetated Roof System

A vegetated roof is composed of up to eight different systems or layers, from bottom to top, combined to protect the roof and maintain a vigorous vegetation cover. See Table P-FIL-02-4 below.

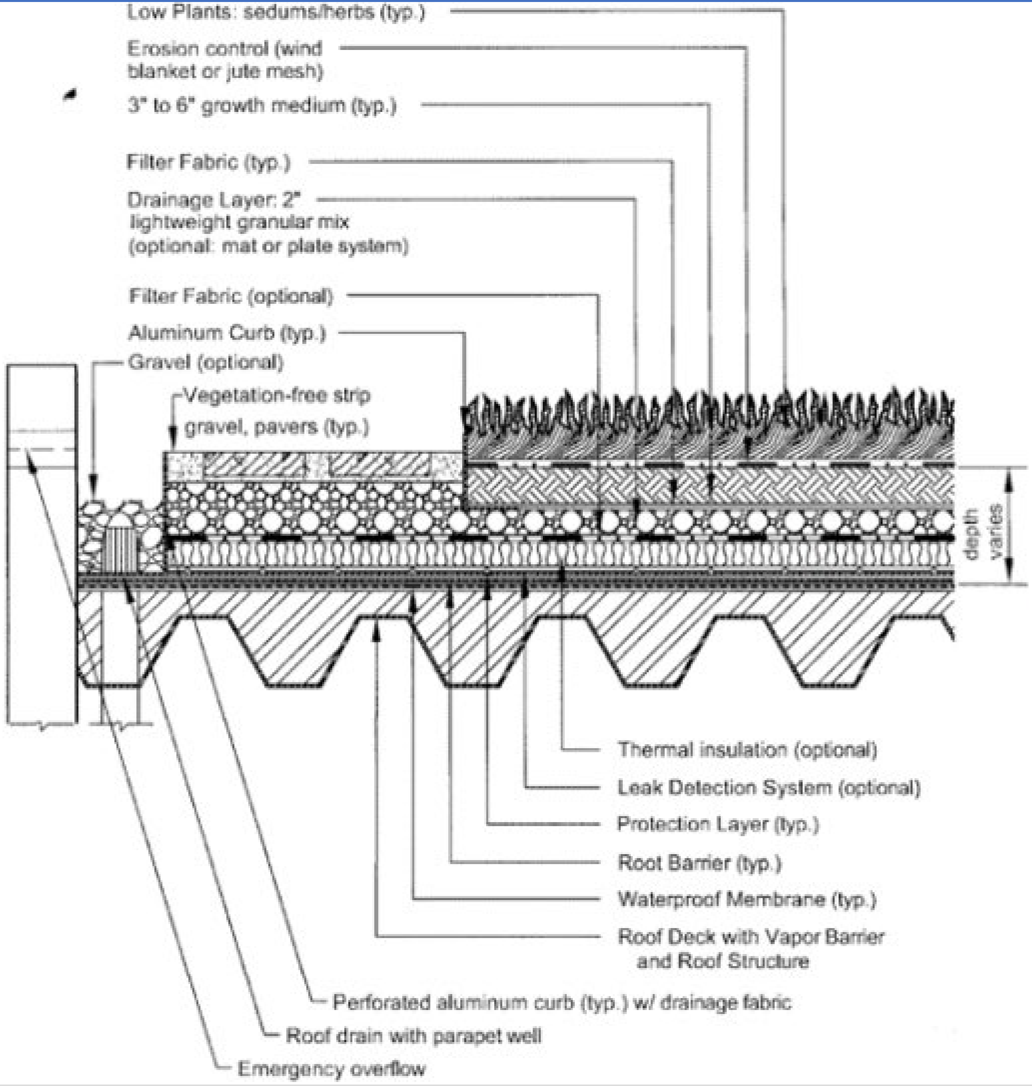
Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system must be assessed to meet design requirements. Some manufacturers offer proprietary vegetated roofing systems, whereas in other cases, the designer or architect must assemble their own system, in which case they are advised to consult Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006), and Dunnett and Kingsbury (2004). See Figure P-FIL-02-1 and Figure P-FIL-02-2 for visual depictions of a vegetated roof system.

| Table P-FIL-02-4 Vegetated Roof Layer Composition | |
|---|---|
| **Layer** | **Composition** |
| Deck Layer | The roof deck layer is the foundation of a vegetated roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load-bearing capacity, longevity, and potential need for insulation and waterproofing in the vegetated roof system. |
| Waterproofing Layer | All vegetated roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. The designer should carefully consider specification and installation of the waterproofing system, as prevention is almost always less costly than repair. The following are key considerations for specifying and installing waterproofing membranes (NCDEQ 2017):<br>1. Specify at least a double-ply waterproofing membrane of high quality or a specialty green roof product such as a heavy-duty, single-ply membrane with felt layer.<br>2. Protect the waterproof membrane throughout construction from nails, screws, or cutting implements. Consider using a drainage mat to provide a physical block for shovels or other gardening implements that could poke holes.<br>3. Test the integrity of the waterproofing layer in place before installing any other features. See Section 6.1 for suggestions on membrane testing methods.<br>4. Cover the waterproof membrane completely with either flashing or growing medium. Any exposed membrane is susceptible to ultraviolet light damage.<br>5. Seal thoroughly around all roof protrusions (e.g., parapets, skylights, mechanical systems, vents). For new construction, roof design should minimize protrusions when a green roof is to be built. Protrusions provide opportunities for leaks in any roof.<br>6. Use a commercial root barrier with the waterproof membrane. Root barriers may be physical or chemical. Some synthetic drainage mats are available with the root barrier already incorporated. Copper, due to its harmful impact on aquatic health, must never be used in root barrier products.<br>The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the vegetated roof system. The design of the waterproofing layer should also consider methods of leak detection. (See Section 6.0, Construction Specifications). |
| Insulation Layer | Many vegetated rooftops contain an insulation layer usually located above (but sometimes below) the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems. |

| Table P-FIL-02-4 Vegetated Roof Layer Composition | |
|---|---|
| **Layer** | **Composition** |
| Root Barrier | The next layer of a vegetated roof system is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options is described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers impregnated with pesticides, metals, or other chemicals that could leach into stormwater runoff should be avoided. Similarly, fibrous systems should be avoided because roots tend to adhere and tangle in the fibers, allowing possible penetration of the waterproofing layer. |
| Drainage Layer and Drainage System | A drainage layer is placed between the root barrier and the growing medium to convey excess water from the vegetation root zone. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, recycled polyethylene) that can retain moisture while also providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used as well as a traditional system of protected roof drains, conductors, and roof leader. Extended retention of water in this layer should be avoided due to potential root rot. The required depth of the drainage layer is governed by both the required stormwater storage capacity and the structural capacity of the rooftop. ASTM Standards E2396 and E2398 can be used to evaluate alternative material specifications.<br><br>Conveyance and Overflow: The drainage should be designed to convey the 10-year storm without water backing up into the growing medium. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the vegetated roof surface. Roof drains adjacent to the growing medium should be boxed and protected by flashing extending at least 3 inches above the growing medium to prevent clogging. |
| Root-Permeable Filter Fabric | A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing medium of a conventional system (not a tray or hybrid system) to prevent the medium from migrating into the drainage layer and clogging it. Proper installation of the fabric is crucial to avoid pooling of water in the drainage layer and leading to root rot. |

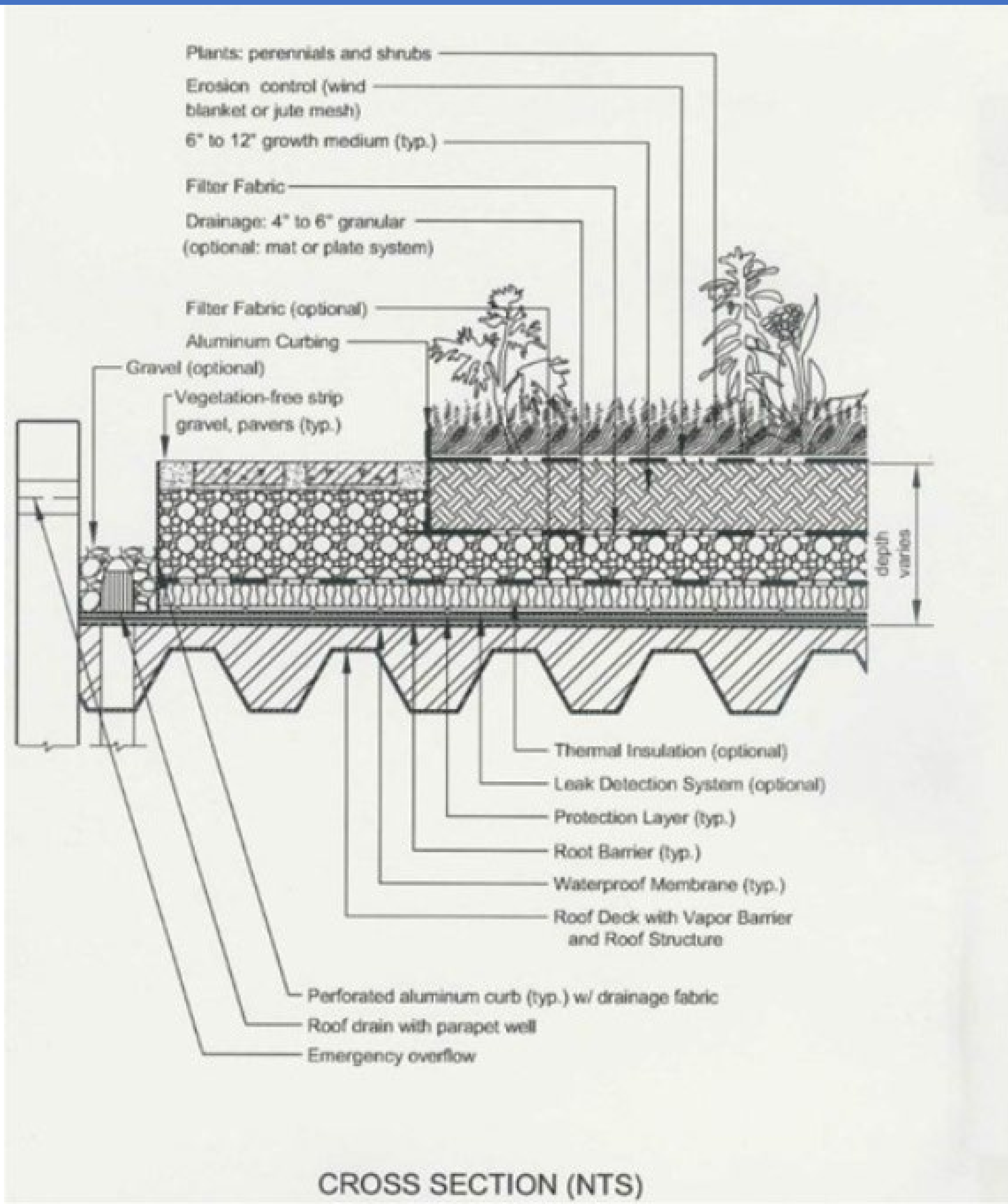
| Table P-FIL-02-4 Vegetated Roof Layer Composition | |
|---|---|
| **Layer** | **Composition** |
| Growing Media | Growing medium for a vegetated roof is typically 2.5 to 8 inches deep. The recommended growing medium for extensive vegetated roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria, or other similar materials. The remaining medium should contain no more than 20% organic matter, normally well-aged compost; see BMP P-FIL-08, Soil Compost Amendment. The percentage of organic matter should be limited because it can clog the permeable filter fabric and lead to increased weed growth while also leaching nutrients into the runoff from the roof. The growing medium should have a maximum water retention capacity of approximately 30%.<br><br>It is advisable to mix the medium in a batch facility before delivery to the roof. More information on growing medium is provided in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006). |
| Vegetation and Surface Cover | The top layer of a vegetated roof consists of shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. Plant selection for vegetated rooftops is an integral design consideration that is governed by local climate and design objectives. A planting plan showing a minimum of 80% plant coverage must be prepared for a vegetated roof by a landscape architect, botanist, or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local development review authority.<br><br>Guidance on selecting the appropriate vegetated roof plants for hardiness zones in the Chesapeake Bay watershed is provided in Snodgrass and Snodgrass (2006). A mix of drought-tolerant Sedum species and accent plants can enhance the visual amenity value of a vegetated roof. |

**Figure P-FIL-02-1 Typical Section – Extensive Vegetated Roof**




*Source: NVRC 2007*

**Figure P-FIL-02-2 Typical Section – Intensive Vegetated Roof**




*Source: NVRC 2007*

### 5.4 Vegetation and Surface Cover

The primary ground cover for most vegetated roof installations is a hardy, low-growing succulent such as *Sedum, Delosperma, Talinum, Semperivum,* or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions of building rooftops (Snodgrass and Snodgrass 2006). Much of the Chesapeake Bay watershed lies within U.S. Department of Agriculture Plant Hardiness Zone 7, although some northern and western areas of the watershed are within the colder Hardiness Zone 6, and some areas in the extreme southeastern portion of the watershed are within the slightly warmer Hardiness Zone 8 (American Horticultural Society 2003).

Table P-FIL-02-5 contains a list of some common vegetated roof plant species that work well in the Chesapeake Bay watershed. Designers may also want to directly contact the short list of mid-Atlantic nurseries for vegetated roof plant recommendations and availability. Designers should encourage the use of at least five species of plants to accommodate seasonal and environmental variation or shifts.

Plant choices can be much more diverse for deeper intensive vegetated roof systems. Herbs, forbs, grasses, shrubs, and even trees can be used, but designers should understand that these carry higher watering, weeding, and landscape maintenance requirements.

The species and layout of the planting plan should reflect the location of building in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire-resistant and able to withstand heat, cold, and high winds.

**Table P-FIL-02-5 Ground Covers for Vegetated Roofs in Zones 6 and 7 of the Chesapeake Bay Watershed**

| Plant Hardiness Zone 7 | Plant Hardiness Zone 6 |
|---|---|
| Delosperma 'Tiffendell Magenta' | Delosperma cooperi |
| Hieracium lanatum | Delosperma ecklonis var.latifolia |
| Sedum lineare 'Variegatum' | Hieracium villosum |
| Sedum makinoi | Orostachys boehmeri |
| Sedum tetractinum | Sedum hispanicum |
| Sedum stoloniferum | Sedum pluricaule var. ezawe |
| | Sedum urvillei |

**Note:**

Landscape architects should choose species based on shade tolerance, ability to sow, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for a definitive list of vegetated roof plants, including accent plants.

- Designers should also match species to optimize the expected rooting depth of the growing medium, which can also provide enough lateral growth to stabilize the growing medium surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on vegetated roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most vegetated roof plant species will *not* be native to the Chesapeake Bay watershed (which is in contrast to *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of vegetated roof plant nurseries in the region, designers should order plants or pre- grown trays at least 6 months (and up to 12 months) before the expected planting or installation date. It is also advisable to have plant materials contract-grown, when feasible.

- When appropriate species are selected, and depending on installation date, most vegetated roofs in the Chesapeake Bay watershed will not require supplemental irrigation, except for possible temporary irrigation during the hot, dry summer months as the vegetated roof is established. More frequent irrigation will likely be required to achieve establishment of a plug-planted system. The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost.
- Plants can be established using cuttings; plugs; mats; and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for vegetated roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation (i.e., minimal mowing, trimming, and weeding) that is self-sustaining.

The vegetated roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the vegetated areas of the roof for weeding and making spot repairs. Installation of walkways should be coordinated with the drainage design.

### 5.5 Material Specifications

Standards specifications for North American vegetated roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. ASTM has issued several overarching vegetated roof standards, which are described and referenced in Table P-FIL-02-6.

**Table P-FIL-02-6 Extensive Vegetated Roof Material Specifications**

| Material | Specification |
|---|---|
| Roof | Structural Capacity should conform to ASTM Standard E-2397-05, Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems. In addition, use standard test methods described in ASTM Standard E2398-05 for Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems, and ASTM Standard E2399-05 for Maximum Media Density for Dead Load Analysis. |
| Waterproof Membrane | See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options designed to convey water horizontally across the roof surface to drains or gutters. This layer may sometimes act as a root barrier. |
| Root Barrier | Impermeable liner that impedes root penetration of the membrane. |
| Drainage Layer | Use 1- to 2-inch layer of clean, washed granular material such as ASTM Standard D 448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with the Virginia Uniform Statewide Building Code. |
| Filter Fabric | Needled, non-woven, polypropylene geotextile.<br>Density (ASTM Standard D3776) greater than 16 ounces per square yard, or approved equivalent. Puncture resistance (ASTM Standard D4833) greater than 220 pounds or approved equivalent. |

| Table P-FIL-02-6 Extensive Vegetated Roof Material Specifications | |
|---|---|
| **Material** | **Specification** |
| Growth Media | Use 80% lightweight inorganic materials and 20% organic matter (e.g., well-aged compost). Medium should have a maximum water retention capacity of approximately 30%. Medium should provide sufficient nutrients and water-holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM Standard E2396-05. |
| Plant Materials | Use sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self- sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM Standard E2400-06, Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems. |

| Table P-FIL-02-7 Extensive Vegetated Roof Additional Design Guidance | |
|---|---|
| **Feature** | **Design Guidance** |
| Structural Capacity of the Roof/Weight | Weight is one of the main factors controlling the feasibility and cost of a green roof. Vegetated roofs can be limited by the additional weight of the fully saturated soil and plants and should be accounted for in the structural design. The designer should consult with a licensed structural engineer or architect to ensure that the building will be able to support the additional live and dead structural load. Dead loads should assume completely saturated media (in lieu of the ASTM weight at the maximum medium water retention) (NCDEQ 2017).<br>The weight of the green roof should be determined per ASTM Standard E2397-11, Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems, and ASTM Standard E2399-11, Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems (NCDEQ 2017). |
| Karst Terrain | Vegetated roofs are ideal stormwater control measures for karst terrain, although it is advisable to direct downspout discharges at least 15 feet away from the building foundation to minimize the risk of sinkhole formation. |
| Coastal Plain Applications | Vegetated roofs are an acceptable runoff reduction practice for the coastal plain, but they have a limited water quality function because rooftops are not a major loading source for nutrients or bacteria. Designers should also choose plant materials that can tolerate drought and salt spray. |
| Cold Climate and Winter Performance | Several design adaptations may be needed for vegetated roofs. The most important is to match the plant species to the appropriate plant hardiness zone. In parts of the Chesapeake Bay watershed with colder climates, vegetated roofs should be designed such that the growing medium is not subject to freeze-thaw and to provide greater structural capacity to account for winter snow loads. |

| Table P-FIL-02-7 Extensive Vegetated Roof Additional Design Guidance | |
|---|---|
| **Feature** | **Design Guidance** |
| Acid Rain | Much of the Chesapeake Bay watershed experiences acid rain, with rainfall pH ranging from 3.9 to 5.1. Research has shown that vegetated roof growing medium can neutralize acid rain (Berhage et al. 2007), but it is not clear whether acid rain will impair plant growth or leach minerals from the growing medium. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence

Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. However, follow these general construction considerations:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method according to manufacturer's specifications.
- Conduct a test to ensure the system is watertight.

The following two methods are used for testing waterproof membranes for leaks (NCDEQ 2017):

- **Flood test**: For flat roofs only. Fill the roof with water and measure water level drop over approximately 24 hours before installing the drainage layer, growing medium, or vegetation. One problem with this method is that very small leaks can be missed. Also, this method can cause damage to the roof if the membrane leaks.
- **Electric Field Vector Mapping (EFVM)**: EFVM is a non-destructive and non-invasive method and may be performed on a sloped roof. A thin layer of water is spread over the geomembrane and a low electrical voltage is applied under the membrane. A leak is present if voltage is detected. The technology indicates the location of the breach, and may also identify future failures (e.g., small punctures that may not have yet fully penetrated the membrane surface).
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) or modules, taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing medium should be mixed before delivery to the site. Medium should be spread evenly over the filter fabric surface. Allow for some settlement by adding additional medium depth. The growing medium should be covered until planting to prevent weeds from growing. Sheets of exterior-grade plywood can also be laid over the growing medium to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing medium to reduce compaction.
- The growing medium should be moistened before planting and then planted with the ground cover and other plant materials per the planting plan or in accordance with ASTM Standard E2400. Plants should be watered and the medium saturated such that water is running from all the vegetated sections of the roof immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the vegetated roof. An initial fertilization using slow-release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth; (pre-grown systems will often include the required fertilization required for establishment). Temporary watering may also be needed during the first summer if drought conditions persist. Hand weeding is also critical in the first 2 years; (see Table 10-1 of Weiler and Scholz-Barth [2009] for a photo guide of common rooftop weeds).

- Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

### 6.2 Construction Inspection

Inspections during construction are needed to ensure that the vegetated roof is built in accordance with these specifications. Detailed inspection checklists should be used that include signoffs by qualified individuals at critical stages of construction and confirmation that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision is needed during the following steps of vegetated roof installation:

- During placement of the waterproofing layer to ensure that it is properly installed and watertight;
- During placement of the drainage layer and drainage system;
- During placement of the growing medium to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants to ensure they conform to the planting plan; and
- Before issuing use and occupancy approvals.

An additional inspection should be conducted at the end of the first or second growing season to ensure that the desired surface cover specified in the Care and Replacement Warranty has been achieved.

Upon final inspection and acceptance, log the Global Positioning System coordinates for the vegetated roof and submit them for entry into the local BMP maintenance tracking database.

## 7.0 Operations and Maintenance Considerations

Maintenance of a vegetated roof must be ensured through written documentation and an enforceable mechanism as per the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) between the VESMP authority and the property owner or manager. Documentation should include provisions for adequate notification or authorization for access to conduct inspections.

In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and plants/medium should be added to repair bare areas (refer to ASTM Standard E2400). Many practitioners also recommend an annual application of slow-release fertilizer in the first 5 years after the vegetated roof is installed.

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., EFVM) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided because their presence could hasten degradation of the waterproof membrane. Also, power washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.

An example maintenance inspection checklist for vegetated roofs is provided in Appendix H, BMP Inspection Checklist.

Records of operation and maintenance must be kept in a known set location and must be available upon request.

| Table P-FIL-02-8 Typical Maintenance Activities Associated with Vegetated Roofs | |
|---|---|
| **Maintenance Activity** | **Schedule** |
| Water to promote plant growth and survival.<br>Inspect the vegetated roof and replace any dead or dying vegetation. | As Needed (following construction) |
| Inspect the waterproof membrane for leaking or cracks. Apply annual fertilization (first 5 years).<br>Weed to remove invasive plants.<br>Inspect roof drains, scuppers, and gutters to ensure they are not overgrown or contain organic matter deposits. Remove any accumulated organic matter or debris.<br>Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed. | Semi-Annually |

Source: NCDEQ 2017.

| Table P-FIL-02-9 Potential Stormwater Control Measure (SCM) Problems and Remedies | | |
|---|---|---|
| **SCM Element** | **Potential Problem** | **How to Remediate the Problem** |
| Plant materials | Weeds are present. | Remove the weeds by hand. For repeat growth of the same weed, systemic weed killer may be applied to the single plant using a cotton swab or paintbrush. Weed killer should not be sprayed. |
| | Plants are dead, diseased, or dying. | Determine the source of the problem (e.g., soils, hydrology, disease). Remedy the problem and replace plants. An alternative species may be required. |
| Growing media | Ponding occurs after the first few rain events. | If not washed before mixing and installation, some aggregates may create a thin surface crust. The crust may be removed by light tilling and should not recur. If it does, consult with the supplier. |
| | Persistent ponding occurs. | Check the particle size distribution of a sample(s) from the area susceptible to ponding. The sample should be representative of the full substrate depth. If particles less than 1 millimeter in diameter exceed 5% by mass, excessive fine particulates are likely the problem. Consult the supplier. The medium may need to be replaced. |
| | Substantial loss of material over time. | Loss can result because of excessive organic matter (>20% by volume) in the medium. Assess whether a reduced medium depth would compromise stormwater retention and hinder permit compliance. Check with a horticultural consultant regarding implications on plant health. Plants should not be sustained by regular fertilizer addition. If needed (and feasible), amend with additional medium. |
| Gutters, drains, and spouts | Clogging has occurred. | Remove leaves, debris, and other foreign matter and dispose of in a manner that will not impact streams or the SCM. Inspect permeable edging and clear if needed. |

| Table P-FIL-02-9 Potential Stormwater Control Measure (SCM) Problems and Remedies | | |
|---|---|---|
| SCM Element | Potential Problem | How to Remediate the Problem |
| | Damage has occurred. | Repair or replace the damaged conveyances. |

Source: NCDEQ 2017.

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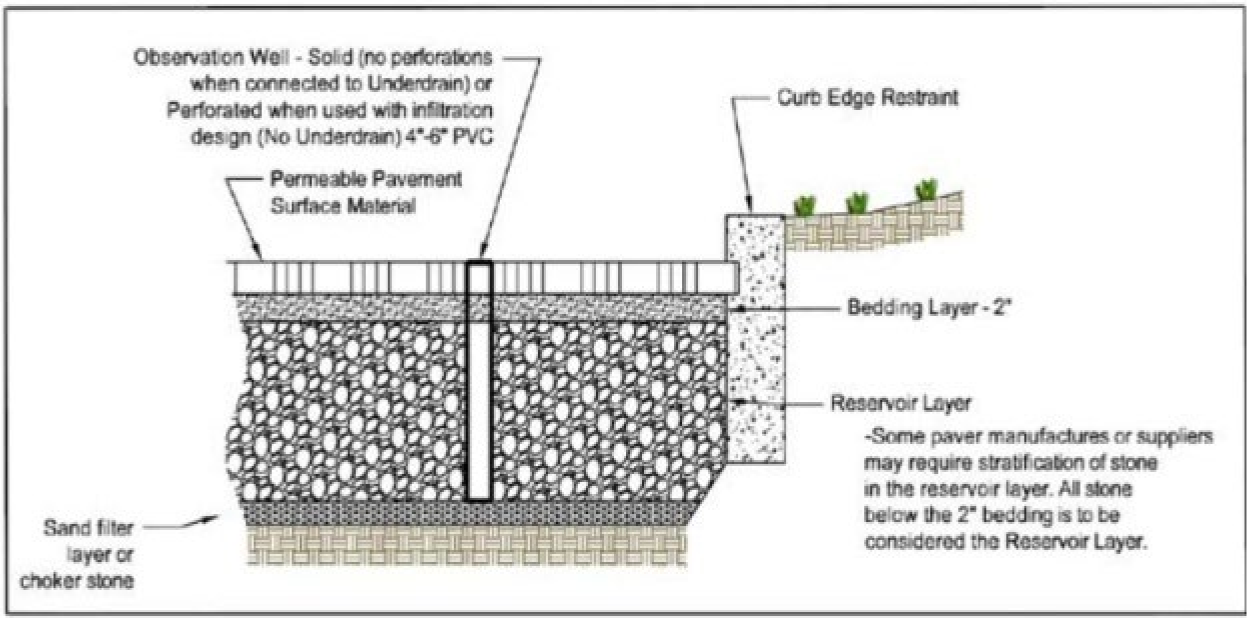
# P-FIL-03 Permeable Pavement

## 1.0 Definition

Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. A variety of permeable pavement surfaces are available, including **pervious concrete, porous asphalt** and permeable grid **pavers** and **interlocking concrete pavers**. Artificial turf can also used as the surface cover for permeable pavement designs. While the specific design may vary, all permeable pavements have a similar structure, consisting of a permeable surface pavement layer, an underlying stone aggregate reservoir layer, and a filter layer or fabric installed on the bottom. See Figure P-FIL-03-1 and Figure P-FIL-03-2.

***Figure P-FIL-03-1 Types of Permeable Pavement: (clockwise from upper left): Concrete Grid Pavers (Chesapeake Stormwater Network); Pervious Concrete (perviouspavement.org), Permeable Interlocking Concrete Pavers (UC Davis), Porous Asphalt (UC Davis)***

**Figure P-FIL-03-2 Typical Cross Section**




## 2.0 Purpose and Applicability of Best Management Practice

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

### 2.1 Feasibility/Limitations

The following feasibility criteria should be evaluated when permeable pavement is considered as the final practice in a treatment train.

| Table P-FIL-03-1 Feasibility Criteria | |
|---|---|
| **Constraint** | **Criteria** |
| Available Space | A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which is an advantage for small sites or areas where land prices are high. |
| Soils | Soil conditions do not constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Groups (HSG) C or D usually require an underdrain, whereas HSG A and B soils often do not. In addition, permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain.<br><br>If the proposed permeable pavement area is designed to infiltrate runoff without underdrains, it must have a field-verified minimum infiltration rate of 0.5 inch per hour. For initial planning purposes, projected soil infiltration rates can be estimated from the U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) soil data, but they must be confirmed by an onsite infiltration measurement for final design. Native soils must have silt/clay content less than 40% and clay content less than 20%. Refer to Appendix C, Soil Characterization and Infiltration Testing, for soil testing requirements and procedures. Soil testing is not needed for Level 1 permeable pavement where an underdrain is used.<br><br>Note: Designers should evaluate existing soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. Areas of HSG A or B soils shown on USDA-NRCS soil surveys should be considered as primary locations for all types of infiltration. |
| External Drainage Area | It is acceptable for an external drainage area to contribute runoff to a permeable pavement installation only when the underlying reservoir is drained by an underdrain. When this is allowed, the external drainage area shall not exceed two and one-half times the surface area of the permeable pavement (ratio of 2.5:1), and it should be as close to 100% impervious as practically feasible. This ratio is intended to facilitate the use of a permeable pavement section in a parking stall to treat an area with the dimensions of the width of the adjacent drive aisle and the length of the opposite parking stall. It is important to note that field experience has shown that an upgradient drainage area (even if impervious) can contribute particulates onto the permeable pavement and lead to clogging (Hirschman et al. 2009). Therefore, careful sediment source control and/or a pretreatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section. Any design with an external drainage area contributing “runon” to the permeable pavement section should include requirements for more frequent operation and maintenance inspections. |

| Table P-FIL-03-1 Feasibility Criteria | |
|---|---|
| **Constraint** | **Criteria** |
| Pavement Slope | Steep slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. Designers should consider using a terraced design for permeable pavement in sloped areas, especially when the local slope is 5% or greater.<br><br>The bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater. However, a maximum longitudinal slope of 1% is permissible if an underdrain and an over-drain are employed. Lateral slopes should be 0%. |
| Minimum Hydraulic Head | The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head may be needed to drive flows through underdrains. Flat terrain may affect proper drainage of Level 1 permeable pavement designs, so underdrains should have a minimum 0.5% slope. |
| Minimum Depth to Water Table | A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonally high water table. |

### 2.2 Setbacks

To avoid the risk of seepage, permeable pavement practices should not be hydraulically connected to structure foundations. Setbacks to structures will vary, based on the size of the permeable pavement installation. See Table P-FIL-03-2.

| Table P-FIL-03-2 Setback/Offset Criteria | |
|---|---|
| **Feature** | **Offset*** |
| 250 to 1,000 square feet of permeable pavement | 5 feet if downgradient from building; 25 feet* if upgradient |
| 1,000 to 10,000 square feet of permeable pavement | 10 feet if downgradient from building; 50 feet* if upgradient |
| More than 10,000 square feet of permeable pavement | 25 feet if downgradient from building; 100 feet* if upgradient |

**Note:**

* In some cases, the use of an impermeable liner along the sides of the permeable pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements can be relaxed.

At a minimum, due to concerns that high concentrations of urban pollutants may be introduced into the pavement via vehicle tires, small spills, etc., permeable pavement applications (using infiltration or an infiltration sump) on commercial properties should be located a minimum horizontal distance of 100 feet from any water supply well and at least 5 feet downgradient from dry or wet utility lines. If groundwater contamination is a concern, it is recommended that groundwater mapping be conducted to determine possible connections to adjacent groundwater wells.

Residential applications should be a minimum horizontal distance of 50 feet from any water supply well and 35 feet from any septic system (20 feet if the stone reservoir is lined). These setbacks are general guidelines and may be adjusted by the local plan-approving authority on residential applications or if underdrains or liners are used, or if other precautions are taken.

Table P-FIL-03-3 outlines design requirements for each of the three scales of permeable pavement installation.

**Table P-FIL-03-3 The Three Design Scales for Permeable Pavement**

| Design Factor | Micro-Scale Pavement | Small-Scale Pavement | Large-Scale Pavement |
|---|---|---|---|
| Impervious Area Treated | 250 to 1,000 square feet | 1,000 to 10,000 square feet | More than 10,000 square feet |
| Typical Applications | Driveways Walkways<br>Court Yards Plazas<br>Individual Sidewalks | Sidewalk Network Fire Lanes<br>Road Shoulders Spill-Over Parking<br>Plazas | Parking Lots with more than 40 spaces<br>Low Speed Residential Streets |
| Most Suitable Pavement | IP | PA, PC, and IP | PA, PC, and IP |
| Load Bearing Capacity | Foot traffic<br>Light vehicles | Light vehicles | Heavy vehicles (moving and parked) |
| Reservoir Size | Infiltrate or detain some or all the Tv | Infiltrate or detain the full Tv and as much of the CPv and design storms as possible | |
| External Drainage Area? | No | Yes, impervious cover up to twice the permeable pavement area may be accepted as long as sediment source controls and/or pretreatment is used | |
| Observation Well | No | No | Yes |
| Underdrain? | Rare | Depends on the soils | Backup underdrain |
| Required Soil Tests | One per practice | Two per practice | One per 5,000 square feet of proposed practice |
| Building Setbacks* | 5 feet if downgradient<br>25 feet if upgradient | 10 feet if downgradient<br>50 feet if upgradient | 25 feet if downgradient<br>100 feet if upgradient |

| Table P-FIL-03-3 The Three Design Scales for Permeable Pavement | | | |
|---|---|---|---|
| Design Factor | Micro-Scale Pavement | Small-Scale Pavement | Large-Scale Pavement |

**Notes:**

* In some cases, the use of an impermeable liner along the sides of the permeable pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements can be relaxed.

CPv = channel protection volume

IP = interlocking pavers

PA = porous asphalt

PC = pervious concrete

Tv = treatment volume

### 2.3 Informed Owner

The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuum sweeping) to maintain the pavement's hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them. The owner may also be required to contract for more frequent periodic inspections conducted by a qualified engineer or contractor if the installation includes external (i.e., run-on) drainage.

### 2.4 High Loading Situations

Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail.

### 2.5 Limitations

Permeable pavement can be used as an alternative to most types of conventional pavement at residential, commercial, and institutional developments, with two exceptions:

Permeable pavement has not been thoroughly tested on high-speed roads in extreme weather conditions,

although it has been successfully applied for low-speed residential streets, parking lanes, and roadway

shoulders.

Permeable pavement should not be used to treat runoff from stormwater hotspots, as noted above. Refer to

BMP P-FIL-04, Infiltration Practices, for more specific guidance regarding hotspots.

### 2.6 Design Scales

Permeable pavement can be installed at the following three scales:

1. The smallest scale is termed **micro-scale pavement**, which applies to converting impervious surfaces to permeable surfaces on small lots and redevelopment projects, where the installations may range from 250 to 1,000 square feet in total area. Where redevelopment or retrofitting of existing impervious areas results in a larger footprint of permeable pavers (i.e., small-scale or large-scale installations, as described below), the designer should implement criteria associated with bearing appropriate loads, installation of observation wells and underdrains, conducting soil tests, and ensuring proper building setbacks, as appropriate for the applicable scale.

2. **Small-scale pavement** applications treat portions of a site between 1,000 and 10,000 square feet in area and include areas that only occasionally receive heavy vehicular traffic.
3. **Large scale pavement** applications exceed 10,000 square feet in area and typically are installed within portions of a parking lot.

Regardless of the scale of the permeable pavement installation, the designer should carefully consider the expected traffic load at the proposed site and the consequent structural requirements of the pavement system. Sites with heavy traffic loads will require a thick aggregate base and, in the case of porous asphalt and pervious concrete, may require the addition of an admixture for strength or a specific bedding design. In contrast, most micro-scale applications should have little or no traffic flow.

## 3.0 Planning and Considerations

### 3.1 Regional and Special Case Design Adaptations

The design adaptations described below permit permeable pavement to be used on a wider range of sites. However, it is important to not force this practice onto marginal sites. Other runoff reduction practices are often preferred alternatives for difficult sites. See Table P-FIL-03-4, Table P-FIL-03-5, and Table P-FIL-03-6.

### 3.2 Karst Terrain

Karst terrain is found in much of the Ridge and Valley physiographic region of Virginia. Karst complicates both land development and stormwater design. A detailed geotechnical investigation may be required for any kind of stormwater design in karst terrain (see Appendix E, Site Assessment and Design Guidelines for Stormwater Management in Karst, Virginia, for further guidance).

- The use of Level 2 (i.e., infiltrative) permeable pavement designs at sites with known karst features may cause the formation of sinkholes (especially for large scale pavement applications) and is, therefore, not recommended. Designers should also avoid a Level 2 permeable pavement design if the site is designated as a severe stormwater hotspot or will discharge to areas known to provide groundwater recharge to an aquifer that is used as a water supply source.
- Micro-scale and small-scale permeable pavement installations are acceptable if they are designed according to Level 1 criteria (i.e., they possess an impermeable bottom liner and an underdrain).

The stone used in the reservoir layer should be carbonate in nature to provide extra chemical buffering capacity.

**Table P-FIL-03-4 Material Specifications for Underneath the Pavement Surface**

| Material | Specification | Notes |
|---|---|---|
| Bedding Layer | PC: None.<br>PA: 2 inches of No. 57 stone.<br>IP: 2 inches of No. 8 stone over 4 inches of No. 57 stone. | ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Should be washed and clean and free of all fines. |
| Reservoir Layer | PC: No. 57 stone. PA: No. 2 stone.<br>IP: No. 2, 3, or 4 stone. | ASTM D448 size No. 57 stone (e.g., 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g., 3 to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be washed and clean and free of all fines. |

| Table P-FIL-03-4 Material Specifications for Underneath the Pavement Surface | | |
|---|---|---|
| **Material** | **Specification** | **Notes** |
| Underdrain | Use 4- to 6-inch diameter perforated PVC (AASHTO M 252) pipe, with 3/8 inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated high-density polyethylene may be used for smaller load-bearing applications). Use perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, to connect with the storm drain system. Ts and Ys should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys. | |
| Filter Layer | The underlying native soils should be separated from the stone reservoir by a thin, 2- to 4-inch layer of choker stone (e.g., No. 8) covered by a 6- to 8-inch layer of coarse sand (e.g., ASTM C33, gradation). | The sand should be placed between the stone reservoir and the choker stone, which should be placed on top of the underlying native soils. |
| Filter Fabric (optional) | Use an appropriate filter fabric for the application based on AASHTO M288-06 Filter Fabric; should have a flow rate greater than 125 gallons per minute per square foot (ASTM D4491), and an AOS equivalent to a US #70 or #80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" soil subgrade, using Federal Highway Administration or AASHTO selection criteria. | |
| Impermeable Liner | Use only in karst regions. Use a 30 mil (minimum) PVC geomembrane liner covered by a 8- to 12-ounce per square yard nonwoven geotextile. | |
| Observation Well | Use a perforated 4- to 6-inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface. | |

**Notes:**

AASHTO = American Association of State Highway and Transportation Officials Standard AOS = apparent opening size

ASTM = ASTM International Standard IP = interlocking pavers

PA = porous asphalt PC = pervious concrete

PVC = polyvinyl chloride

### 3.3 Coastal Plain

Experience in North Carolina and Virginia has shown that properly-designed and installed permeable pavement systems can work effectively in the demanding conditions of the coastal plain, if the following conditions are met:

- The distance from the bottom of the permeable pavement system to the top of the water table must be at least 2 feet.
- If an underdrain is used beneath permeable pavement, a minimum 0.5% slope must be maintained to ensure proper drainage.

| Table P-FIL-03-5 Permeable Pavement Specifications | | |
|---|---|---|
| **Material** | **Specification** | **Notes** |
| Permeable Interlocking Concrete Pavers | Surface open area: 5% to 15%.<br>Thickness: 3.125 inches for vehicles.<br>Compressive strength: 55 MPa.<br>Open void fill media: Aggregate. | Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load. |
| Concrete Grid Pavers | Open void content: 20% to 50%.<br>Thickness: 3.5 inches. Compressive strength: 35 MPa.<br>Open void fill media: Aggregate, topsoil and grass, coarse sand. | Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load. |
| Plastic Reinforced Grid Pavers | Void content: Depends on fill material.<br>Compressive strength: Varies, depending on fill material.<br>Open void fill media: Aggregate, topsoil and grass, coarse sand. | Reservoir layer required to support the structural load. |
| Pervious Concrete | Void content: 15% to 25 %.<br>Thickness: 4 to 8 inches.<br>Compressive strength: 2.8 to 28 MPa.<br>Open void fill media: None. | May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or saturated conductivity/permeability. |
| Porous Asphalt | Void content: 15% to 20%.<br>Thickness: 3 to 7 inches (depending on traffic load).<br>Open void fill media: None. | Reservoir layer required to support the structural load. |

**Notes:**

ASTM = ASTM International Standard MPa = megapascal

### 3.4 Piedmont/Clay Soils

In areas where the underlying soils are not suitable for complete infiltration, permeable pavement systems with underdrains can still function effectively to reduce runoff volume and nutrient loads.

- If the underlying soils have an Ksat of less than 0.5 inch per hour, an underdrain must be installed to ensure proper drainage from the system.
- Permeable pavement should not be installed over underlying soils with a high shrink or swell potential.
- To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain configuration may be used.

### 3.5 Cold Climate and Winter Performance

In cold climates and winter conditions, freeze-thaw cycles may affect the structural durability of the permeable pavement system. In these situations, the following design adaptations may be helpful:

- To avoid damage caused by freezing, designs should not allow water to pond in or above the permeable pavement. An over-drain should be placed at least 6 inches below the pavement section and bedding layer.

- To reduce freezing potential, extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size.
- Be aware of the long-term maintenance concerns described in Table P-FIL-03-6 regarding "Cold Climate or Wintertime Operation" and reference those issues in the Maintenance Agreement for this practice.

| Table P-FIL-03-6 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Requirement** |
| Compliance with the Americans with Disabilities Act (ADA) | Porous concrete and porous asphalt are generally considered to be ADA compliant. Most localities also consider interlocking concrete pavers to be complaint if designers ensure that surface openings between pavers do not exceed 1/2 inch. However, some forms of interlocking pavers may not be suitable for handicapped parking spaces. Interlocking concrete pavers interspersed with other hardscape features (e.g., concrete walkways) can be used in creative designs to address ADA issues. |
| Groundwater Protection | While well-drained soils enhance the ability of permeable pavement to reduce stormwater runoff volumes, they may also increase the risk that stormwater pollutants might migrate into groundwater aquifers. Designers should avoid the use of infiltration-based permeable pavement in areas known to provide groundwater recharge to aquifers used for water supply. In these source water protection areas, designers should include liners and underdrains in large-scale permeable pavement applications (i.e., when the proposed surface area exceeds 10,000 square feet). |
| Stormwater Hotspots | Designers should also certify that the proposed permeable pavement area will not accept any runoff from a severe stormwater hotspot. Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk of spills, leaks, or illicit discharges. Examples include certain industrial activities, gas stations, public works areas, petroleum storage areas (for a complete list of hotspots where infiltration is restricted or prohibited. See BMP P-FIL-04, Infiltration Practices.<br><br>For potential hotspots, restricted infiltration means that a minimum of 50% of the total treatment volume must be treated by a filtering or bioretention practice prior to the permeable pavement system. For known severe hotspots, the risk of groundwater contamination from spills, leaks, or discharges is so great that infiltration of stormwater or snowmelt through permeable pavement is prohibited. |

| Table P-FIL-03-6 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Requirement** |
| Underground Injection Control Permits | The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control Program, which is administered either by the U.S. Environmental Protection Agency (USEPA) or a delegated state groundwater protection agency. In general, the USEPA (2008) has determined that permeable pavement installations are not classified as Class V injection wells, since they are always wider than they are deep. There may be an exception in karst terrain if the discharge from permeable pavement is directed to an improved sinkhole, although this would be uncommon. More guidance on stormwater design in karst terrain can be found in Appendix E, Site Assessment and Design Guidelines for Stormwater Management in Karst, Virginia. |
| Cold Climate or Wintertime Operation | Experience has shown that permeable pavement can operate properly in snow and ice conditions, and there is evidence that a permeable surface increases melting rates compared to conventional pavement (thereby reducing the need for deicing chemicals). However, in larger parking lot applications certain snow management practices need to be modified to maintain the hydrologic function of the permeable pavement. These include not applying sand for traction and educating snowplow operators to keep blades from damaging the pavement surface. The jointing material for interlocking concrete paver systems (typically No. 8 stone) can be spread over surface ice to increase tire traction.<br><br>Additional winter maintenance considerations include:<br><br>• Large snow storage piles should be in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the permeable pavement.<br><br>• Sand or cinders should not be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since this will quickly clog the system. If applied, the materials must be removed by vacuuming in the spring.<br><br>• When plowing plastic reinforced grid pavements, snowplow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt, pervious concrete, and permeable interlocking concrete pavers can be plowed like traditional pavements using similar equipment and settings.<br><br>• Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Salt can be applied, but environmentally sensitive deicers are recommended. Permeable pavement applications will generally require less salt application than traditional pavements. |

| Table P-FIL-03-6 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Requirement** |
| Air and Runoff Temperature | Permeable pavement appears to have some value in reducing summer runoff temperatures, which can be important in watersheds with sensitive cold water fish populations. The temperature reduction effect is greatest when runoff is infiltrated into the sub-base, but some cooling may also occur in the reservoir layer, when underdrains are used. The Interlocking Concrete Pavement Institute® (ICPI 2008) notes that the use of certain reflective colors for interlocking concrete pavers can also help moderate surface parking lot temperatures.<br>*Vehicle Safety.* Permeable pavement is generally considered to be a safer surface than conventional pavement, according to research reported by Smith (2006), Jackson (2007) and the American Concrete Institute® (ACI 2008). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement. |

## 4.0 Stormwater Performance Summary

The overall stormwater functions of permeable pavement are shown in Table P-FIL-03-7.

The choice of what kind of permeable pavement to use is influenced by site-specific design factors and the intended future use of the permeable surface. A general comparison of the engineering properties of the three major permeable pavement types is provided in Table P-FIL-03-8. Designers should check with product vendors and the local plan review authority to determine their specific requirements and capabilities. Other paver options, such as concrete grid pavers and reinforced turf pavers, function in the same general manner as permeable pavement.

| Table P-FIL-03-7 Summary of Stormwater Functions Provided by Permeable Pavement | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Reduction Volume | 45% | 75% |
| Total Phosphorus EMC Reduction1 by BMP Treatment Process | 25% | 25% |
| Total Phosphorus Mass Load Removal | 59% | 81% |
| Total Nitrogen EMC Reduction[1] | 25% | 25% |
| Total Nitrogen Mass Load Removal | 59% | 81% |
| Channel Protection | Use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a Curve Number adjustment[2]; or<br>Design extra storage in the stone underdrain layer and peak rate control structure (optional, as needed) to accommodate detention of larger storm volumes. | |

| Table P-FIL-03-7 Summary of Stormwater Functions Provided by Permeable Pavement | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Flood Mitigation | Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers. | |

**Notes:**

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.

1. Change in event mean concentration (EMC) through the best management practice (BMP). Actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate.
2. USDA-NRCS Technical Release 55 Urban Hydrology for Small Watersheds (TR-55) Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).

| Table P-FIL-03-8 Comparative Properties of the Three Major Permeable Pavement Types | | | |
|---|---|---|---|
| **Design Factor** | **Porous Concrete** | **Porous Asphalt** | **Interlocking Pavers** |
| Scale of Application | Small- and large-scale paving applications | Small- and large-scale paving applications | Micro, small- and large-scale paving applications |
| Pavement Thickness[1] | 5 to 8 inches | 3 to 4 inches | 3 inches |
| Bedding Layer[1,8] | None | 2 inches No. 57 stone | 2 inches of No. 8 stone over 4 inches No. 57 stone[8] |
| Reservoir Layer[2,8] | No. 57 stone | No. 2 stone | No. 2, 3, or 4 stone |
| Construction Properties[3] | Cast in place; 7-day cure; must be covered | Cast in place; 24-hour cure | No cure period; manual or mechanical installation of pre-manufactured units, over 5,000 square feet/day per machine |
| Design Permeability[4] | 10 feet/day | 6 feet/day | 2 feet/day |
| Construction Cost[5] | $8.00 to $15.00 per square foot | $7.00 to $12.50 per square foot | $5.00 to $15.00 per square foot |
| Minimum Batch Size | 500 square feet | 500 square feet | NA |
| Longevity[6] | 20 to 30 years | 15 to 20 years | 20 to 30 years |
| Overflow | Drop inlet or overflow edge | Drop inlet or overflow edge | Surface, drop inlet or overflow edge |
| Temperature Reduction | Cooling in the reservoir layer | Cooling in the reservoir layer | Cooling at the pavement surface and reservoir layer |
| Colors/Texture | Limited range of colors and textures | Black or dark grey color | Wide range of colors, textures, and patterns |
| Traffic Bearing Capacity[7] | Can handle all traffic loads, with appropriate bedding layer design. | | |
| Surface Clogging | Replace paved areas or install drop inlet | Replace paved areas or install drop inlet | Replace permeable stone jointing materials |
| Other Issues | -- | Avoid seal coating | Snowplow damage |
| Design Reference | ACI #522.1.08 | Jackson (2007) | Smith (2006) |

| Table P-FIL-03-8 Comparative Properties of the Three Major Permeable Pavement Types | | | |
|---|---|---|---|
| Design Factor | Porous Concrete | Porous Asphalt | Interlocking Pavers |

**Notes:**

1. Individual designs may depart from these typical cross-sections due to site, traffic and design conditions.
2. Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks.
3. ICPI 2008.
4. Northern Virginia Regional Commission 2007.
5. Based on consultant research.
6. Based on pavement being maintained properly; resurfacing or rehabilitation may be needed after the indicated period.
7. Depends primarily on the onsite geotechnical considerations and structural design computations.
8. Stone sizes correspond to ASTM International Standard D448, Standard Classification for Sizes of Aggregate for Road and Bridge Construction.

## 5.0 Design Criteria

The major design goal of permeable pavement is to maximize nutrient removal and runoff reduction. To this end, designers may choose to use a baseline permeable pavement design (Level 1) or an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the design must meet all design criteria shown in the right-hand column of Table P-FIL-03-9. Illustrations are shown on Figure P-FIL-03-3, Figure P-FIL-03-4, Figure P-FIL-03-5, Figure P-FIL-03-6, and Figure P-FIL-03-7.

**Table P-FIL-03-9 Permeable Pavement Design Criteria**

| Level 1 Design | Level 2 Design |
|---|---|
| Tv = (1)(Rv)(A) / 12<br>The volume reduced by an upstream BMP1 | Tv = (1.1)(Rv)(A) / 12 |
| Soil infiltration is less than 0.5 inch/hour | Soil infiltration rate must exceed 0.5 inch/hour to remove underdrain requirement or use a drawdown design in accordance with Section 5.4. |
| Underdrain required | 1. No underdrain; or<br>2. If an underdrain is used, provide a 12-inch (minimum) stone reservoir infiltration sump below the underdrain invert that meets the drawdown requirements of Section 6.0 Construction Specifications; or<br>3. The Tv stone reservoir volume has at least a 48-hour drain time, as regulated by a control structure. |
| CDA1 = The permeable pavement area plus upgradient parking, if the ratio of external contributing area to permeable pavement does not exceed 2.5:1. | • CDA = The permeable pavement area; or<br>• If option 3 above is used, CDA ratio may be 2.5:1. |

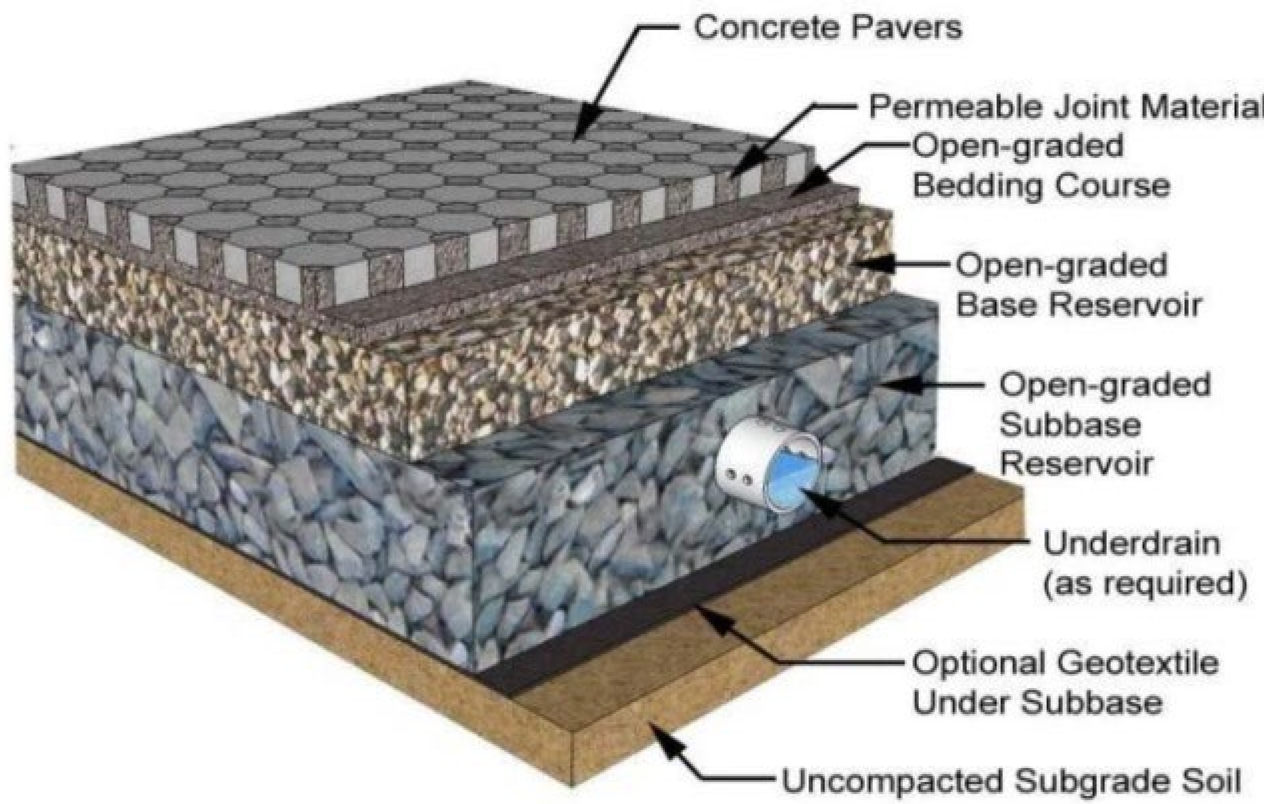
| Table P-FIL-03-9 Permeable Pavement Design Criteria | |
|---|---|
| **Level 1 Design** | **Level 2 Design** |

**Notes:**

1. The contributing drainage area to the permeable pavements should be limited to paved surfaces to avoid sediment wash-on. When pervious areas are conveyed to permeable pavement, sediment source controls and/or pretreatment must be provided strip or sump should be used.

   The pretreatment may qualify for a runoff reduction credit if designed accordingly.

***Figure P-FIL-03-3***




*Source: Smith 2006*

**Figure P-FIL-03-4 Typical Section Permeable Pavement Level 1**

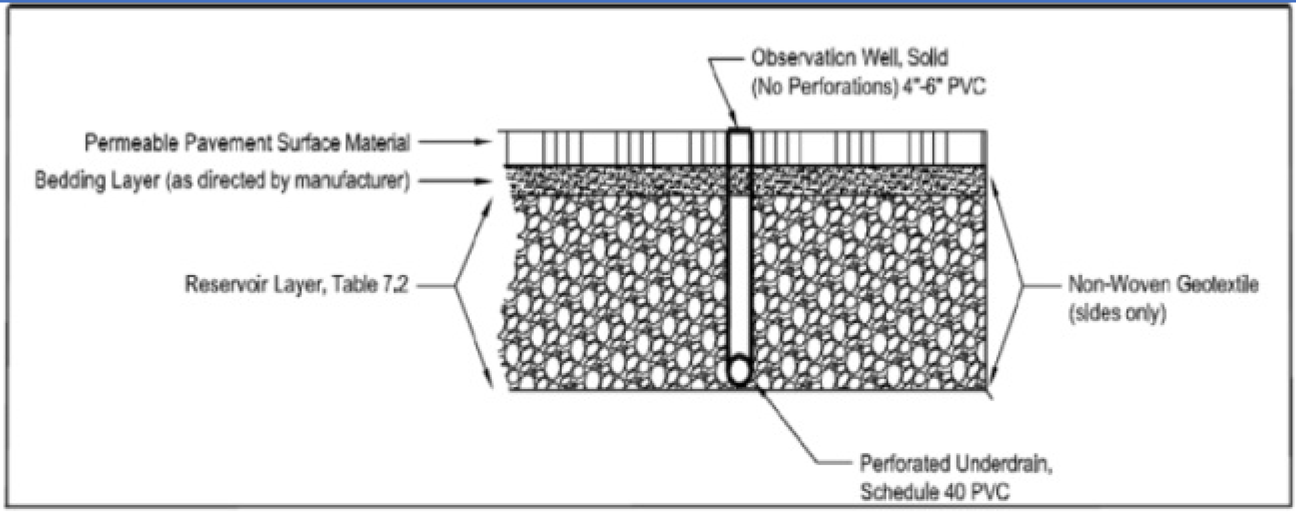



**Figure P-FIL-03-5 Typical Section Permeable Pavement Level 2 with Infiltration Sump**

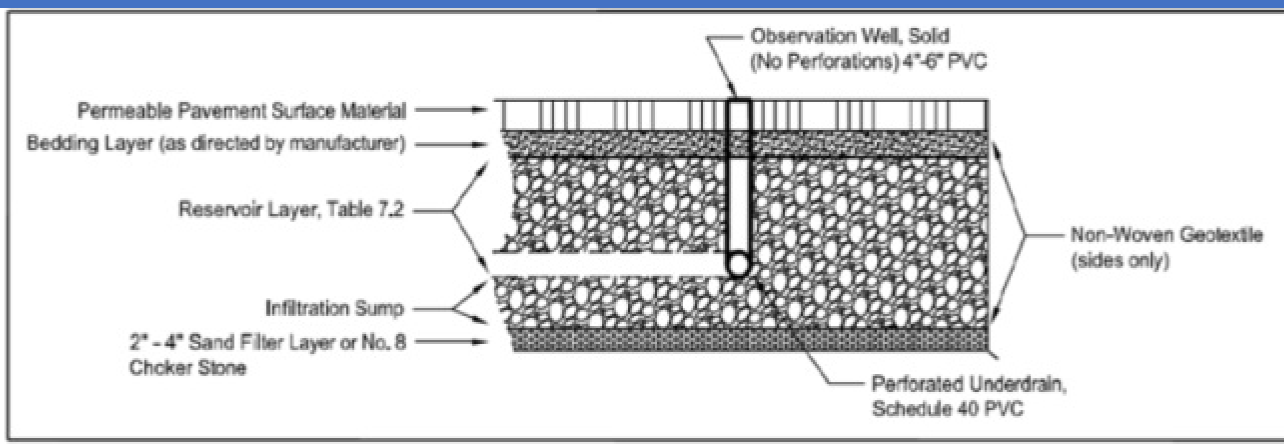


**Figure P-FIL-03-6 Infiltration Sump with an "Upturned Elbow" or Weir Control**

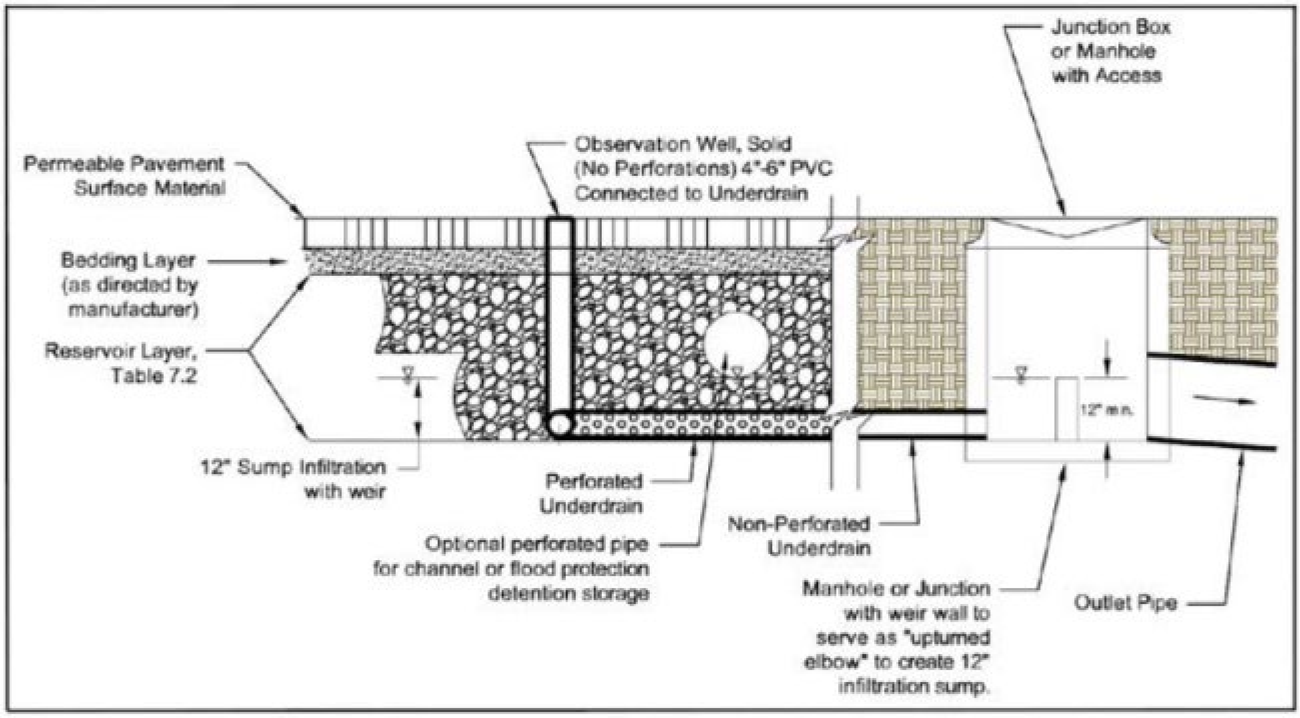
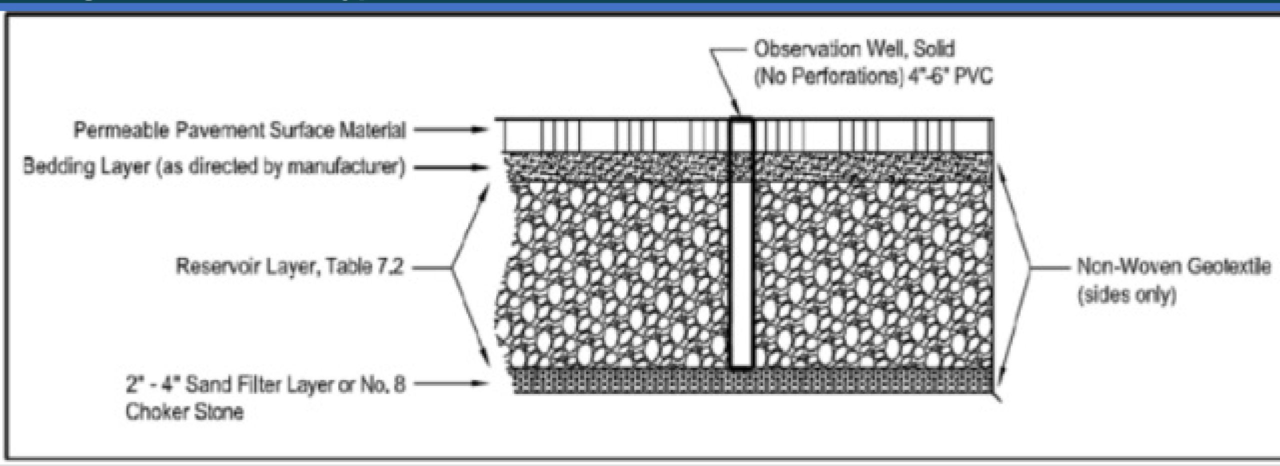



**Figure P-FIL-03-7 Typical Section Permeable Pavement Level 2 with Infiltration**




### 5.1 Sizing of Permeable Pavement

#### 5.1.1 Structural Design

If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design will vary according to the type of pavement selected and the manufacturer's specific recommendations. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Surface materials, bedding and reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally limits their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- Virginia Department of Transportation (VDOT) Pavement Design Guide for Subdivision and Secondary Roads in Virginia (2000; or latest edition);
- AASHTO Guide for Design of Pavement Structures (1993); and
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998).

The structural design process for supporting vehicles varies according to the type of pavement selected. ASTM International test methods for characterizing compressive or flexural strengths of pervious concrete are currently being developed. These tests are needed to model pavement fatigue under loads. As an interim step, fatigue equations published by the American Concrete Pavement Association (ACPA 2010) assume such inputs to be comparable in nature (but not magnitude) to those used for conventional concrete pavements. The ACPA design method should be consulted for further information.

General guidelines for pervious concrete surface thickness are published by the National Ready Mix Concrete Association and the Portland Cement Association (Leming 2007).

Porous asphalt (Hansen 2008) and permeable interlocking pavements (Smith 2010) use flexible pavement design methods adopted from the AASHTO Guide for Design of Pavement Structures (1993). In addition, manufacturer's specific recommendations should be consulted.

Concrete grids only see intermittent traffic and generally only require a minimum 8-inch thick compacted, dense-graded base. The minimum open-graded base and sub-base thicknesses under permeable interlocking concrete grid pavement can generally be used for water storage.

There has been little research or full-scale testing of the structural behavior of open-graded bases used under permeable pavements in order to better characterize the relationships between loads and deformation. Therefore, conservative values (i.e., AASHTO layer coefficients) should be assumed for open-graded base and sub-base aggregates in permeable pavement design.

Regardless of the type of permeable pavement, structural design methods should account for the following in determining surface and base thicknesses to support vehicular traffic:

- Pavement life and total anticipated traffic loads, expressed as 18,000-pound equivalent single axle loads (ESALs); this method of assessing loads accounts for the additional pavement wear caused by trucks;
- Soil strength, expressed in terms of the soaked California Bearing Ratio (CBR), R-value, or resilient modulus (Mr);
- Strength of the surfacing, base, and sub-base materials; and
- Environmental factors, including freezing climates and extended saturation of the soil subgrade.

Soil stability under traffic should be carefully reviewed for each application by a qualified geotechnical or civil engineer and the lowest anticipated soil strength or stiffness values used for design. Structural design for vehicular applications assumes the following:

- Minimum soil CBR of 4% (96-hour soaked per ASTM D1883 or AASHTO T-193); or
- Minimum R-value = 9 per ASTM D2844 or AASHTO T-190; or
- Minimum Mr of 6,500 pounds per square inch (45 MPa) per AASHTO T-307.

Soil compaction required to achieve this criterion will reduce the infiltration rate of the soil. Therefore, the permeability or infiltration rate of soil should be assessed at the density required to achieve one of these values.

**Hydraulic Design**

The permeable pavement reservoir layer is typically sized to store the water quality treatment volume (*Tv*) and, in some cases, the additional detention volume from larger storms. The infiltration rate will be significantly less than the flow rate through the pavement, so the outflow attributed to infiltration is typically ignored. Equation P-FIL-03-1 is used to determine the depth of the stone reservoir layer required to capture and fully infiltrate the design *Tv* into the underlying soil.

***Equation P-FIL-03-1***

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_p)}{\eta_r \times A_p}$$

Where:

$dstone$ = Depth of the stone reservoir layer (feet).

$P$ = The rainfall depth (in feet) for the Treatment Volume (Level 1 = 1 inch [0.08 foot]; Level 2 = 1.1 inch [0.09 foot]), or other design storm.

$AI$ = Contributing impervious drainage area (square feet).

$RvI$ = Volumetric runoff coefficient for impervious cover = 0.95.

$AP$ = Area of permeable pavement (square feet).

$\eta r$ = Porosity of reservoir layer (0.4).

Notes for Equation P-FIL-03-1:

1. When contributing drainage area consists of pervious or combined pervious and impervious, the term $AI$ will refer to the contributing drainage area and the term $RvI$ will be the corresponding volumetric runoff coefficient as calculated using the VRRM Compliance Spreadsheet (or refer to Appendix A for the weighted Rv computation formula).
2. The area of contributing drainage is limited to a ratio of 2.5:1 (external drainage area to the area of permeable pavement) and is allowed only on installations where the stone reservoir is drained by an underdrain; (see Table P-FIL-03-9 above, Level 1 and Level 2 Design Option 3).
3. Equation P-FIL-03-1 assumes that the area or footprint of the stone reservoir is the same as that of the permeable pavement.
4. In cases of highly permeable soils, designers may modify Equation P-FIL-03-1 to account for the outflow of the exfiltration into the subsoils.

When designing permeable pavement Level 2 with infiltration or an infiltration sump, the maximum allowable depth of the reservoir layer (or the infiltration sump) is constrained by the maximum allowable drain time, which is established as two days (48 hours). The maximum reservoir depth is calculated using Equation P-FIL-03-2.

***Equation P-FIL-03-2***

$$d_{stone-max} = \frac{\frac{1}{2}i + t_d}{\eta_r \times 12}$$

Where:

$d_{stone-max}$ = The maximum depth of the infiltration reservoir or the infiltration sump (feet).

$i$ = The field-verified infiltration rate for the native soils (inch/hour).

$t_d$ = The maximum allowable time to drain the reservoir layer or sump, 48hours.

$\eta_r$ = Porosity of reservoir layer.

If the depth of the reservoir layer is too great (i.e., $d_{stone}$ exceeds $d_{stone-max}$), or the verified soil infiltration rate is less than 0.5 inch per hour, then the design must include underdrains. An infiltration sump can be installed below the underdrain (to achieve Level 2 performance credit) with soil infiltration rates as low as 0.1 inch per hour.

However, for the volume of the infiltration sump to count for *Tv* storage, the field-verified infiltration rate must be at least 0.5 inch per hour. If the field verified infiltration rate is less than 0.5 inch per hour, the sump will still qualify the facility as a Level 2 design; however, any additional storage needed to hold the Tv must be added above the sump through additional stone. As an option, the entire Tv can be drained by the underdrain with a design drain time of 48 hours, using a control structure on the underdrain outlet.

Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with receiving channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, expected soil infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

The permeability of the pavement surface and that of the gravel media is very high. However, the permeable pavement reservoir layer will drain increasingly slower as the storage volume decreases (i.e., the hydraulic head decreases). To account for this change, a conservative stage discharge relationship should be established for routing flow through the stone reservoir. The underdrains can provide hydraulic control to limit flows, or an external control structure can be used at the outlet of the system.

### 5.2 Over-drain Relief

In all cases, an over-drain (i.e., a perforated pipe drain near the top of the stone reservoir and below the pavement section) should be used to prevent the volume of runoff from backing up into the pavement surface. On pavement sections with a long grade, designers should use a stepped design with an over-drain in each cell to establish level reservoir storage areas and prevent flow from exiting the pavement through the surface at the low end of the grade.

### Testing the Soil Infiltration Rate

To design a permeable pavement system without an underdrain, the measured infiltration rate of subsoils must be 0.5 inch per hour or greater. Procedures for testing the site's soil infiltration rate are outlined in BMP P-FIL-04, Infiltration Practices. A minimum of one soil profile and two infiltration tests must be conducted for each facility that has up to 2,500 square feet of surface area. Refer to Appendix C, Soil Characterization and Infiltration Testing, for the number of soil explorations required for larger systems.

### 5.3 Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in Table P-FIL-03-9 and designed according to the product manufacturer's recommendations.

### 5.4 Internal Geometry and Drawdowns

**Elevated Underdrain (or “upturned elbow”)**. To promote greater runoff reduction for permeable pavement located on marginal soils, an underdrain should be placed above an infiltration sump as shown on Figure P-FIL-03-5, or it can be placed at the bottom of the reservoir sump with an upturned elbow configuration as shown on Figure P-FIL-03-6. This configuration places the perforated underdrain at the bottom of the stone reservoir layer, with the outlet elevated to the same elevation as the top of the sump. The underdrain transitions to a solid-wall pipe prior to exiting the stone reservoir layer and is directed toward an outlet manhole or other structure. To create the higher outlet elevation, the outlet manhole is configured with an internal weir wall, with the top of the weir set at the same elevation as the top of the stone sump, rather than a vertical bend or elbow on the outlet pipe. This configuration is preferred for ease of maintenance. This design variant can also include a drain orifice in the bottom of the weir to allow the sump to be drained if, over time, the exfiltration into the soil becomes restricted. This orifice should be covered with a plate with a clear label or other indication that it remains blocked under normal operating conditions.

**Infiltration Sump**. An infiltration sump qualifies the permeable pavement as a Level 2 design; however, the field-verified infiltration rate must be at least 0.5 inch per hour in order for the volume of the infiltration sump to count toward the required Tv storage.

**Slow Drawdown**. The permeable pavement stone reservoir should be designed to detain the design Tv runoff reduction storage volume. Extending the drawdown for at least 48 hours promotes infiltration even in marginal soils and, therefore, qualifies the design for the Level 2 credit. Control of the drawdown can best be achieved through the design of the weir/control structure in the outlet manhole or junction box.

**Conservative Infiltration Rates**. Designers should always decrease the measured infiltration rate by a factor of 2 during design (see Equation P-FIL-03-2) to approximate long term infiltration rates.

### 5.5 Pretreatment

Pretreatment for most permeable pavement applications is not necessary since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment is required if the pavement receives run-on from an adjacent pervious or impervious area. For example, a gravel filter strip can be placed along the edge of the permeable pavement section to trap coarse sediment particles before they reach the permeable pavement surface. Refer to BMP P-SUP-06, Pre-Treatment, for design guidance on gravel filter strips or diaphragms.

### 5.6 Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-year, 10-year) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The over-drain pipe should be perforated on the underside only such that the incoming runoff is not captured until the reservoir layer is filled.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (i.e., create freeboard).
- However, the design computations used to size the reservoir layer should not include the additional volume for freeboard.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic, or concrete arch structures, etc. Refer to BMP P-SUP-07, Quantity Only Approach to BMPs.
- Route excess flows to another detention or conveyance system that is designed for the management of extreme event flows.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff away from the system. The design should also make allowances

for relief of unacceptable ponding depths during larger rainfall events, as would be required on traditional paved areas.

### 5.7 Reservoir Layer

The thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and the frost depth. A soils or geotechnical professional should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer should consist of clean washed stone. The bottom of the reservoir layer or infiltration sump may be completely flat so that runoff will infiltrate evenly through the entire surface. Where underdrains are used in areas of marginal soils, a slight grade of 0.5% may be used to ensure the reservoir drains.

### 5.8 Underdrains

The use of underdrains is recommended when underlying soils have an infiltration rate of less than 0.5 inch per hour, or when there is a reasonable potential for infiltration rates to decrease over time, or when soils must be compacted to achieve a desired proctor density. Underdrains can also be used to manage extreme storm events and keep detained stormwater from backing up into the permeable pavement.

- An underdrain(s) should be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- The underdrain outlet can be fitted with a flow-reduction orifice as a means of regulating the stormwater detention time. The minimum diameter of any orifice should be 0.5 inch.
- An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability. The underdrain pipe should be straight or include cleanouts above at 45 degree (maximum) horizontal bends, as shown on Figure P-FIL-03-7.
- The perforated underdrain pipe should transition to solid wall pipe before exiting the stone reservoir.

### 5.9 Maintenance Reduction Features

Maintenance is a crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment, which can be reduced by the following measures:

- **Periodic Vacuum Sweeping**. The pavement surface is the first line of defense in trapping and eliminating sediment that may otherwise enter the stone base and soil subgrade. The rate of sediment deposition should be monitored, and vacuum sweeping performed once or twice per year. This frequency should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. At least one sweeping pass should occur at the end of winter.
- **Protecting the Bottom of the Reservoir Layer**. There are two options to protect the bottom of the reservoir layer from intrusion by underlying soils. The first method involves covering the bottom with a barrier of choker stone and sand. In this case, underlying native soils should be separated from the reservoir base/subgrade layer by a thin 2- to 4-inch layer of clean, washed, choker stone (i.e., ASTM D448 No. 8 stone) covered by a layer of 6 to 8 inches of course sand.
- The second method is to place a layer of filter fabric on the native soils at the bottom of the reservoir. Some practitioners recommend avoiding the use of filter fabric, since it may become a future plane of clogging within the system; however, designers should evaluate the paving

application and refer to AASHTO M288-06 for an appropriate fabric specification. AASHTO M288-06 covers six geotextile applications: Subsurface Drainage, Separation, Stabilization, Permanent Erosion Control, Sediment Control, and Paving Fabrics. However, AASHTO M288-06 is not a design guideline. It is the engineer's responsibility to choose a geotextile for the application that takes into consideration site-specific soil and water conditions. Fabrics for use under permeable pavement should, at a minimum, meet criterion for Survivability Classes (1) and (2). Permeable filter fabric is still recommended to protect the excavated sides of the reservoir layer, to prevent soil piping.

- **Observation Well**. An observation well consisting of a well-anchored, perforated 4- to 6-inch (diameter) PVC pipe that extends vertically to the bottom of the reservoir layer should be installed at the downstream end of all large-scale permeable pavement systems. The observation well should be fitted with a lockable cap installed flush with the ground surface (or under the pavers) to facilitate periodic inspection and maintenance. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event.
- **Overhead Landscaping**. Many local communities now require from 5% to 10% (or more) of the area of parking lots to be in landscaping. Large-scale permeable pavement applications should be carefully planned to integrate this landscaping in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and other organic material will inadvertently clog the paving surface.

## 6.0 Construction Specifications

Experience has shown that proper installation is critical to the effective operation of a permeable pavement system.

### 6.1 Necessary Erosion and Sediment Controls

- All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should be clearly marked on all construction documents and grading plans. To prevent soil compaction, heavy vehicular and foot traffic should be kept out of permeable pavement areas during and immediately after construction.
- During construction, do not track sediments onto any permeable pavement surface to avoid clogging.
- Any area of the site intended to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub-base, base, and surface materials.

### 6.2 Permeable Pavement Construction Sequence

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified to depending on whether porous asphalt, pervious concrete, or interlocking paver designs are employed.

***Step 1.*** Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen aggregate materials.

***Step 2.*** As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials that are contaminated by sediments must be removed and replaced with clean materials.

***Step 3.*** Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For micro-scale and small-scale pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can use a cell construction approach, whereby the proposed permeable pavement area is split into 500- to 1,000-square-foot temporary cells with a 10- to 15-foot earth bridge in between, such that cells can be excavated from the side. Excavated material should be placed away from the open excavation to prevent jeopardizing the stability of the side walls.

***Step 4.*** The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or filter fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (Note: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design.)

***Step 5.*** The filter layer should be installed on the bottom of the reservoir layer and, where appropriate, filter fabric can be placed on the sides.

***Step 6.*** Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down toward the outlet at a grade of 0.5% or steeper. The upgradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there should be no perforations within 1 foot of the structure. Ensure that there are no perforations in cleanouts and observation wells within 1 foot of the surface.

***Step 7.*** Spread 6-inch lifts of the appropriate clean, washed stone aggregate. Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

***Step 8.*** Install over-drain if required and connect into the outlet conveyance system.

***Step 9.*** Install the desired depth of the bedding layer, depending on the type of pavement, as follows:

- **Pervious Concrete**: No bedding layer is used.
- **Porous Asphalt**: The bedding layer for porous asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D448 No.57 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four passes of a 10-ton steel drum static roller.
- **Interlocking Pavers**: The bedding layer for open-jointed pavement blocks should consist of 2 inches of washed ASTM D448 No.8 stone.

***Step 10.*** Install paving materials in accordance with manufacturer or industry specifications for the pavement.

- **Installation of Porous Asphalt**. The following has been excerpted from various documents, most notably Jackson (2007).

1. Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be

between 230 degrees Fahrenheit (°F) and 260°F, with a minimum air temperature of 50°F to ensure that the surface does not stiffen before compaction.

2. Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
3. The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM D1664. If the estimated coating area is not above 95%, additional antistripping agents must be added to the mix.
4. Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. Cover the mix during transportation to control cooling.
5. Test the full permeability of the pavement surface by application of clean water at a rate of at least 5 gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
6. Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding to determine whether the facility is draining properly.

- **Installation of Pervious Concrete**. The basic installation sequence for pervious concrete is outlined by ACI (2008). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the National Ready Mixed Concrete Association. The basic installation procedure is as follows:

1. Drive the concrete truck as close to the project site as possible.
2. Water the underlying aggregate (reservoir layer) before the concrete is placed, so that the aggregate does not draw moisture from the freshly laid pervious concrete.
3. After the concrete is placed, strike off/remove approximately 3/8 to 1/2 inch using a vibratory screed. This is to allow for compaction of the concrete pavement.
4. Compact the pavement with a steel pipe roller. Care should be taken so that over compaction does not occur.
5. Cut joints for the concrete to a depth of 1/4 inch.
6. The curing process is very important for pervious concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least 7 days. Do not allow traffic on the pavement during this time.

- **Installation of Interlocking Pavers**. The basic installation process is described in greater detail by Smith (2006). Permeable paver job foremen should successfully complete the ICPI's Interlocking Concrete Paver Installer Course or Permeable Interlocking Concrete Pavement Course. The following installation method also applies to clay paving units. Contact manufacturers of composite units for installation specifications.

1. Moisten, place, and level the No. 2 stone sub-base and compact it in minimum 12-inch-thick lifts with four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
2. Place edge restraints before the base layer, bedding and pavers are installed. Permeable interlocking pavement systems require edge restraints to prevent vehicle loads from moving the pavers. Edge restraints may be standard concrete curbs or curbs and gutters.
3. Moisten, place, and level the No. 57 base stone in a single lift (4 inches thick). Compact it into the reservoir course beneath with at least four passes of a 10-ton steel drum

static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode.

4. Place and screed the bedding course material (typically No. 8 stone, 2 inches thick).
5. Place pavers by hand or with mechanical installers.
6. Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third of the full unit size, if subject to tire movement.
7. Fill the joints and openings with stone. Joint openings must be filled with No. 8 or 9 stone per the paver manufacturer's recommendation. Sweep and remove excess stones from the paver surface.
8. Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000 pound-force, 75- to 95-hertz plate compactor. Do not compact within 6 feet of the unrestrained edges of the pavers.
9. Thoroughly sweep the surface after construction to remove all excess aggregate.
10. Inspect the area for settlement. Any paving units that settle must be reset and reinspected.
11. The contractor should return to the site within 6 months to top up the paver joints with stones.

### 6.3 Construction Inspection

Inspections before, during, and after construction are needed to ensure that permeable pavement is built in accordance with these specifications. Use a detailed inspection checklist that requires signoffs by qualified individuals at critical stages of construction and ensure that the contractor's interpretation of the plan is consistent with the designer's intent. The basic elements of a permeable pavement construction checklist are provided at the end of this design specification.

Once the final construction inspection has been completed, log the Global Positing System coordinates for each facility and submit them for entry into the local BMP maintenance tracking database. It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when upgradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles that are often produced shortly after conventional asphalt is laid down.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the permeable pavement BMP, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification requirements to the local program upon transfer of ownership, and right-of-entry for local program personnel.

- The Regulation requires that all post-construction BMPs, including permeable pavement installations, must be covered by a long-term maintenance agreement and drainage easement to allow inspection and maintenance.
- The maintenance agreements should note which conventional parking lot maintenance tasks must be avoided. Signs should be posted on large parking lots to indicate their stormwater function and special maintenance requirements. When micro-scale or small-scale permeable pavement are installed on private residential lots, owners should be provided a document that explains the purpose of the permeable pavement and outlines: (1) the routine maintenance needs; (2) the long-

term maintenance plan; and (3) the basic parameters of the deed restriction, drainage easement, or other mechanism enforceable by the VESMP authority to help ensure that the permeable pavement system is maintained and functioning.

- The mechanism should, if possible, grant authority for the VESMP Authority to access the property for inspection or corrective action.

**7.2 Maintenance Tasks**

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. Most installations work reasonably well year after year with little or no maintenance, whereas some have problems right from the start.

The following activities must be avoided on all permeable pavements:

- Sanding;
- Resealing;
- Resurfacing;
- Power washing;
- Storage of snow piles containing sand;
- Storage of mulch or soil materials; and
- Construction staging on unprotected pavement.

A preventative maintenance task for large-scale applications involves regenerative air vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the small stones between pavement blocks.

**Table P-FIL-03-10 Recommended Maintenance Tasks for Permeable Pavement Practices**

| Task Maintenance | Frequency[1] |
|---|---|
| For the first 6 months following construction, the practice and contributing drainage area should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization. | After installation |
| Mow grass in grid paver applications. | At least once every 1 to 2 months during the growing season |
| Stabilize the contributing drainage area to prevent erosion. Remove any soil or sediment deposited on pavement.<br>Replace or repair any necessary pavement surface areas that are degenerating or spalling. | As needed |
| Vacuum pavement with a standard street sweeper to prevent clogging. | 2 to 4 times per year (depending on use) |
| Conduct a maintenance inspection.<br>Spot weed grass applications. | Annually |

| Table P-FIL-03-10 Recommended Maintenance Tasks for Permeable Pavement Practices | |
|---|---|
| **Task Maintenance** | **Frequency[1]** |
| Remove any accumulated sediment in pretreatment cells and inflow points. | Once every 2 to 3 years |
| Conduct maintenance using a regenerative street sweeper. Replace any necessary joint material. | If clogged |

**Note:**

1. Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.

### 7.3 Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications.

Maintenance of permeable pavement is driven by annual inspections that evaluate the condition and performance of the practice. Any permeable pavement installation that captures external drainage (run-on) should be inspected more frequently during the first year (including during all four seasons) to ensure that there are no unexpected loads of sediment or pavement particulates from the contributing area. If so, the property owner should assess ways to limit the contributions, or the maintenance schedule should be adjusted to ensure the pavement does not become clogged.

The following are suggested routine annual maintenance inspection points for permeable pavements:

- The drawdown rate should be measured at the observation well for 3 days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after 3 days, this is a clear sign that clogging is a problem.
- Inspect the surface of the permeable pavement for evidence of sediment deposition, organic debris, staining, or ponding that may indicate surface clogging. If any signs of clogging are noted, schedule a vacuum sweeper (do not use brooms or water spray) to remove deposited material. Then, test sections by pouring water from a 5-gallon bucket to verify the clogging has stopped and the permeable pavement is working properly.
- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration such as slumping, cracking, spalling, or broken pavers. Replace or repair affected areas, as necessary.
- Check inlets, pretreatment cells, and any flow diversion structures for sediment buildup and structural damage. Note whether any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Generally, inspect any contributing drainage area for any controllable sources of sediment or erosion.

An example maintenance inspection checklist for permeable pavement is provided in Appendix H, BMP Inspection Checklist. Based on inspection results, specific maintenance tasks will be triggered and scheduled to keep the facility in operating condition.

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# P-FIL-04 Infiltration Practices

## 1.0 Definition

Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices have the greatest runoff reduction capability of any stormwater practice and are suitable for use in residential and other urban areas where *measured* soil permeability rates exceed 1/2 inch per hour. To prevent possible groundwater contamination, infiltration should not be used at sites designated as stormwater hotspots.

## 2.0 Purpose and Applicability of Best Management Practice

Since infiltration practices have a very high runoff reduction capability, they should always be considered when initially evaluating a site. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of Hydrologic Soil Group A or B soils shown on U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) soil surveys should be considered as primary locations for infiltration practices. At this point, designers should carefully identify and evaluate constraints on infiltration, as follows:

***Contributing Drainage Area.*** The maximum contributing drainage area (CDA) to an individual infiltration practice should be less than 2 acres and as close to 100% impervious as possible. This specification covers three scales of infiltration practices: Micro-infiltration (250 to 2,500 square feet of CDA); small-scale infiltration (2,500 to 20,000 square feet of CDA); and conventional infiltration (20,000 to 100,000 square feet of CDA). The design, pretreatment and maintenance requirements differ, depending on the scale at which infiltration is applied. See Table P-FIL-04-1 for a summary.

**Table P-FIL-04-1 The Three Design Scales for Infiltration Practices**

| Design Factor | Micro-Infiltration | Small-Scale Infiltration | Conventional Infiltration |
|---|---|---|---|
| Impervious Area Treated | 250 to 2,500 square feet | 2,500 to 20,000 square feet | 20,000 to 100,000 square feet |
| Typical Practices | Dry Well<br>French Drain Paving Blocks | Infiltration Trench<br>Permeable Paving[1] | Infiltration Trench<br>Infiltration Basin |
| Minimum Infiltration Rate | | 1/2 inch per hour field verified | |
| Design Infiltration Rate | | 50% of measured rate | |
| Observation Well | No | Yes | Yes |
| Type of Pretreatment | External (leaf screens, grass filter strip, etc.) | Vegetated filter strip or grass channel, forebay, etc. | Pretreatment cell, forebay |
| Depth Dimensions | Maximum 3-foot depth | Maximum 5-foot depth | Maximum 6-foot depth |
| Underground Injection Control Permit Needed? | No | No | Only if the surface width is less than the maximum depth |
| Head Required | Nominal: 1 to 3 feet | Moderate: 1 to 5 feet | Moderate: 2 to 6 feet |
| Underdrain Requirements? | An elevated underdrain only on marginal soils | None required | Back up underdrain |
| Required Soil Tests | Based on surface area of practice; minimum of one soil profile, one infiltration tests per location. Refer Appendix C. | Varies based on surface area of practice Refer to Appendix C. | Varies based on surface area of practice. Refer to Appendix C. |
| Building Setbacks | 10 feet downgradient[2] | 10 feet downgradient 50 feet upgradient | 25 feet downgradient 100 feet upgradient |

| Table P-FIL-04-1 The Three Design Scales for Infiltration Practices | | | |
|---|---|---|---|
| Design Factor | Micro-Infiltration | Small-Scale Infiltration | Conventional Infiltration |

**Notes:**

1. Although permeable pavement is an infiltration practice, a more detailed specification is provided in BMP P-FIL-03, Permeable Pavement.
2. Note that the building setbacks are intended for simple foundations. The use of a dry well or French drain adjacent to an in-ground basement or finished floor area or any building should be carefully designed and coordinated with the design of the structure's waterproofing system (foundation drains, etc.) or avoided altogether.

| Table P-FIL-04-2 Feasibility Criteria | |
|---|---|
| **Site Feature** | **Requirement** |
| Site Topography | Unless slope stability calculations demonstrate otherwise, infiltration practices should be located a minimum horizontal distance of 200 feet from downgradient slopes greater than 20%. The average slope of the contributing drainage areas should be less than 15%. |
| Practice Slope | The bottom of an infiltration practice should be flat (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater, although a maximum longitudinal slope of 1% is permissible if an underdrain is employed. Lateral slopes should be 0%. |
| Minimum Hydraulic Head | The elevation difference needed to operate a micro-scale infiltration practice is nominal. However, 2 feet or more of head may be needed to drive small-scale and conventional infiltration practices. |
| Minimum Depth to Water Table or Bedrock | A minimum vertical distance of 2 feet must be provided between the bottom of the infiltration practice and the seasonal high-water table or bedrock layer. The seasonal high-water table (SHWT) is defined as the shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (more than a few weeks). Other factors that influence the determination of the SHWT include (but are not limited to) natural vegetation (overstory and understory), soil colors, soil mottles (an indicator of water-saturated anaerobic conditions), depth to the root zone (free standing water is the greatest impediment to root growth), and depth to the clay layer (hardpan). All of the above indicators may not be present in the soil. |
| Soils | Native soils in proposed infiltration areas must have a minimum infiltration rate (permeability or hydraulic conductivity per Appendix C, Soil Characterization and Infiltration Testing) of 1/2 inch per hour; (typically Hydrologic Soil Group A and B soils meet this criterion). Initially, soil infiltration rates can be estimated from USDA- NRCS soil data, but they must be confirmed by an onsite infiltration evaluation. |
| Use on Urban Soils/Redevelopment Sites | Sites that have been previously graded or disturbed do not retain their original soil permeability due to compaction. Therefore, such sites are not good candidates for infiltration practices. In addition, infiltration practices should never be situated above fill soils. |

| Table P-FIL-04-2 Feasibility Criteria | |
|---|---|
| **Site Feature** | **Requirement** |
| Dry Weather Flows | Infiltration practices should not be used on sites receiving regular dry weather flows from sump pumps, irrigation nuisance water, and similar kinds of flows. |
| High Loading Situations | Infiltration practices are not intended to treat sites with high sediment or trash/debris loads, because such loads will cause the practice to clog and fail. |
| Hotspots and Groundwater Protection | Table P-FIL-04-5 presents a list of potential stormwater hotspots that pose a risk of groundwater contamination. Infiltration of runoff from designated hotspots is highly restricted or prohibited. |

| Table P-FIL-04-3 Infiltration Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and similar structures | 25-foot horizontal | Closer offsets may be considered on a case-by-case basis where impermeable liners are specified by the designer.<br>Infiltration practices should not be hydraulically connected to structure foundations or pavement, to avoid harmful seepage. Setbacks to structures and roads vary based on the scale of infiltration. |
| Property Lines | 10-foot horizontal | |
| Septic System Drain Fields | 50-foot horizontal | |
| Private Water Wells | 100-foot horizontal | |
| Wet and Dry Utilities | 5-foot horizontal | |

**Note:**

* Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the toe of the embankment on the downstream side and the design high water on the upstream side.

***Site-Specific Considerations***. Infiltration practices can be applied to most land uses that have measured soil infiltration rates that exceed 1/2 inch per hour. However, there is no single infiltration application that fits every development situation. The nature of the actual design application depends on four key design factors, described below:

1. The first factor is the **design scale** at which infiltration will be applied:
   - **Micro-infiltration** is intended for residential rooftop disconnection, rooftop rainwater harvesting systems, or other small-scale application (250 to 2,500 square feet of impervious area treated).
   - **Small-scale infiltration** is intended for residential and/or small commercial applications that meet the feasibility criteria noted above.
   - **Conventional infiltration** can be considered for most typical development and redevelopment applications and therefore has more rigorous site selection and feasibility criteria.

   Table P-FIL-04-1 compares different design approaches and requirements associated with each infiltration scale.

2. The second key design factor relates to the **mode** (or method) of temporarily storing runoff prior to infiltration – either on the surface or in an underground trench. When storing runoff on the surface (e.g., an infiltration basin), the maximum depth should be no greater than 1 foot. However, if pretreatment cells are used, a maximum depth of 2 feet is permissible if appropriate safety features are included. In the underground mode, runoff is stored in the voids of the stones, and infiltrates into the underlying soil matrix. Perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond.
3. The third design factor relates to the degree of **confidence that exfiltration can be maintained** over time, given the measured infiltration rate for the subsoils at the practice location and the anticipated land uses. This factor helps determine whether infiltration is an appropriate practice for the site. Alternative practices that provide comparable volume and pollutant reduction include bioretention, the dry swale, permeable pavement, etc., all of which can incorporate an underdrain.
4. The final factor is whether the infiltration practice will be designed as an **on-line or off-line facility**, as this determines the nature of conveyance and overflow mechanisms needed. Off-line practices are sized to only accept some portion of the treatment volume (*Tv*) and employ a flow splitter to safely bypass large storms. On-line infiltration practices may be connected to underground perforated pipes to detain the peak storm event or have suitable overflows to pass the storms without erosion. On-line designs require careful design of the pretreatment in order to avoid the large flows from causing scour or turbulence within the practice that can lead to clogging.

## 3.0 Planning and Considerations

### 3.1 Regional and Special Case Design Adaptations

| Table P-FIL-04-4 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Requirement** |
| Karst Terrain | Conventional infiltration practices should not be used in karst regions due to concerns about sinkhole formation and groundwater contamination. Micro- or small-scale infiltration areas are permissible only if geotechnical studies indicate there is at least 4 feet of vertical separation between the bottom of the infiltration facilities and the underlying karst layer AND an impermeable liner and underdrain are used. In many cases, bioretention is a preferred stormwater management alternative to infiltration in karst areas. Refer to Appendix E for guidance for karst areas. |
| Coastal Plain | The flat terrain, low head and high-water table of many coastal plain sites can constrain the application of conventional infiltration practices. However, such sites are still suited for micro-scale and small-scale infiltration practices. Designers should maximize the surface area of the infiltration practice and keep the depth of infiltration to less than 24 inches plus the groundwater separation. Where soils are extremely permeable (more than 4.0 inches per hour), shallow bioretention is a preferred alternative. Where soils are more impermeable (i.e., marine clays with less than 0.5 inch per hour), designers may prefer to use a constructed wetland practice. |

| Table P-FIL-04-4 Community and Environmental Concerns | |
|---|---|
| **Concern** | **Requirement** |
| Steep Terrain | Forcing conventional infiltration practices in steep terrain can be problematic with respect to slope stability, excessive hydraulic gradients, and sediment delivery. Unless slope stability calculations demonstrate otherwise, it is generally recommended that infiltration practices should be located a minimum horizontal distance of 200 feet from downgradient slopes greater than 20%. Micro-scale and small-scale infiltration can work well, as long as their smaller up gradient and downgradient building setbacks are satisfied. |
| Cold Climate and Winter Performance | Infiltration practices can be designed to withstand more moderate winter conditions. The main problem is caused by ice forming in the voids or the subsoils below the practice, which may briefly result in nuisance flooding when spring melting occurs. The following design adjustments are recommended for infiltration practices installed in higher elevations:<br>• The bottom of the practice should extend below the frost line.<br>• Infiltration practices are not recommended at roadside locations that are heavily sanded and/or salted in the winter months (to prevent movement of chlorides into groundwater and prevent clogging by road sand).<br>• Pretreatment measures can be oversized to account for the additional sediment load caused by road sanding (up to 40% of the Tv).<br>• Infiltration practices must be set back at least 25 feet from roadways to prevent potential frost heaving of the road pavement. |
| Linear Highway Sites | Infiltration practices can work well for linear highway projects, where soils are suitable and can be protected from heavy disturbance and compaction during road construction operations. |
| Linear Utility Sites | Infiltration practices are poorly suited to treat runoff within utility rights-of-way or easements due to their size and would typically require acquisition of additional land adjacent to the utility corridor. |

### 3.2 Designation of Stormwater Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk for spills, leaks, or illicit discharges. Table P-FIL-04-5 presents a list of potential land uses or operations that may be designated as a stormwater hotspot. It should be noted that the actual hotspot generating area may only occupy a portion of the entire proposed use, and that some “clean” areas (such as rooftops) can be diverted away to another infiltration or runoff reduction practice. Communities should carefully review development proposals to determine whether any future operation on all or part of the site will be designated as a potential stormwater hotspot. Based on this designation, one or more design responses are required, as shown below:

1. ***Stormwater Pollution Prevention Plan (SWPPP)***. The SWPPP, required as part of a Virginia Pollutant Discharge Elimination System (VPDES) industrial activity or a municipal stormwater permit, outlines pollution prevention and treatment practices that will be implemented to minimize polluted discharges from the ongoing operations of the facility. (Note: This is different from the SWPPP

required as part of regulated construction activities.) Other facilities or operations that are not classified as industrial activities (SIC Codes) are not required to have an Industrial VPDES permit but may still be designated as potential stormwater hotspots by the local review authority as part of their local stormwater ordinance (these are shown in the shaded areas of Table P-FIL-04-5). It is recommended that these facilities include an addendum to their stormwater plan that details the pollution prevention practices and employee training measures that will be used to reduce contact of pollutants with rainfall or snowmelt.

2. ***Restricted Infiltration***. A minimum of 50% of the total Tv must be treated by a filtering or bioretention practice prior to any infiltration. Portions of the site that are not associated with the hotspot-generating area should be diverted away and treated by another acceptable stormwater management practice.
3. **Infiltration Prohibition**. The risk of groundwater contamination from spills, leaks, or discharges is so great at hotspot sites that infiltration of stormwater or snowmelt is prohibited.

**Table P-FIL-04-5 Potential Stormwater Hotspot and Site Design Responses**

| Potential Stormwater Hotspot Operation | SWPPP Required? | Restricted Infiltration | No Infiltration |
|---|---|---|---|
| Facilities with National Pollutant Discharge Elimination System industrial permits | Yes | ■ | ■ |
| Public works yard | Yes | | ✓ |
| Ports, shipyards, and repair facilities | Yes | | ✓ |
| Railroads/equipment storage | Yes | | ✓ |
| Auto and metal recyclers/scrapyards | Yes | | ✓ |
| Petroleum storage facilities | Yes | | ✓ |
| Highway maintenance facilities | Yes | | ✓ |
| Wastewater, solid waste, and composting facilities | Yes | | ✓ |
| Industrial machinery and equipment | Yes | ✓ | |
| Trucks and trailers | Yes | ✓ | |
| Airfields | Yes | ✓ | |
| Aircraft maintenance areas | Yes | | ✓ |
| Fleet storage areas | Yes | | ✓ |
| Parking lots (with 40 or more parking spaces) | No | ✓ | |
| Gas stations | No | | ✓ |
| Highways (2,500 ADT) | No | ✓ | |
| Construction business (paving, heavy equipment storage, and maintenance | No | ✓ | |
| Retail/wholesale vehicle/equipment dealers | No | ✓ | |
| Convenience stores/fast food restaurants | No | ✓ | |
| Vehicle maintenance facilities | No | | ✓ |

| Table P-FIL-04-5 Potential Stormwater Hotspot and Site Design Responses | | | |
|---|---|---|---|
| Potential Stormwater Hotspot Operation | SWPPP Required? | Restricted Infiltration | No Infiltration |
| Car washes | No | | ✓ |
| Nurseries and garden centers | No | ✓ | |
| Golf courses | No | ✓ | |

**Note:** For a full list of potential stormwater hotspots consult Schueler et al. 2005.

**Key:** ■ = depends on facility; ✓ = criterion applies.

### 3.3 Other Environmental and Community Issues

The following is a list of several other community and environmental concerns that may also arise when infiltration practices are proposed:

| Table P-FIL-04-6 Community and Environmental Concerns | |
|---|---|
| Concern | Requirement |
| Nuisance Conditions | Poorly designed infiltration practices can create potential nuisance problems such as basement flooding, poor yard drainage, and standing water. In most cases, these problems can be minimized through proper adherence to the setback, soil testing, and the pretreatment requirements outlined in this specification. |
| Mosquito Risk | Infiltration practices have some potential to create conditions favorable to mosquito breeding, if they clog and have standing water for extended periods. |
| Groundwater Injection Permits | Groundwater injection permits are required if the infiltration practice is deeper than the longest surface area dimension of the practice (U.S. Environmental Protection Agency 2008). Designers should investigate whether or not a proposed infiltration practice is subject to a state or local groundwater injection permit requirements. |

## 4.0 Stormwater Performance Summary

When used appropriately, infiltration has a very high runoff volume reduction capability, as shown in Table P-FIL-04-7.

| Table P-FIL-04-7 Summary of Stormwater Functions Provided by Infiltration | | |
|---|---|---|
| Stormwater Function | Level 1 Design | Level 2 Design |
| Annual Runoff Reduction Volume | 50% | 90% |
| Total Phosphorus EMC Reduction[1] by BMP Treatment Process | 25% | 25% |
| Total Phosphorus Mass Load Removal | 63% | 93% |
| Total Nitrogen EMC Reduction[1] by BMP Treatment Process | 15% | 15% |

| Table P-FIL-04-7 Summary of Stormwater Functions Provided by Infiltration | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Total Nitrogen Mass Load Removal | 57% | 92% |
| Channel and Flood Protection | • Use the Virginia Runoff Reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment; or<br>• Design for extra shortage (optional; as needed) on the surface or in the subsurface storage volume to accommodate larger storm volumes, and use USDA-NRCS TR-55 Runoff Equations[2] to compute the CN Adjustment. | |

**Notes:**

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.

1. Change in the event mean concentration (EMC) through the best management practice (BMP). The actual nutrient mass load removed is the product of the removal rate and the runoff reduction (RR) rate; (see Table 1 in the Introduction to the New Virginia Stormwater Design Specifications).
2. USDA-NRCS Technical Release 55 Urban Hydrology for Small Watersheds (TR-55) Runoff Equations 2-1 through 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events, based on the retention storage provided by the practice(s).

## 5.0 Design Criteria

The major design goal for Infiltration is to maximize runoff volume reduction and nutrient removal. To this end, designers may choose to go with the baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the infiltration practice must meet all the design criteria shown in the right-hand column of Table P-FIL-04-8.

| Table P-FIL-04-8 Level 1 and Level 2 Infiltration Design Guidelines | |
|---|---|
| **Level 1 Design** | **Level 2 Design** |
| **Runoff Reduction: 50; Total Phosphorous: 25; Total Nitrogen: 15** | **Runoff Reduction: 90; Total Phosphorous: 25; Total Nitrogen: 15** |
| Sizing: Tv = [(Rv)(A)/12]<br>– the volume reduced by an upstream BMP | Sizing: Tv = [1.1(Rv)(A)/12]<br>– the volume reduced by an upstream BMP |
| At least two forms of pretreatment (see Table P-FL-04-9) | At least three forms of pretreatment (see Table P-FL-04-9) |
| Soil infiltration rate 1/2 to 1 inch/hour (see Appendix C, Soil Characterization and Infiltration Testing); number of tests depends on the scale (see Table P-FIL-04-1). | Soil infiltration rates of 1.0 to 4.0 inches/hour (see Appendix C); number of tests depends on the scale (see Table P-FIL-04-1). |
| Minimum of 2 feet between the bottom of the infiltration practice and the seasonal high-water table or bedrock. Tv infiltrates within 36 to 48 hours.<br>Building setbacks – see Table P-FIL-04-3.<br>All designs are subject to hotspot runoff restrictions/prohibitions.<br>Infiltration practices must completely drain within 72 hours of the end of a rainfall event. | |

**Figure P-FIL-04-1 Infiltration Trench or Basin Plan View with Concentrated Inflow and Sheet Inflow**

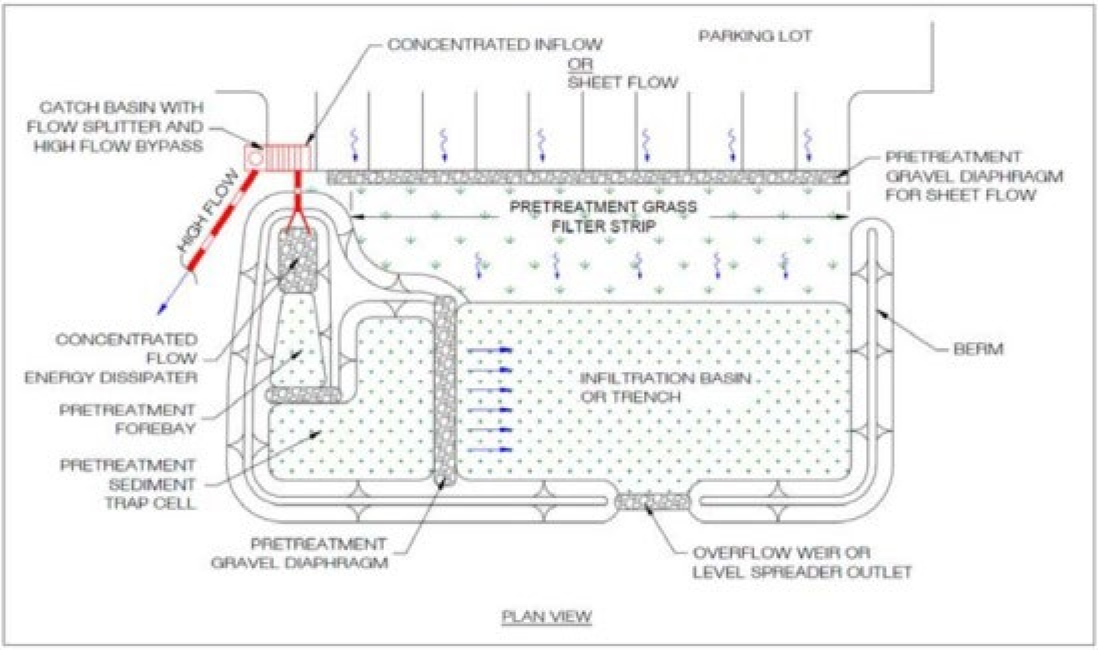
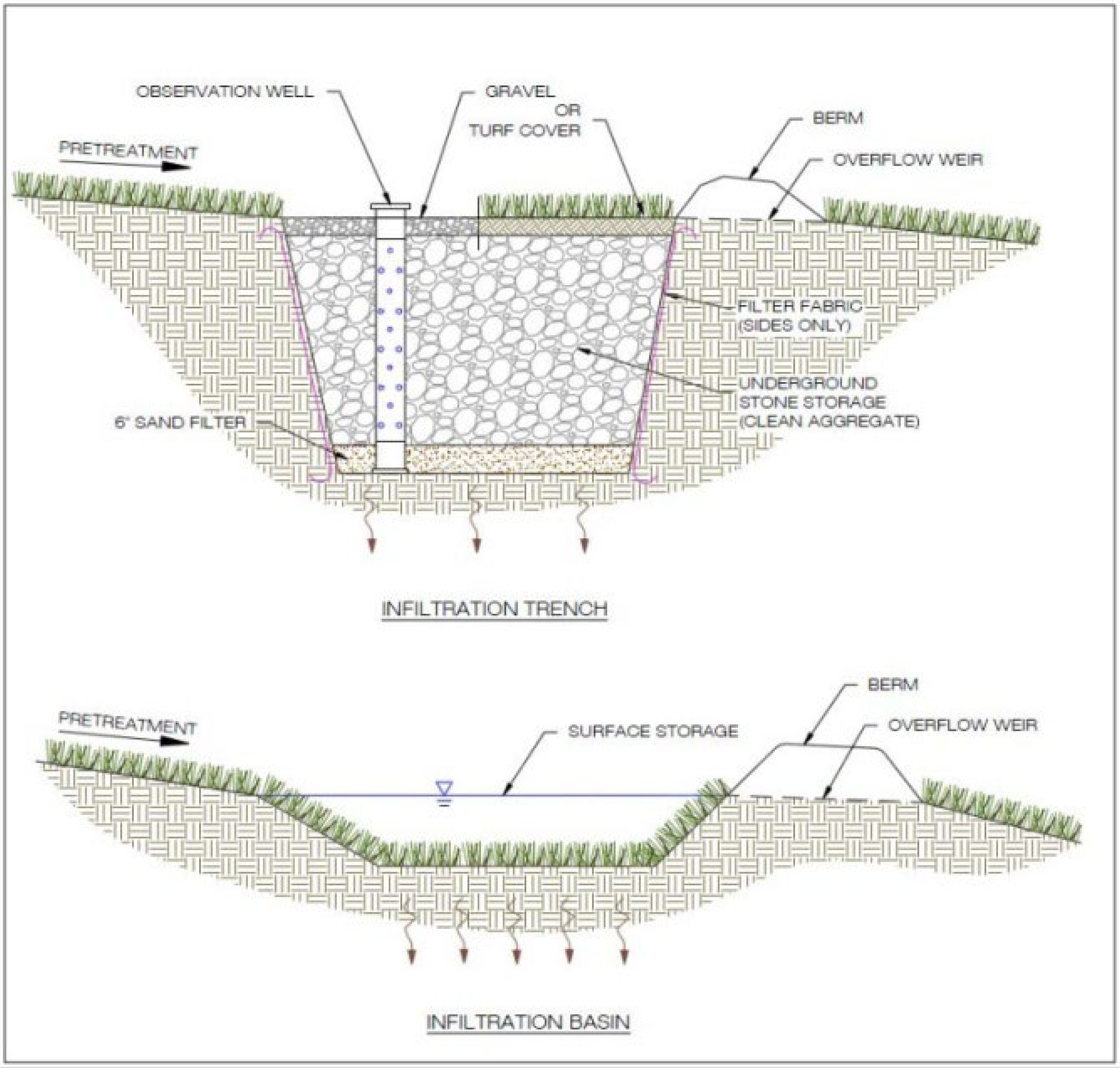


**Figure P-FIL-04-2 Infiltration Trench or Basin Section View**



## *Figure P-FIL-04-3 Infiltration Section with Supplemental Pipe Storage*

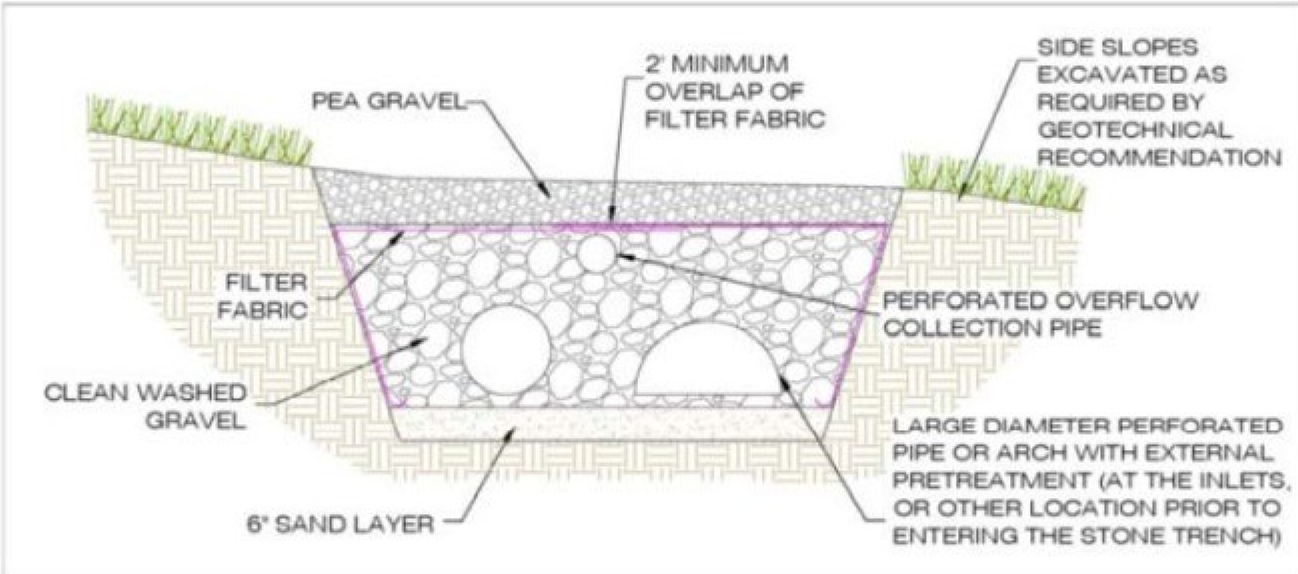
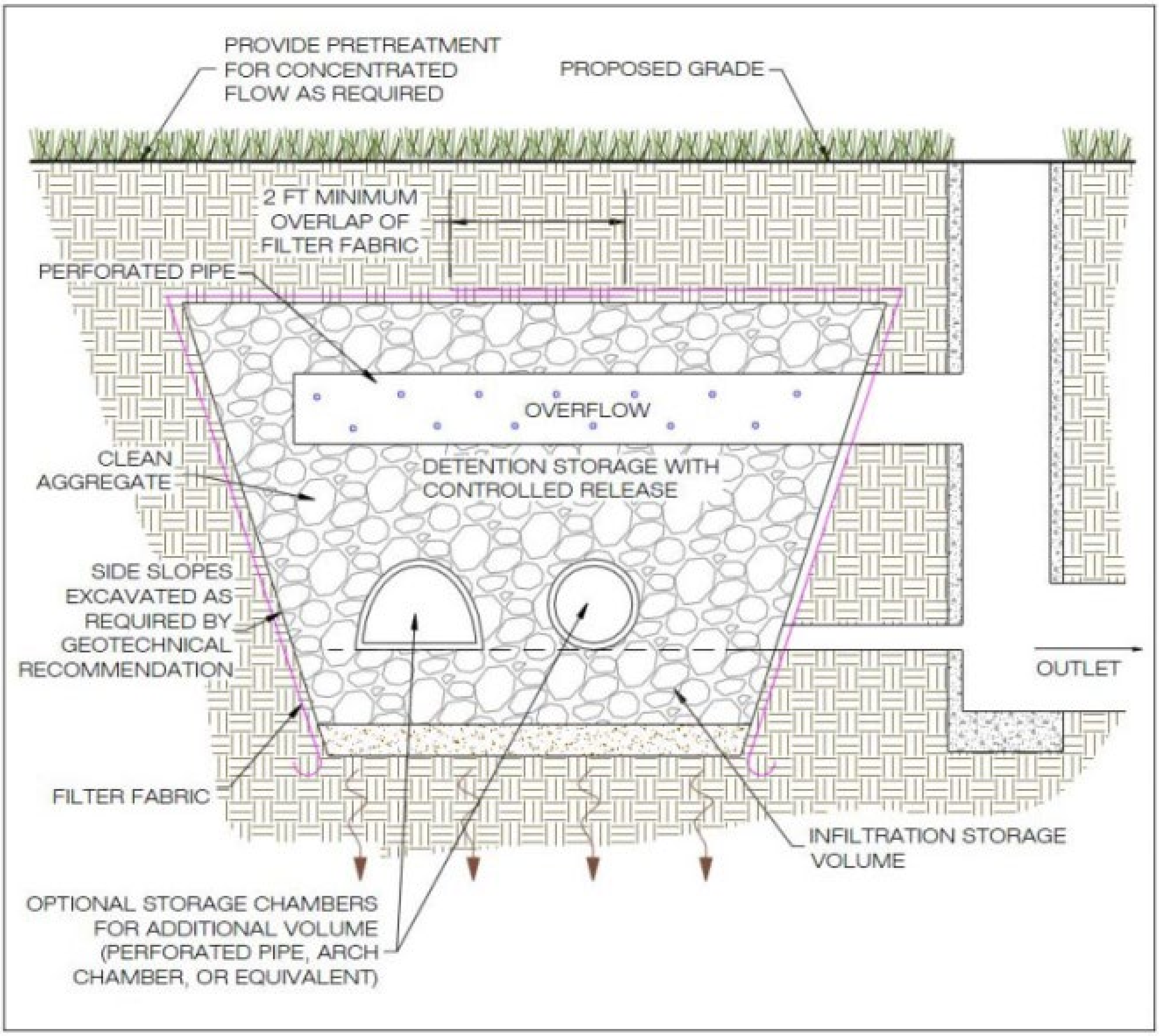
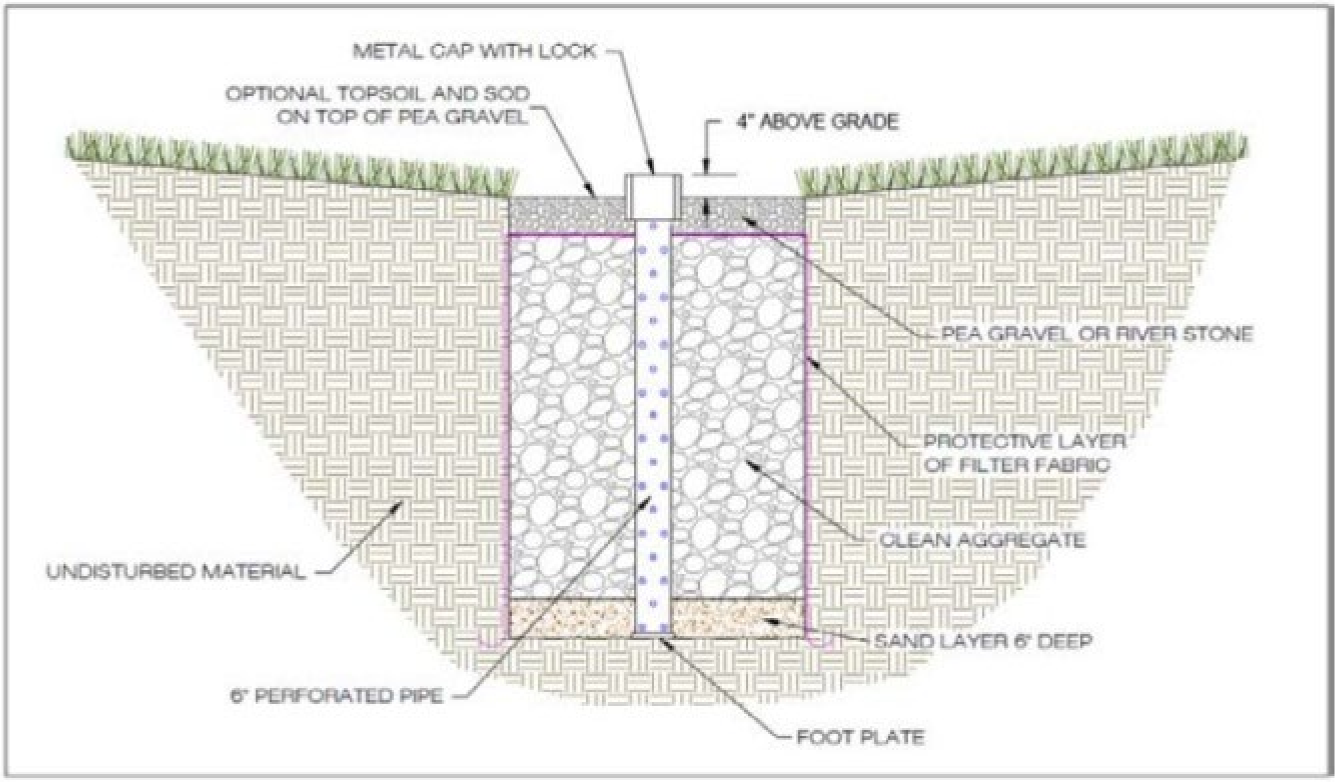


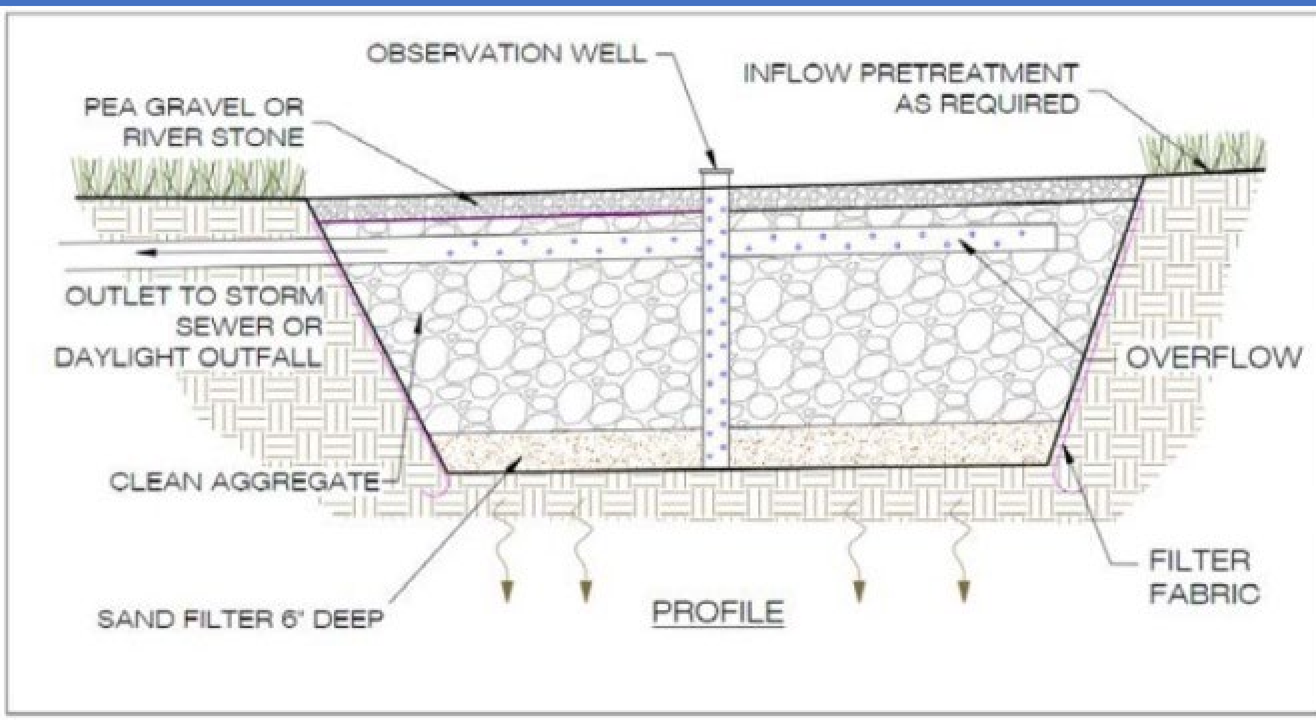
**Figure P-FIL-04-4 Infiltration Combined with Detention (Channel and/or Flooding Protection)**



## Figure P-FIL-04-5 Observation Well




## Figure P-FIL-04-6 Typical Infiltration Trench




### 5.1 Defining the Infiltration Rate

Soil permeability is the single most important factor when evaluating infiltration practices. A field-verified minimum infiltration rate of at least 1/2 inch per hour is needed for the practice to work.

***Projected Infiltration Rate***. For planning purposes, the projected infiltration rate for the site can be estimated using the USDA-NRCS soil textural triangle for the prevailing soil types shown on the local USDA-NRCS Soil Survey. This data is used solely to locate portions of the site where infiltration may be feasible and to pinpoint where actual on-site infiltration tests will be taken to confirm feasibility.

***Measured Infiltration Rate***. Onsite infiltration investigations should always be conducted to establish the actual infiltration capacity of underlying soils, using the methods presented in Appendix C, Soil Characterization and Infiltration Testing.

***Design Infiltration Rate***. Several studies have shown that ultimate infiltration rates decline by as much as 50% from initial rates; therefore, designers should be conservative and not attempt to use infiltration on questionable soils. To provide a factor of safety, the infiltration rate used in the design may be no greater than 50% of the measured rate.

### 5.1.1 Sizing of Infiltration Facilities

Several equations are needed to size infiltration practices. The first equations establish the maximum depth of the infiltration practice, depending on whether it is a surface basin (Equation P-FIL-04-1) or underground reservoir (Equation P-FIL-04-2).

***Equation P-FIL-04-1 Maximum Surface Basin Depth***

$$d_{max} = (\frac{1}{2}f \times t_d)/12$$

***Equation P-FIL-04-2 Maximum Underground Reservoir Depth***

$$d_{max} = (\frac{1}{2}f \times t_d)/(\eta \times 12)$$

Where:

$d_{max}$ = maximum depth of the infiltration practice (feet).

$f$ = measured infiltration rate (inch per hour).

$td$ = maximum drawn down time (normally 48 hours).

$\eta$ = porosity of the stone reservoir (assume 0.4).

Designers should compare these results to the maximum allowable depths in Table P-FIL-04-8, and use whichever value is *less* for subsequent design.

**Table P-FIL-04-8 Maximum Depth (in feet) for Infiltration Practices**

| Mode of Entry | Scale of Infiltration | | |
|---|---|---|---|
| | Micro-Infiltration | Small-Scale Infiltration | Conventional Infiltration |
| Surface Basin | 1.0 | 1.5 | 2.0 |
| Underground Reservoir | 3.0 | 5.0 | varies |

Once the maximum depth is known, calculate the surface area needed for an infiltration practice using Equation P-FIL-04-3 or Equation P-FIL-04-4.

***Equation P-FIL-04-3 Surface Basin Surface Area***

$$SA = Tv_{BMP}/d + [\frac{\left(\frac{1}{2}\right) f \times t_f}{12}]$$

***Equation P-FIL-04-4 Underground Reservoir Surface Area***

$$SA = Tv_{BMP}/(\eta \times d) + [\frac{\left(\frac{1}{2}\right) f \times t_f}{12}]$$

Where:

$SA$ = Surface area (square feet).

$TvBMP$ = Design volume for the BMP, e.g., Tv from the contributing drainage area plus any remaining volume from upstream runoff reduction practices (cubic feet).

$\eta$ = Porosity of stone reservoir (assume 0.4).

$d$ = Infiltration depth (maximum depends on the scale of infiltration and the results of Equation P-FIL-04-1 (feet).

$f$ = Measured infiltration rate (inch per hour).

$tf$ = Time to fill the infiltration facility (typically 2 hours).

If the designer chooses to infiltrate less than the full *Tv* (e.g., using micro-infiltration or small-scale infiltration), the runoff reduction rates shown in Table P-FIL-04-1 must be directly prorated in the VRRM compliance spreadsheet.

To qualify for Level 2 runoff reduction rates, designers must provide 110% of the site-adjusted *Tv* (1.1**Tv*).

### 5.1.2 Soil Infiltration Rate Testing

Regardless of the scale of the infiltration application, perform at least one soil profile and one infiltration test per facility. The acceptable methods and the number of on-site soil explorations are outlined in Appendix C, Soil Characterization and Infiltration Testing.

### 5.2 Pretreatment Features

Every infiltration practice must include multiple pretreatment techniques, although the nature of pretreatment practices depends on the scale at which infiltration is applied. The number, volume, and type of acceptable pretreatment techniques needed for the three scales of infiltration are provided in Table P-FL-04-9. Refer to BMP P-SUP-06, Pre-Treatment, for design details and guidance on pretreatment.

| Table P-FL-04-9 Required Pretreatment Elements for Infiltration Practices | | | |
|---|---|---|---|
| Pretreatment[1] | Scale of Infiltration | | |
| | Micro-Infiltration | Small-Scale Infiltration | Conventional Infiltration |
| Number and Volume of Pretreatment Techniques Employed | Two external techniques; no minimum pretreatment volume required | Three techniques; 15% minimum pretreatment volume required (inclusive) | Three techniques; 25% minimum pretreatment volume required (inclusive); at least one separate pretreatment cell |
| Acceptable Pretreatment Techniques | Leaf gutter screens<br>Grass filter strip<br>Upper sand layer<br>Washed bank run gravel<br>Roof stormwater isolation | Grass filter strip<br>Grass channel<br>Plunge pool<br>Gravel diaphragm<br>Treatment train<br>Limit hydraulic loading | Sediment forebay<br>Sand filter cell<br>Inlet sumps<br>Grass filter strip<br>Grass channel<br>Gravel diaphragm<br>Manufactured treatment device<br>Manufactured flow control devices<br>Treatment train<br>Limit hydraulic loading |

**Note:**

1. A minimum of 50% of the runoff reduction volume must be pretreated by a filtering or bioretention practice prior to infiltration if the site is a restricted stormwater hotspot.

Note that conventional infiltration practices require pretreatment of at least 25% of the Tv, including a surface pretreatment cell capable of keeping sediment and vegetation out of the infiltration cell. All pretreatment practices should be designed such that exit velocities are non-erosive for the 2-year design storm and evenly distribute flows across the width of the practice (e.g., using a level spreader).

### 5.3 Conveyance and Overflow

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line (Table P-FIL-04-10). Where possible, conventional infiltration practices should be designed off-line to avoid damage from the erosive velocities of larger design storms.

| Table P-FIL-04-10 Conveyance and Overflow Choices Based on Infiltration Scale | | | |
|---|---|---|---|
| Conveyance and Overflow | Scale of Infiltration | | |
| | Micro Infiltration | Small-Scale Infiltration | Conventional Infiltration |
| On-line Design | Discharge to a non-erosive pervious overland flow path designed to convey the 10-year design storm to the street or storm drain system. | An overflow mechanism such as an elevated drop inlet or flow splitter should be used to redirect flows to a non-erosive down-slope overflow channel or stabilized water course designed to convey the 10-year design storm. Inlet areas should be stabilized to ensure that non-erosive conditions exist during storm events up to the overbank flood event (i.e., the 10-year storm event). Outlet protection or energy dissipation should be provided consistent with BMP C-ECM-15, Outlet Protection. | |
| Off-line Design | Not recommended. | A flow splitter or overflow structure; the overflow should be sized to safely pass the peak flows anticipated to reach the practice, up to a 100-year, 24-hour storm event. | |

### 5.4 Internal Geometry and Drawdowns

***Runoff Reduction Volume Sizing***. The proper approach for designing infiltration practices is to avoid forcing a large volume of runoff into a comparatively small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to achieve the full Tv for the contributing drainage area, as long as other runoff reduction practices are applied at the site to meet the remainder of the Tv. Account for the total Tv as computed using the VRRM compliance spreadsheet.

***Infiltration Basin Restrictions***. The maximum vertical depth to which runoff may be ponded over an infiltration area is 24 inches (i.e., infiltration basin). The side slopes should be no steeper than 4H:1V; if the basin serves a CDA greater than 20,000 square feet, a surface pretreatment cell must be provided (this may be sand filter or dry sediment basin).

***Rapid Drawdown***. When possible, infiltration practices should be sized such that the target runoff reduction volume infiltrates within 36 to 48 hours to provide a factor of safety that prevents nuisance ponding conditions.

***Conservative Infiltration Rates***. Designers should always use the design infiltration rate (safety factor of 2), rather than the measured infiltration rate, to approximate long term infiltration rates.

***Porosity***. A value of 0.40 should be used in the design of stone reservoirs, although a larger value may be used if perforated corrugated metal pipe, plastic pipe, concrete arch pipe, or comparable materials are installed within the reservoir.

### 5.5 Landscaping and Safety

Infiltration trenches can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover, subject to the following additional design considerations:

- Infiltration practices should never be installed until all upgradient construction is completed *AND* pervious areas are stabilized with dense and healthy vegetation.

- A landscaping plan should be prepared for all infiltration basins. The landscaping plan should be reviewed and approved by the local development review authority prior to construction.
- Vegetation associated with the infiltration practice buffers should be regularly mowed and maintained to keep organic matter out of the infiltration device and maintain enough native vegetation to prevent soil erosion from occurring.
- Infiltration practices should fit into and blend with the surrounding area. Native grasses are preferable, if compatible (refer to Appendix G for plant selection guidance). A basin may be covered with permeable topsoil and planted with grass in a landscaped area.
- Infiltration practices do not pose any major safety hazards after construction. However, if an infiltration practice will be excavated to a depth greater than 5 feet, then Occupational Safety and Health Administration health and safety guidelines must be followed for safe construction practices.
- Infiltration trenches and basins with temporary ponding should not be designed to hold water greater than 1 foot deep. Deeper surface ponding (up to 2 feet maximum) may require safety provisions.
- The landscaped area above the surface of an infiltration practice may also be covered with pea gravel (i.e., ASTM International Standard D448 size No. 8, 3/8-inch to 1/8-inch). This pea gravel layer provides sediment removal and additional pretreatment upstream of the infiltration practice and can be easily removed and replaced when it becomes clogged.
    - Alternatively, an infiltration practice may be covered with an engineered soil mix, such as that prescribed for an infiltration basin, and planted with managed turf or other herbaceous vegetation. This may be an attractive option when infiltration practices are placed in disturbed pervious areas (e.g., lawns, parks, and community open spaces).
- Vegetation commonly planted in infiltration basins includes native trees, shrubs, and other herbaceous vegetation. When developing a landscaping plan, site planning and design teams should choose vegetation that will be able to stabilize soils and tolerate the stormwater runoff rates and volumes that will pass through the infiltration basin. Vegetation used in infiltration basins should also be able to tolerate both wet and dry conditions. See Appendix G, Plant Selection, for a list of grasses and other plants that are appropriate for use in infiltration practices installed in the state of Virginia.
- Methods used to establish vegetative cover within an infiltration basin should achieve at least 75% vegetative cover one year after installation.
- The soils used within infiltration basin planting beds should be an engineered soil mix that meets the following specifications:
    - Texture: Sandy loam or loamy sand should be used.
    - Sand Content: Soils should contain 85% to 88% clean, washed sand.
    - Topsoil Content: Soils should contain 8% to 12% topsoil.
    - Organic Matter Content: Soils should contain 3% to 5% organic matter.
    - Infiltration Rate: Soils should have an infiltration rate of at least 0.25 inch per hour, although an infiltration rate of between 1 and 2 inches per hour is preferred.
    - Phosphorus Index (P-Index): Soils should have a P-Index of less than 30.
    - Exchange Capacity (CEC): Soils should have a CEC that exceeds 10 milliequivalents per 100 grams of dry weight.
    - pH: Soils should have a pH of 6 to 8.

The organic matter used within an infiltration basin planting bed should be a well-aged compost that meets the specifications outlined in BMP P-FIL-08, Soil Compost Amendments.

Designers should always evaluate the nature of future operations to determine whether the proposed site will be designated as a potential stormwater hotspot (see Table P-FIL-04-5) and comply with the appropriate restrictions or prohibitions applicable to infiltration.

### 5.6 Maintenance Reduction Features

Maintenance is a crucial element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the surface stone by organic matter and sediment. The following design features can either minimize the risk of clogging or help to identify maintenance issues before they cause failure of the facility:

***Pretreatment Filter Strip of Low Maintenance Vegetation***. Regular mowing of turf generates a significant volume of organic debris that can eventually clog the surface of an infiltration trench or basin when located in a turf area; similarly, mulch from landscaped areas can migrate into the infiltration facility. Landscaping vegetation adjacent to the infiltration facility should consist of low maintenance ground cover.

***Observation Well***. Small-scale and conventional infiltration practices should include an observation well, consisting of an anchored 6-inch diameter perforated polyvinyl chloride (PVC) pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance.

***Filter Fabric***. Geotextile filter fabric should not be installed along the bottom of infiltration practices. Experience has shown that filter fabric is prone to clogging, and a layer of coarse washed stone (choker stone) is a more effective substitute. However, permeable filter fabric must be installed on the trench sides to prevent soil piping. A layer of fabric may also be installed along the top of the practice to help keep organic debris or topsoil from migrating downward into the stone. Periodic maintenance to remove and replace this surface layer will be required to ensure that surface runoff can get into the infiltration practice.

***Direct Maintenance Access***. Access must be provided to allow personnel and equipment to perform non-routine maintenance tasks, such as practice reconstruction or rehabilitation. While a turf cover is permissible for micro-and small-scale infiltration practices, the surface should not be covered by an impermeable material, such as asphalt or concrete.

### 5.7 Infiltration Material Specifications

The basic material specifications for infiltration practices are outlined in Table P-FIL-04-11.

**Table P-FIL-04-11 Infiltration Material Specifications**

| Material | Specification | Notes |
|---|---|---|
| Grass and Landscaping | See BMP C-SSM-10, Permanent Seeding, and Appendix G, Plant Selection. | Prevent adjacent vegetation from forming an overhead canopy above infiltration practices to prevent leaf litter, fruits, and other vegetative material from clogging the stone. |
| Inlet and Outlet Protection | See BMP C-ECM-15, Outlet Protection, and BMP C-ECM-13, Riprap. | |
| Pretreatment | See BMP Support Component: Pretreatment. | |
| Infiltration Planting Bed | See BMP P-FIL-08, Soil Compost Amendment, and BMP P-FIL-05, Bioretention. | |

| Table P-FIL-04-11 Infiltration Material Specifications | | |
|---|---|---|
| **Material** | **Specification** | **Notes** |
| Stone | Use clean aggregate with a maximum diameter of<br>3.5 inches and a minimum diameter of 1.5 inches (Virginia Department of Transportation [VDOT] No. 1 Open-Graded Coarse Aggregate) or the equivalent. | |
| Observation Well | Install a vertical 6-inch Schedule 40 PVC perforated pipe with a lockable screw cap and anchor plate. | Install one per 50 feet of length of infiltration the practice. |
| Trench Bottom | Install a 6- to 8-inch sand layer (VDOT Fine Aggregate, Grade A or B). | |
| Trench Surface Cover | Install a 3-inch layer of river stone or pea gravel. Turf is acceptable when there is subsurface inflow (e.g., a roof leader). | This provides an attractive surface cover that can suppress weed growth. |
| Filter Fabric (sides only) | Use non-woven polyprene geotextile with a flow rate of >110 gallons/minute/square foot (e.g., Geotex 351 or equivalent). | |
| Choking Layer | Install a 2- to 4-inch layer of choker stone (typically #8 or #89 washed gravel) over the underdrain stone. | |
| Overflow Collection Pipe (where needed) | Use 6-inch rigid Schedule 40 PVC pipe, with 3/8-inch perforations at 6 inches on center, with each perforated underdrain installed at a slope of 1% for the length of the infiltration practice. | Install non-perforated pipe with one or more caps, as needed. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence

The following is a typical construction sequence to properly install infiltration practices. The sequence may need to be modified to reflect the scale of infiltration, site conditions, and whether or not an underdrain needs to be installed.

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed. Ideally, the infiltration practice should be outside the limits of disturbance.

During site construction, the following steps are absolutely critical:

- Avoid excessive compaction by delineating the area of the proposed practice and preventing construction equipment and vehicles from traveling over the proposed location.
- Keep the infiltration practice "off-line" until construction is complete. Prevent sediment from entering the infiltration site by using super silt fence, diversion berms, or other means. In the erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to a

conventional infiltration basin The erosion and sediment control plan must also indicate the specific methods to be used to temporarily keep runoff from the infiltration site.

- Infiltration practice sites should never serve as the sites for temporary sediment control devices (e.g., sediment traps, etc.) during construction.
- Upland drainage areas must be completely stabilized with a thick layer of vegetation prior to commencing excavation for an infiltration practice, as verified by the local erosion and sediment control inspector/program.

### 6.2 Installation

The infiltration practice should be installed according to the following steps:

1. Excavate the infiltration practice to the design dimensions from the side using a backhoe or excavator. The floor of the pit should be completely level, but equipment should be kept off the floor area to prevent soil compaction.
2. Correctly install filter fabric on the trench sides. Large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The filter fabric itself should be tucked under the sand layer on the bottom of the infiltration trench. Stones or other anchoring objects should be placed on the fabric at the trench sides to keep the trench open during windy periods. Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids to ensure the fabric conforms smoothly to the sides of excavation.
3. Scarify the bottom of the infiltration practice and spread 6 inches of sand on the bottom as a filter layer.
4. Anchor the observation well(s) and add stone to the practice in 1-foot lifts.
5. Use sod to establish a dense turf cover for at least 10 feet on each side of the infiltration practice to reduce erosion and sloughing. If the vegetation is seeded instead, use native grasses adapted to local climates and soil conditions. Refer to Appendix G for information on plant selection.

### 6.3 Construction Inspection

Inspections are needed during and immediately after construction to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists, including sign-offs, at critical stages of construction to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions. (See Appendix H.) Inspection during the following key points during construction will help insure successful performance:

- Check elevations of the excavation invert. Ensure that the soil at the bottom of the infiltration facility has not been smeared by the excavation equipment. The bottom soil should be scarified with the teeth of the backhoe bucket.
- Inspect the installation of the bottom 6-inch sand filter layer and the initial layer of stone prior to placement of any storage components.
- Verify the top cover of pea gravel or turf as required on plans.
- Inspect the stabilization of adjacent pretreatment filter strips and the contributing drainage area prior to bringing the infiltration area into service.
- Upon final inspection and acceptance, Global Positioning System coordinates should be logged for all infiltration practices and submitted for entry into the local BMP maintenance tracking database.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of infiltration practices, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- When micro-scale or small-scale infiltration practices are installed on private residential lots, homeowners will need to: (1) be educated about their routine maintenance needs; (2) understand the long-term maintenance plan; and (3) be subject to a deed restriction, drainage easement, or other mechanism enforceable by the VESMP Authority to ensure that infiltrating areas are not converted or disturbed.
- The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

### 7.2 Maintenance Inspections

Annual site inspections are critical to the performance and longevity of infiltration practices, particularly for small-scale and conventional infiltration practices. Maintenance of infiltration practices is driven by annual inspections that evaluate the condition and performance of the practices, including the following:

- The drawdown rate should be measured at the observation well for 3 days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after 3 days, this is a clear sign that clogging is a problem.
- Check inlets, pretreatment cells, and any flow diversion structures for sediment buildup and structural damage. Note whether any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Check that no vegetation forms an overhead canopy that may drop leaf litter, fruits, and other vegetative materials that could clog the infiltration device.
- Evaluate the vegetative quality of the adjacent grass buffer and perform spot-reseeding if the cover density is less than 90%.
- Generally, inspect the upland contributing drainage area for any controllable sources of sediment or erosion.
- Look for weedy growth on the stone surface that might indicate sediment deposition or clogging.
- Inspect maintenance access to ensure it is free of woody vegetation and verify whether valves, manholes, and/or locks can be opened and operated.
- Inspect internal and external infiltration side slopes for evidence of sparse vegetative cover, erosion, or slumping, and make necessary repairs immediately.

Based on inspection results, specific maintenance tasks will be triggered. See Appendix H for example maintenance inspection checklists for infiltration practices.

### 7.3 Ongoing Maintenance

Effective long-term operation of infiltration practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in Table P-FIL-04-12. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

| Table P-FIL-04-12 Typical Maintenance Activities for Infiltration Practices | |
|---|---|
| **Maintenance Activity** | **Schedule** |
| Replace pea gravel/topsoil and top surface filter fabric (when clogged).<br>Mow vegetated filter strips as necessary and remove the clippings. | As needed |
| Ensure that the contributing drainage area, inlets, and facility surface are clear of debris.<br>Ensure that the contributing drainage area is stabilized.<br>Remove sediment and oil/grease from pretreatment devices, as well as from overflow structures.<br>Repair undercut and eroded areas at inflow and outflow structures. | Quarterly |
| Check observation wells 3 days after a storm event in excess of 1/2 inch in depth. Standing water observed in the well after 3 days is a clear indication of clogging.<br>Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.<br>Remove trees that start to grow in the vicinity of the infiltration facility. | Semi-annually |
| Clean out accumulated sediments from the pretreatment cell. | Annually |

## 8.0 References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# P-FIL-05 Bioretention

## 1.0 Definition

Bioretention is a method of treating stormwater by pooling water on the surface of a vegetated media system and allowing filtering and settling of suspended solids and sediment at the top mulch layer, prior to infiltrating and passing through the underlying biofiltration media, so that further pollutant removal via a range of biogeochemical processes occurs. As such, bioretention areas are shallow stormwater basins or landscaped areas that utilize engineered soil media and vegetation to retain and sequentially treat stormwater runoff via a combination of mechanisms before its discharge to local surfacewater or groundwater.

## 2.0 Purpose and Applicability of Best Management Practice

Bioretention can be used harmoniously with any land use. Bioretention offers many different design alternatives that make it a versatile practice for use within various locations in the development site. Typical locations for bioretention include the following:

- **Parking lot islands***.* The parking lot grading is designed for sheet flow towards linear landscaping areas and parking islands between rows of spaces. Curb-less pavement edges can be used to convey water into a depressed island landscaping area. Curb cuts can also be used for this purpose.
- **Parking lot edge***.* Small parking lots can be graded so that flows reach a curb-less pavement edge or curb cut before reaching catch basins or storm drain inlets. The turfgrass at the edge of the parking lot functions as a filter strip to provide pre-treatment for the bioretention practice. The depression for bioretention is in the pervious area adjacent to the parking lot.
- **Road medians, roundabouts, interchanges, and cul-de-sacs***.* The road cross-section is designed to slope towards the center median or center island rather than the outer edge, using a curb-less edge.
- **Right-of-way or commercial setback***.* A linear configuration can be used to convey runoff in sheet flow from the roadway. Runoff can also be conveyed by way of a grass channel or pipe to the bioretention practice.
- **Courtyards***.* Runoff collected in a storm drain system or roof leaders can be directed to courtyards or other pervious areas on site where bioretention can be installed.
- **Dry Extended Detention (ED) basin***.* A bioretention practice can be located on an upper shelf of an extended detention basin, after the sediment forebay, to boost treatment. Depending on the ED basin design, the designer may choose to locate the bioretention practice in the bottom of the basin.
- **Tree Planters and Other Local Landscape Planting Structures**. Tree planting pits or other urban landscape planting structures (e.g. rain gardens) can be designed to accept local curb or sheet flow from roadways, sidewalks, roofs, or other adjacent surfaces with a designed bioretention soil media. This and other urban retention applications of varying scales are described in more detail in 9.0 Appendix A Micro-bioretention and 10.0 Appendix B Ultra-Urban Bioretention.

## 3.0 Planning and Considerations

Bioretention facilities can receive stormwater from impervious and non-impervious drainage areas. With bioretention practices, surface runoff is directed into a shallow landscaped depression that incorporates volume reduction and a range of pollutant removal mechanisms. Bioretention facilities are composed of three main components:

1. Surface ponding area,
2. Soil filter media, and
3. Gravel layer and drainage (Figure P-FIL-05-1 and Figure P-FIL-05-2).

### 3.1 Ponding Area

The ponding area is a depression that temporarily stores the stormwater as it enters the practice, allows for some sediment to settlle out, and facilitates infiltration into the soil filter media and underlying native soil (depending on design options).

### 3.2 Soil Filter Media

The soil filter media is comprised of an engineered soil media, which filters stormwater, facilitates nutrient removal processes, and supports the rooted vegetation growing in the bioretention practice.

### 3.3 Gravel Layer and Drainage

The gravel layer is comprised of stone located between the soil filter media and the native soil. This layer protects the engineered soil media from the native soil and stores water until it exfiltrates into the surrounding soil or exits via an underdrain, i.e., a perforated pipe laid within the gravel layer that conveys treated water away from the practice.

### 3.4 Types of Bioretention

Bioretention installations can be divided into different categories. The choice of which specification to use is based on the size of the contributing drainage area and the site's available space. The three main types of bioretention are summarized in Table P-FIL-05-1, below.

**Table P-FIL-05-1 Summary of the Three Main Types of Bioretention**

| Type | Details |
|---|---|
| Bioretention | Focuses on general bioretention practices that are used to treat parking lots and/or commercial rooftops, usually in commercial or institutional areas. Inflow can be either sheet flow or concentrated flow. Bioretention practices may also be distributed throughout a residential subdivision, but ideally, they should be in a common area or within drainage easements to treat a combination of roadway and lot runoff (Figure P-FIL-05-3). |
| Micro-bioretention (a.k.a. Rain Gardens) | Small, distributed practices designed to treat runoff from small areas, such as individual rooftops, driveways, and other on-lot features in detached, single-family residential developments. Inflow is typically sheet flow or can be concentrated flow with energy dissipation when located at downspouts. Please refer to Appendix A Micro-bioretention for design criteria for Micro-bioretention (Figure P-FIL-05-4). |
| Ultra Urban Bioretention | Structures such as expanded tree pit planters, curb extensions, and foundation planters located in ultra-urban developed areas such as city streetscapes. Please refer to Appendix B Ultra-Urban Bioretention for design criteria for Urban Bioretention (Figure P-FIL-05-5). |

**Figure P-FIL-05-1 Image of typical bioretention practice**

**Figure P-FIL-05-2 Image of typical bioretention practice**

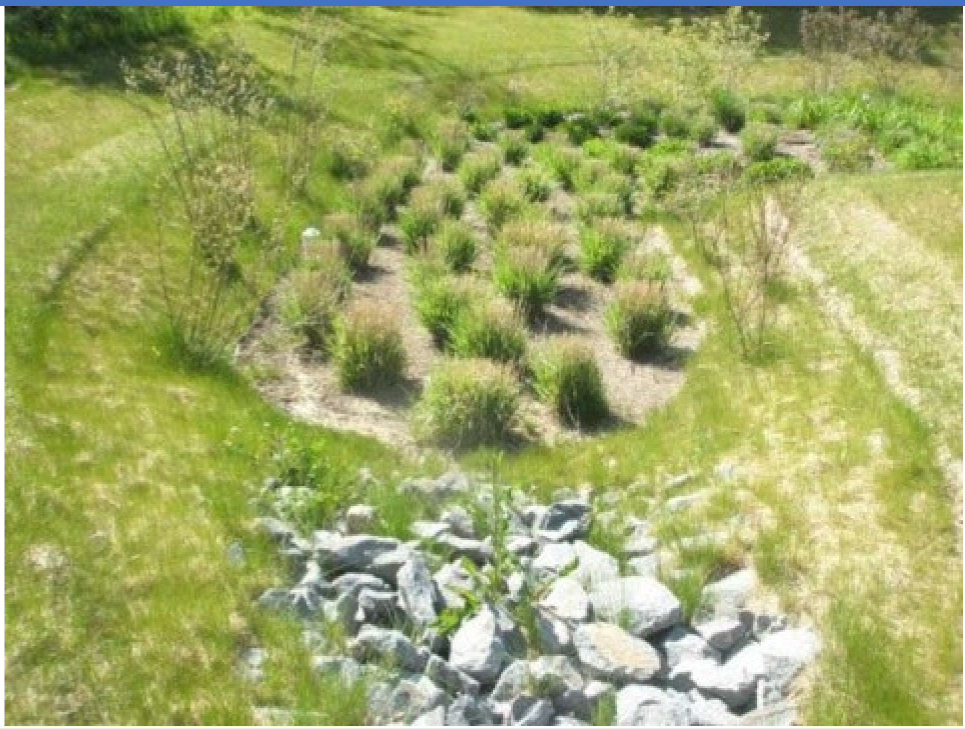


**Figure P-FIL-05-3 Image of bioretention cell receiving stormwater runoff from multiple input points (3) in a mixed-use development in Blacksburg, VA**

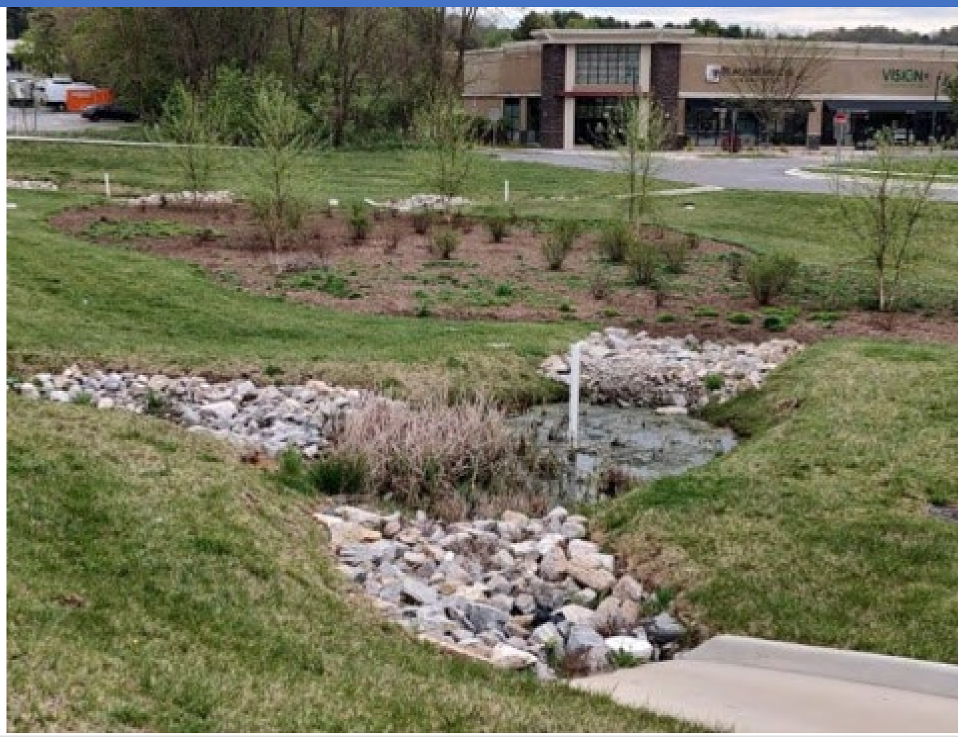
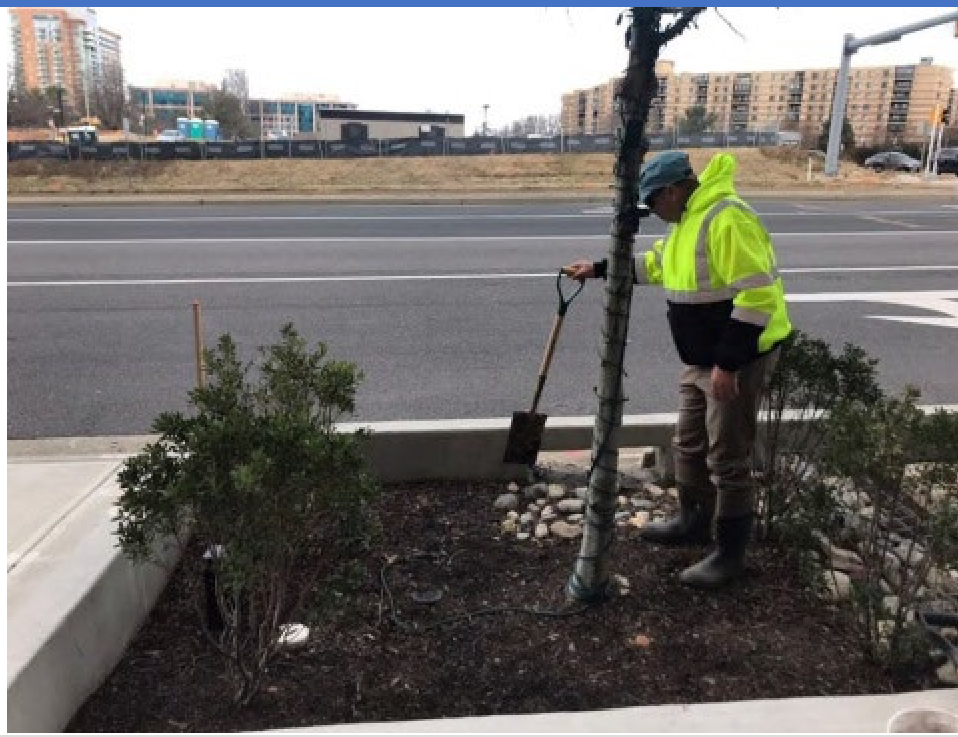


**Figure P-FIL-05-4 Image of a micro-bioretention/rain garden cell receiving direct roof downspout input in Blacksburg Virginia**

**Figure P-FIL-05-5 Image of Ultra-urban bioretention/tree planter cell receiving curb/road drainage in Fairfax VA**



The bioretention design level, drainage area size, and the land use composition influence the space required. A designer will not know the dimensions of the bioretention practice until the treatment volume is determined from the VRRM. In addition to the footprint of the surface ponding area, space will be needed for pre-treatment measures and access for maintenance. A general guideline for preliminary surface area sizing is 3 to 10 percent of the contributing drainage area.

## 4.0 Stormwater Performance Summary

Bioretention configurations can vary based on the amount of nutrient load reduction required, the site's available space, the underlying native soil's hydraulic conductivity, and/or the ability to daylight an underdrain if used. The design configurations are split into two categories (Level 1 and Level 2) to help the designer determine which configuration is best suited for a particular set of needs. These two levels have specific design requirements and receive different removal performance credits.

### 4.1 Design Levels

The major design goal for bioretention is to maximize runoff volume reduction and nutrient removal. To this end, designers may choose to go with the traditional baseline design (Level 1) or choose an enhanced design (Level 2) that maximizes nutrient and runoff reduction. Level 1 installations are exclusively designed for retention and treatment in the bioretention media, whereas Level 2 installations include infiltration into the surrounding underlying native soil as a part of the treatment process. The decision to choose Level 1 or Level 2 design will depend on the hydraulic conductivity of the underlying native soil and the amount of total phosphorus (TP) reduction needed. For Level 1 designs, the assigned performance credit is based on the practice's void storage, assumed soil media filtration, plant N and P uptake, and other removal processes that occur within the confines of the bioretention unit. For Level 2, the performance credit is based on the same processes as in Level 1 and the ability of the native soils to accept the water leaving the bioretention practice.

### 4.2 Performance

The Virginia Runoff Reduction Method (VRRM) provides performance credits for TP removal. Performance credits are composed of two processes, namely runoff reduction (RR) and pollutant removal (PR). The RR credit is based on volume loss, and the PR credit is based on combined physical, chemical, and biological processes. The overall removal credit is based on an annual mass load reduction, which combines the RR and PR. The assigned credit is greater for Level 2 than for Level 1 because of the design enhancements of Level 2 plus the infiltration of the stormwater into underlying native soils (see Table P-FIL-05-2).

**Table P-FIL-05-2 Summary of Stormwater Treatment Functions Provided by Bioretention**

| Stormwater Function | Level 1 Design | Level 2 Design |
|---|---|---|
| Annual Runoff Reduction Volume | 40% | 80% |
| Total Phosphorus EMC Reduction[1] by BMP Treatment Process | 25% | 50% |
| Total Phosphorus Mass Load Removal | 55% | 90% |
| Total Nitrogen EMC Reduction[1] by BMP Treatment Process | 40% | 60% |
| Total Nitrogen Mass Load Removal | 64% | 90% |

**Notes:**

Source: Hirschman et al 2009.

1. Change in event mean concentration (EMC) through the best management practice (BMP).

## 5.0 Design Criteria

A summary of the design elements for bioretention are provided in Table P-FIL-05-3. The table includes references to other sections and tables within this specification and appendices. The differences in the two levels of design that enable bioretention systems to maximize nutrient reduction are detailed in Table P-FIL-05-3 below.

**Table P-FIL-05-3 Bioretention Design Primary Criteria**

| Level 1 Design | Level 2 Design |
|---|---|
| Surface Area: Tv (cu ft)† = [(1.0)(Rv)(A)] / 12 – the volume reduced by an upstream BMP | Surface Area: Tv (cu ft)† = [1.25(Rv)(A)] / 12 – the volume reduced by an upstream BMP |
| Perform soil test if no underdrain | Soil Test must be performed |
| Hydraulic conductivity (Ksat):<br>Min > 0.5 in./hr. to remove the underdrain requirement<br>Max ≤ 10 in./hr. without underdrain* | Hydraulic Conductivity (Ksat):<br>Min > 0.25 in./hr.<br>Min > 0.5 in./hr. to remove the underdrain requirement<br>Max ≤ 10 in./hr.* |
| Drain Time:<br>Ponding Volume ≤ 48 hrs.<br>Design Volume ≤ 48 hrs. (with underdrain) Design Volume ≤ 72 hrs. (if no underdrain) | Drain Time:<br>Ponding Volume ≤ 48 hrs. Design Volume ≤ 72 hrs. |

| Table P-FIL-05-3 Bioretention Design Primary Criteria | |
|---|---|
| **Level 1 Design** | **Level 2 Design** |
| Stormwater quantity:<br>Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the gravel layer/sump to accommodate a larger storm. OR<br>Use the VRRM Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment | |
| Pond Depth: Minimum 6 inches and maximum of 12 inches‡ | |
| Side Slopes: 3H:1V or flatter | |
| Surface Cover: 2-3 inches of mulch or alternative, such as managed approved vegetation | |
| Planting Plan: A planting template to include turfgrass, herbaceous vegetation, shrubs, and/or trees to cover at least 75% of surface area in 2 years. | Planting Plan: A planting template to include turfgrass, herbaceous vegetation, shrubs, and/or trees to cover at least 90% of surface area in 2 years. Turfgrass must be combined with shrubs and/or trees. |
| Filter Media Depth:<br>Min: 24 inches<br>Max: 48 inches§<br>Min: 36 inches rooting depth for trees** | Filter Media Depth:<br>Min: 36 inches<br>Max: 48 inches§<br>Min: 36 inches rooting depth for trees** |
| Filter Media: Supplied and certified by vendor per criteria provided in Appendix F. | |
| Gravel Layer:<br>Min choker stone layer: 3 in.<br>Min gravel layer with no underdrain: 0 in. Min gravel layer with underdrain: 9 in.<br>Max gravel layer: 12 in.§ | Gravel Layer:<br>Min choker stone layer: 3 in.<br>Min sump depth with underdrain: 9 in. Max sump depth: 12 in.§ |
| Underdrain: Schedule 40 PVC or equivalent with clean-outs. Use slotted pipe under the filter bed and closed pipe elsewhere. | |
| Observation Wells: Schedule 40 PVC or equivalent closed pipe. | |
| Conveyance and Overflow: Off-line/On-line option | |
| Geometry:<br>Concentrated flow: Locate inlets and outlets as far apart as possible. Non-concentrated flow: Distribute inflow evenly across filter surface area. | |
| Maintenance:<br>Deeded Maintenance Agreement<br>See Sections 7.11 and 7.12 for routine and non-routine maintenance requirements as well as a maintenance checklist. | |

| Table P-FIL-05-3 Bioretention Design Primary Criteria | |
|---|---|
| Level 1 Design | Level 2 Design |

**Notes:**

* The native soil may be amended to lower the hydraulic conductivity below 10 inches per hour (see Appendix F).

† If part of a treatment train, the treatment volume calculated by the VRRM spreadsheet includes the remaining volume from an upstream practice(s).

‡ Ponding depths between 6-12 inches need to incorporate plants that tolerate widely fluctuating water levels.

§ Additional depth can be added to the filter media and/or gravel layer/sump to help meet water quantity requirements. This additional depth is not used for surface area sizing calculations. See Section 5.2.

**When used in tree planter applications, at least 36" of suitable rooting depth must be maintained. For example, if filter media depth is 24", at least 12" of non-compacted suitable soil that meets overall media Ksat criteria should be employed between the media and the underdrain or soil infiltration zone.

### 5.1 BMP Sizing

To function as designed, a bioretention practice must be sized based on the design criteria in Table P-FIL-05-3. An example of initial sizing calculations is given in Appendix F. The final footprint of the bioretention practice will consist of the pretreatment area and the surface ponding area. The size of the practice is determined by the design level (Level 1 or 2), which will depend on the amount of P to be removed, the hydraulic conductivity ($K_{sat}$) of the underlying native soils, and whether an underdrain can be daylighted. The size of the practice could also be influenced by storage added to meet water quantity requirements. This section provides the means to properly size a bioretention practice to capture the BMP design treatment volume ($T_{vBMP}$) and any additional volume to help manage water quantity.

#### 5.1.1 Component Depths

The various layers of the bioretention practice are referred to as components. A bioretention practice must contain a ponding area and soil filter media. A gravel layer can also be added, and designers can choose from different options for the gravel layer. The gravel layer is called a "sump" for Level 2 designs because the underdrain is located at the top of the gravel. Each component has established minimum and maximum depths (Table P-FIL-05-3). The depths of the selected components are used in the computation for the surface area of the practice.

#### 5.1.2 Surface Area Sizing

**Surface Area Sizing for Stormwater Quality**. Proper sizing of the surface area is important for bioretention for three main reasons:

1. The first is to ensure that the surface area size is not too small to accommodate the expected design volume of flow. If the practice is too small, a portion of the treatment volume will bypass the practice. As an example, runoff volume bypass could occur at 0.7 inches of rainfall or greater depending on rainfall intensity. Local topography and the hydraulic conductivity ($K_{sat}$) of the soil media or native soil, whichever is the limiting $K_{sat}$ value.
2. The second reason is to confirm that the design storage volume passes through and exfiltrates from the practice within specified drain times. Drain times aim to ensure storage is available within the practice between storm events and to prevent the soil media from being saturated for an extended period.
3. The third reason involves the land use designation within the VRRM spreadsheet. Provided the bioretention practice is designed and maintained as directed in this specification, the surface area is counted as forest and mixed open space in the VRRM spreadsheet (DEQ VRRM User Guide).

The surface area size for any practice will be based on the comparison of two equations. One equation is based on the volumetric requirements of the practice (Volumetric method) and the other is based on the interaction of the practice with its surrounding soil environment (Flow-rate method). Both equations require knowing $Tv_{BMP}$, which is the treatment volume based on the runoff generated from the 1-inch storm event, and includes runoff from impervious surfaces and managed turf within the contributing drainage area to the BMP plus any remaining runoff volume from upstream runoff reduction practices. Any forest or mixed open space areas included within the contributing drainage area are not part of the $Tv_{BMP}$. The $Tv_{BMP}$ for Level 1 designs can be obtained from the VRRM spreadsheet. For Level 2 designs, use Equation P-FIL-05-1 to calculate the *TvBMP :*

**Equation P-FIL-05-1:** Treatment Volume Calculation.

$$Tv_{BMP} = (C_{Level} \text{ x } R_v \text{ x } A) / 12$$

Where:

$C_{Level}$ = factor that is set to 1 in. (for Level 1 designs) or 1.25 in. (for Level 2 designs)

$R_v$ = composite volumetric runoff coefficient, which comes from the VRRM Drainage Area (DA) Tab.

$A$ = drainage area to BMP (sq. ft.)

*Volumetric Approach*: The required surface area (SA; in square feet) is computed as the $Tv_{BMP}$ (in cubic feet) divided by the equivalent storage depth, ESD (in feet; Equation P-FIL-05-2). The equivalent storage depth represents the void space available for water storage within the surface ponding area, soil media, and gravel layer (if needed) of the bioretention practice. The equivalent storage depth is computed as the sum of the depths (in feet) of the utilized components multiplied by their respective accepted porosity (Table P-FIL-05-4). Therefore, the selection of the component depths (within the required minimums and maximums of Table P-FIL-5-3) will influence the size of the surface area.

***Equation P-FIL-05-2 Bioretention Surface Area Using Volumetric Approach.***

$$SA = Tv_{BMP} / ESD$$

Where:

$SA$ = surface area (sq. ft.)

$Tv_{BMP}$ = BMP treatment volume (cu. ft.)

= Level 1 BMP design treatment volume (cu. ft.) = [(1.0 in.)($R_v$)($A$) / 12];

= Level 2 BMP design treatment volume (cu. ft.) = 1.25[(1.0 in.)($R_v$)($A$) / 12]

$R_v$ = Composite volumetric runoff coefficient from the VRRM Compliance Spreadsheet or User Guide

$A$ = drainage area to BMP (sq. ft.)

$ESD$ = equivalent storage depth (ft.)

$= (d_{ponding} \times \eta_{ponding}) + (d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})$

$d$ = depth of the respective layer (ponding, media, or gravel; ft.)

$\eta$ = available porosity of the respective layer (ponding, media or gravel; Table P-FIL-05-4)

| Table P-FIL-05-4 Estimated Porosity for Each Bioretention Component | |
|---|---|
| **Bioretention Component** | **Available Porosity ($\eta$)** |
| Ponding Area | 1.0 |
| Soil Media | 0.25 * |

| Table P-FIL-05-4 Estimated Porosity for Each Bioretention Component | |
|---|---|
| **Bioretention Component** | **Available Porosity ($\eta$)** |
| Gravel Layer | 0.40 |

**Note:**

*Estimated value assuming full media dry-down.

*Flow-rate Approach*: In addition to utilizing the $Tv_{BMP}$ and the depths for the ponding area and soil filter media, this method also includes drain time $K_{sat}$ (Claytor and Schueler 1996). The selected Ksat will either be that of the soil filter media or native soil, depending on the design level of the practice and the results of the soil test for the native soil. This approach also provides a level of insurance that the practice will drain within the two-day specified time.

***Equation P-FIL-05-3 Bioretention Surface Area Using Darcy's Law.***

$$SA = (12 \times Tv_{BMP} \times d_{media}) / (td \times K_{sat}\ x\ (d_{ponding} + d_{media}))$$

Where:

$SA$ = surface area of bioretention practice (ft.2)

$Tv_{BMP}$ = treatment volume of the BMP (cu. ft.)

$d_{media}$ = depth of soil filter media (ft.)

$t_d$ = required drain time (hr.); maximum is 48 hours for ponding volume

$K_{sat}$ = hydraulic conductivity (in./hr.);

if Level 1 with an underdrain, use the Ksat of the soil filter media;

if Level 2 or Level 1 without an underdrain, use the Ksat of the most restrictive layer (soil filter media, native soil)

$d_{ponding}$ = depth of ponding area (ft.) 213

**Surface Area Sizing for Stormwater Quantity**. The credit from RR can be used to reduce the stormwater volume that discharges from the site. The reduction of the stormwater volume can therefore be applied to meet both water quality and water quantity requirements. The VRRM spreadsheet calculates the RR credit for water quality and applies the credit to the water quantity volumes. This reduced runoff volume is shown on the Runoff Volume and Curve Number Calculations Tab. Detailed information on this process can be found in DEQ VRRM User Guide.

Designers may be able to create additional surface storage by expanding the surface ponding footprint to accommodate a greater quantity credit for channel and/or flood protection. This surface ponding expansion can be accomplished without necessarily increasing the soil media footprint. In other words, the engineered soil media would only underlie part of the surface area of the bioretention. In this regard, the ponding footprint can be increased as follows to allow for additional storage:

- 50% surface area increase if the ponding depth is 6 inches.
- 25% surface area increase if the ponding depth is between 6 and 12 inches.

Both Level 1 and Level 2 designs are limited by the percentage surface ponding expansion described above. For Level 1 practices with an underdrain, the added volume of storage for channel and flood protection is also limited by the ponding volume drain time of 48 hours. For Level 2 practices or Level 1 without an underdrain, the storage volume for channel and flood protection must drain within 72 hours (See Section 5.1.3 on Drain Times).

Note: Any depths used to increase storage for additional quantity credit are not to be used in the surface area equations (Equations P-FIL-05-2 and 05-3).

### 5.1.3 Drain Times

The drain time is defined as the time it takes for a storage volume to exit either the entire practice or a component of the practice, e.g., ponding area, soil media, sump. The drain time is important for two reasons:

1. To ensure void storage is available for successive storm events, and
2. To prevent anaerobic conditions within the soil media that can cause the release and transport of nutrients and metals.

A predetermined drain time (Table P-FIL-05-5) has been assigned for a given storage volume. The storage volumes of interest are the volume of water contained in the ponding area (PV) and the design volume (DV). The DV, at a minimal, will equal $Tv_{BMP}$. The maximum DV is composed of the $Tv_{BMP}$ and the water quantity volume that can be applied toward meeting channel/flood protection requirements (QV).

**Table P-FIL-05-5 Design Parameters for Drain Time Calculations**

| Bioretention Component | Unit | Design Criteria |
|---|---|---|
| Treatment volume of BMP (TvBMP) | ft.$^3$ | Obtain from VRRM spreadsheet* |
| Ponding volume (PV) | ft.$^3$ | Total volume of water in ponding area |
| Water quantity volume (QV) | ft.$^3$ | Volume applied for channel/flood protection |
| Design volume (DV) | ft.$^3$ | Total volume of water that drains within the established drain time (48 or 72 hours)<br>DV = TvBMP + QV |
| Hydraulic conductivity of soil filter media (media Ksat) | in./hr. | Supplied by vendor or use 0.5 |
| Hydraulic conductivity of native soil (soil Ksat) | in./hr. | No underdrain: ≥ 0.5 and < 10<br>Level 2 with sump or internal water storage: ≥ 0.25 |
| Maximum drain time of ponding volume | hrs. | 48 |
| Maximum drain time of practice | hrs. | 72 (or 48 hours if Level 1 with an underdrain) |

**Note:**

* For Level 2 practices, multiple TvBMP from VRRM spreadsheet by 1.25.

**Drain time of the surface ponding area:** The maximum drain time of the ponding volume is 48 hours. If the two-day limit is exceeded, adjust the sizing of the practice or alter the landcover to reduce the volume to the facility.

***Equation P-FIL-05-4 Drain Time of the Surface Ponding Area.***

$$t_{d\text{-}PV} = 12 \times PV / (K_{sat} \times SA)$$

Where

$t_{d\text{-}PV}$ = drain time of the ponding volume (hours)

$PV$ = ponding volume (ft.$^3$)

$K_{sat}$ = hydraulic conductivity of the soil filter media (in./hr.)

$SA$ = surface area of soil filter media (ft.$^2$)

**Drain time of the practice:** Use the drain time of the practice to ensure that the treatment volume exfiltrates within 48 hours for Level 1 designs with an underdrain and within 72 hours for Level 1 designs without an underdrain and for Level 2 designs (Equation P-FIL-05-35). If the limit is exceeded, make sizing adjustments for the practice or alter the landcover to reduce the volume to the facility.

***Equation P-FIL-05-5 Drain Time of the Treatment Volume.***

$$t_{d-TV} = 12 \times Tv_{BMP} / (K_{sat} \times SA)$$

$t_{d-TV}$ = drain time of the treatment volume (hours)

$Tv_{BMP}$ = treatment volume of BMP (cu. ft.)

$K_{sat}$ = hydraulic conductivity of the most restrictive layer (in./hr.)

- Level 1 with underdrain, use $K_{sat}$ of soil filter media
- Level 1 without underdrain, use limiting Ksat of soil filter media or native soil.
- Level 2, use limiting Ksat of soil filter media or native soil

$SA$ = surface area of soil filter media (sq. ft.)

This calculation determines the additional storage that can be added for channel and flood protection. The volume available for channel and flood protection is the difference between the $Tv_{BMP}$ that drains within 72 hours (or 48 hours if Level 1 with an underdrain) and any remaining volume that would drain within that drain time limit. If storage is to be used for channel and flood protection, use the following equation to determine the volume available:

**Equation P-FIL-05-6:** Volume Available for Quantity Requirements.

$$QV = (K_{sat} \times SA \times td\text{-}TV / 12) - Tv_{BMP}$$

Where:

QV = Volume available for channel/flood protection (cu. ft.)

$K_{sat}$ = hydraulic conductivity of the most restrictive layer (soil filter media, native soil) (in./hr.)

$SA$ = surface area of soil filter media (sq. ft.)

$t_{d-TV}$ = drain time of the treatment volume (hours); maximum = 72 hours (or 48 hours if Level 1 with an underdrain)

$Tv_{BMP}$ = Treatment volume of the practice (cu. ft.)

### 5.1.4 Storage Volume

The designer should calculate the total storage volume located within the surface ponding area, soil media, and gravel layer to determine the actual storage volume that the practice contains. The volume of the ponding area needs to account for the side slopes of 3H:1V or flatter. Because of the side slopes, the actual storage volume will be larger than the design volume. However, only the design volume is required to drain within 72 hours (or 48 hours if Level 1 with an underdrain).

**Equation P-FIL-05-7:** Total Storage Volume of the Practice**.**

$$SV_{practice} = [(SA_{avg\text{-}ponding} \times d_{ponding}) + (SA_{media} \times d_{media} \times \eta_{media}) + (SA^{gravel} \times d_{gravel} \times \eta_{gravel})]$$

Where:

$SV_{practice}$ = storage volume of the practice (ft.$^3$)

$SA_{avg\text{-}ponding}$ = the average area of the ponding layer (ft.$^2$)

= 0.5 × [(surface area at the top of the layer) + (surface area at the bottom of the layer)]

$d$ = depth of the respective layer (ponding, media, or gravel; ft.)

$SA$ = surface area of the respective layer (media or gravel; ft.$^2$)

$\eta$ = porosity of the respective layer (media or gravel; $\eta_{ponding}$ = 1; see Table P-FIL-05-4)

If the media and/or gravel layers have side slopes, use the equation above and replace $SA_{media}$ with $SA_{avg\text{-}media}$ and/or replace $SA_{gravel}$ with $SA_{avg\text{-}gravel}$ (as needed). The symbols for $SA_{avg\text{-}media}$ and $SA_{avg\text{-}gravel}$ refer to the following:

$SA_{avg}$ = the average area of the respective layer (media or gravel; ft.$^2$)

= 0.5 × [(surface area at the top of the layer) + (surface area at the bottom of the layer)]

**Note:** The surface area computed using Equation P-FIL-05-2 and 05-3 must not use component depths added for the purpose of water quantity volume.

**Note:** The VRRM spreadsheet computes the treatment volume that is used to size the practice. This treatment volume represents the largest storage volume that the practice contains based on the bioretention specifications for water quality management and is the only volume recognized by the VRRM spreadsheet.

### 5.2 Surface Ponding Area

The surface ponding area includes the portion of the bioretention practice located between the top of the filter media and the top of the ponded water surface.

The minimum surface storage requirements are based on the need to capture the $Tv_{BMP}$ from a full range of expected storm intensities. Rainfall distribution in the mid-Atlantic includes both short intense storms, as well as long, steady, low-intensity rain events. During high intensity storm events, the bioretention practice may fill up faster than the collected stormwater is able to filter through the soil media. In addition, the hydraulic conductivity of the surface layer of mulch and the soil media will vary over the maintenance life cycle of the practice.

Therefore, an adequate ponding volume is necessary to allow the runoff to begin to filter into the soil media before the runoff bypasses or overflows the surface storage. The method provided in determining the surface ponding area is an attempt to capture and treat the majority of the TvBMP for most storm events.

The surface ponding area must be primarily covered with vegetation and includes planting zones on the bottom and sides of the ponded area. Design elements for the surface ponding area include the ponding depth, side slopes, surface cover, and planting plan.

#### 5.2.1 Depth

The surface ponding area of a bioretention practice must have a minimum ponding depth of 6 inches and a maximum ponding depth of 12 inches. A ponding depth of 6 inches is preferred unless site constraints mandate the deeper ponding depth.

#### 5.2.2 Side Slopes

Side slopes of the ponding area are required to be 3H:1V or flatter.

*A residential bioretention used to manage upgradient street runoff that was formerly causing nuisance flooding downstream*
*Photo Credit: Hirschman Water & Environment, LLC.*

**5.2.3 Surface Cover**

- **Mulch**. Include a 2- to 3-inch layer of mulch on the surface of the filter bed unless managed grass cover is utilized with a high $K_{sat}$ establishment soil cover. Shredded, aged-hardwood bark (aged at least 6 months) makes a very good mulch surface cover, as it may retain some pollutants and typically will not float away. The maximum depth of the mulch layer is 3 inches.

The surface cover is the layer of materials located on the top of the soil filter media. The purpose of the cover is to enhance plant survival, suppress weed growth, and pre-treat runoff before it reaches the soil filter media. The choice of surface cover will also influence the maintenance activities of the soil filter media and plantings (see Section 7.0 Maintenance). This layer is not included in the sizing calculations. The surface cover options are listed below.

- **Managed grass or non-leguminous herbaceous cover**. Managed grass is defined as grassy areas that are not used for food or fodder and have a minimum maintenance of at least two mowing events per year. Any perennial grass mixture or monostand that covers the soil well (at least 70% living cover) will protect soil and allow infiltration. Species that will persist the best (i.e., cover the soil) at the location should be used. Grass performance and persistence is very much dependent on the geography, characteristics and intended maintenance of the site. The following sources and others provide more information:
    - "Virginia Turfgrass Variety Recommendations" by Virginia Cooperative Extension
    - "Virginia Department of Transportation Specifications for Standard and Non-Standard Seed" (e.g., Green Tag list) by Virginia Department of Transportation
- **Alternative Vegetative Covers and/or Zones**. In some situations, designers may consider alternative surface covers such as native groundcover, erosion control matting (coir or jute matting), river stone, or pea gravel. Native groundcover serves a dual role, as both surface cover and vegetation (see Section 5.3.4). Stone or gravel are not recommended in parking lot applications because they increase soil temperature and have low water holding capacity. Furthermore, the use of stone or gravel disqualifies the surface area of the bioretention from being counted as forest and mixed open space in the VRRM spreadsheet.

**5.2.4 Planting Plan**

A planting plan must be developed for the intended vegetated zones in each bioretention area. The primary objective of the planting plan is to cover as much of the surface area of the filter bed as quickly as possible to provide some level of vegetative resistance to water flow and enhance evapotranspiration and nutrient uptake (see Table P-FIL-05-6). The planting plan should be prepared by a landscape or revegetation/restoration professional to tailor it to the site-specific conditions. Minimum plan elements shall include the following:

- Delineation of planting area into moisture zones,
- Template,

- Vegetation Plan, and
- Installation and Maintenance Plan.

**Delineation of Planting Area**. The planting area needs to be sectioned into different moisture and/or plant type (e.g., grass, shrub, tree) zones. Delineate the low, medium, and high moisture zones of the practice. In, the lowest area, plant facultative species that tolerate frequently wet conditions, and in the highest areas, plant species that do well under drier conditions. Also indicate the location of inlets, outlets, underdrains and any utilities that cross the bioretention practice to ensure that the vegetation planted in these areas is appropriate given assumed wetness gradients and constraints.

**Planting Options/Templates**. The planting template for a given site BMP describes the types of vegetation to be planted within the bioretention practice, e.g., herbaceous vegetation, shrubs, and/or trees. The choice of which planting template to use depends on the scale of bioretention, the context of the site in the urban environment, the filter depth, the desired landscape amenities, and the owner's capability to maintain the landscape. Six potential bioretention vegetation options/templates are summarized in Table P-FIL-05-6.

**Table P-FIL-05-6 Bioretention Vegetation Options and Templates**

| Vegetation Component | Options |
|---|---|
| Managed Grass | This option serves as both vegetation and surface cover (see Section 5.2.3). For Level 1 practices, managed grass is all that is needed. For Level 2 practices, managed grass must be combined with shrubs and/or trees. Use grass species that have dense cover, are relatively slow growing, and require limited mowing (see Table P-FIL-05-7). |
| Perennial Garden | This option uses herbaceous plants and native grasses to create a garden effect with seasonal cover. This option is attractive, but it requires diligent maintenance in the form of weeding. Use of pollinator friendly mixes is encouraged. |
| Perennial garden with shrubs | This option mixes native shrubs and perennials together in the bioretention area. This option is frequently used when the soil filter media is too shallow to support tree roots (which have a minimum effective rooting depth of 36 inches). |
| Tree, shrub and herbaceous plants | This template is the traditional landscaping option for bioretention and is highly recommended.<br>The landscape goal is to simulate the structure and function of a native early successional forest plant community. |
| Managed grassland and trees | This option is a lower maintenance version of the tree-shrub-herbaceous option. Trees are planted within larger mulched islands to prevent damage during mowing operations. |
| Herbaceous meadow | This approach focuses on the herbaceous layer and may resemble a wildflower meadow or roadside vegetated area (e.g., with Joe-Pye weed, New York ironweed, sedges, grasses, etc.). The goal is to establish a natural look that may be appropriate if the practice is located in a lower maintenance area (e.g., further from buildings and parking lots). Shrubs and trees may be incorporated around the perimeter. |

**Vegetation Plan**. The vegetation plan includes the number and list of plants to be planted, recommended spacing, and size of planting stock. Some popular native species that work well in bioretention areas and are commercially available can also be found in Table P-FIL-05-7. Commonly used ornamental non-native (non-invasive and/or problematic) are also provided in Table P-FIL-05-7. Internet links to more detailed bioretention plant lists developed in Piedmont and Coastal Plain communities of the Chesapeake Bay region are provided in Section 5.3.

Consider the following when selecting vegetation for a bioretention practice:

- Native plant species should be specified over non-native species where possible to meet design expectations, but some ornamental and non-native species may be used for landscaping effect if they are not aggressive or invasive.
- Use of pollinator friendly species is encouraged where compatible with design expectations.
- Plants should be selected based on a specified zone of hydric tolerance and must be capable of surviving both wet and dry conditions. Care is needed in selecting vegetation for facilities with ponding depths greater than 6 inches.
- Use turfgrass, perennials or shrubs instead of trees in practices with shallower filter beds (e.g. where 36" of effective rooting depth cannot be assured).
- If trees are used, plant shade-tolerant ground covers within the drip line.
- Tree species should be those that tolerate expected non-pristine air and water inputs from the urban landscape.
- Maintenance is an important consideration in selecting plant species. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site that will receive minimum annual maintenance.
- If the bioretention area is to be used for snow storage or is to accept snowmelt runoff, it should be planted with salt-tolerant, herbaceous perennials and shrubs.

This list is not exclusive and additional sources of information are given in below the table. Use of native species adapted to fluctuating wetness (redox) conditions is encouraged over the use of non-native ornamental species for direct planting into bioretention media zones. Dryer mesic species are best utilized around bioretention margins, berms and conveyances.

**Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications**

| Common name | Botanical Name | Spread | Height | Tolerances | Soil moisture | Availability (e.g., seeds, plants) | Other notes |
|---|---|---|---|---|---|---|---|
| **Shrubs** | | | | | | | |
| American beautyberry | *Callicarpa americana* | 4-6 ft | 4-6 ft | Clay soil, cold, drought | Mesic to wet | Seed, plugs, cuttings | Zones 6-12. Full sun to part shade. Attractive purple seeds. Conspicuous flowers. Attracts birds and butterflies. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Sweet pepperbush | *Clethra alnifolia* | 3-6 ft | 3-8 ft | Wet soil, acid soil, sands and clays, salt spray, heavy shade | Mesic to wet | Potted plants | Fragrant, showy flowers. Fall color. Attracts birds, bees, and butterflies. Part shade to full shade. Zones 3-9. |
| Buttonbush | *Cephalanthus occidentalis* | 4-8 ft | 5-12 ft | Erosion, wet soil, shallow standing water | Mesic to wet | Potted plants, bareroot seedlings | Zones 5-9. Full sun to part shade. Attracts pollinators. Does not tolerate dry soils |
| Silky dogwood | *Cornus amomum* | 6-12 ft | 6-12 ft | Deer, erosion, wet soil, black walnut, shade | Mesic to wet | Potted plants | Zones 5-8. Full sun to part shade. Attracts pollinators. Prefers rich, acidic soils. Can spread via rhizomes. |
| Gray dogwood | *Cornus racemosa* | 10-15 ft | 10-15 ft | Deer, wet soil, somewhat dry soil, air pollution | Mesic | Potted plants | Zones 4-8. Full sun to part shade. Attracts pollinators. Tolerates many soil types. Can spread via rhizomes. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Red osier dogwood | *Cornus sericea* | 7-10 ft | 6-9 ft | Deer, erosion, clay soil, wet soil, | Mesic to wet | Potted plants | Zones 3-7. Full sun to part shade. Attracts pollinators. Winter interest. Prefers rich, fertile, most soils. Stressed in heat/humidity. Can spread via rhizomes. |
| Winterberry | *Ilex verticillata* "Red Sprite" -many cultivars | 2.5-3 ft | 6-10 ft | Erosion, clay soil, wet soil, air pollution | Mesic to wet | Potted plants | Full to part shade. Zones 3-9. Need 1 male per 9-10 females to produce berries. |
| Yaupon | *Ilex vomitoria* | 8-12 ft | 12-25 ft | Clay soil, moderate deer resistance | Dry to Mesic | Potted plants | Zones 7-9. Full sun to part shade. Attractive red berries (male and female plants are required to have berries). Attracts birds and butterflies. Evergreen |
| Sweetspire | *Itea virginica* | 3-5 ft | 3-5 ft | Deer, heavy shade, wet soil, erosion | Mesic to wet | Potted plants | Many cultivars. Full sun to part shade. Zones 5-9. Prefers high OM soils. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Inkberry | *Ilex glabra* "Shamrock" | 3-4 ft | 3-4 ft | Rabbit, deer, erosion, wet soil, air pollution | Mesic to wet | Potted plants | Many cultivars. Full sun to part shade. Zones 4-9. Prefers high OM, acidic soils. Evergreen |
| Wax myrtle | *Morella cerifera* | 10-15 ft | 6-15 ft (can reach a max of 25 ft) | Clay soil. Saline soils. Flood and drought when established. Deer and rabbit resistant | Mesic to wet | Potted plants | Evergreen. Zones 7-10. Needs constant moisture to establish (drought and flood tolerant once established). Sun to part shade. Fragrant. |
| Common ninebark | *Physocarpus opulifolius* | 4-6 ft | 5-8 ft | Drought, erosion, clay soil, dry soil, wet soil, shallow-rocky soil, black walnut | Dry to mesic – well drained | Potted plants, bare roots | Zones 2-8. Full sun to part shade. Struggles with heat and humidity. Needs pruning after flowering. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Elderberry | *Sambucus canadensis* | 5-12 ft | 5-12 ft | Erosion, clay soil, wet soil. | Mesic to wet | Potted plants | Zones 3-9. Full sun to part shade. Showy, fragrant flowers that attract pollinators. Edible berries attract birds. Grows best in humic soils. Spreads by suckers. |
| Arrowwood | *Viburnum dentatum* | 6-10 ft | 6-10 ft | Black walnut, var. soil types | Mesic – well drained | Potted plants | Zones 2-8. Full sun to part shade. Showy flowers, fall foliage. Blue Muffin cultivar ~ half size. Prefers moist loams, tolerates many soils. |
| Blackhaw viburnum | *Viburnum prunifolium* | 6-12 ft | 12-15 ft | Drought, clay soil, black walnut, air pollution | Dry to mesic-well drained | Potted plants, bare root | Zones 3-9. Full sun to part shade. Attracts pollinators. Showy flowers, fruits, fall foliage. Can be pruned to grow as a small tree (30’). Edible fruits. |
| **Grasses and Herbaceous Perennials** | | | | | | | |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Big bluestem | *Andropogon gerardii* | 2-3 ft | 4-6 ft | Deer, Drought, Erosion, Dry Soil, Black Walnut, Air Pollution | Dry to mesic | Seeds, potted plants | Many cultivars, some smaller. Full sun. Zones 4-9. |
| Swamp milkweed | *Asclepias incarnata* | 2-3 ft | 2-5 ft | Heavy clay, wet soil, high deer resistance | Mesic to wet | Potted plants | Zones 3-8. Full sun to part shade. Attracts pollinators. Pink flowers. Poisonous |
| Pennsylvania sedge | *Carex pensylvanica* | 6-12 in | 6-12 in | Heavy shade, wet soil | Dry to mesic – well drained. | Plugs, small pots, seeds | Part to full shade. Zones 3-8. Prefers loose soils. |
| Riveroats | *Chasmanthium latifolium,* | 1-2.5 ft | 2-5 ft | Poor soils, black walnut. | Mesic to wet | Seed, potted plants | Zones 3-8. Full sun to part shade. Spreads via seeds |
| Virginia dayflower | *Commelina virginica* | 1.5-3 ft | 1.5-3 ft | Wet soil | Mesic to wet | Small pots | Hardiness zones 5/6-9. Small blue flowers. Sun to shade |
| Trumpetweed (Joe-Pye Weed) | *Eutrochium fistulosum* | 2-4 ft | 2-7 ft | Wet soil, deer and rabbit resistant | Mesic to wet | Seed, potted plants | Shrubby perennial. Zones 4-10. Full sun to part shade. Showy flowers. Attracts pollinators |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Swamp mallow | *Hibiscus moscheutos* | 2-4 ft | 3-7 ft | Wet soil, some light shade, heat and humidity | Mesic to wet | Seeds, plants | Zones 5-9. Full sun. Prefers high OM soils, does not tolerate dry soils. Showy flowers, attracts pollinators. |
| Blue flag iris | *Iris versicolor* | 2-2.5 ft | 2-2.5 ft | Deer, wet soil, erosion | Mesic to wet | Seeds, small pots | Zones 3-9. Full sun to part shade. Likes humic soils. |
| Southern blue flag iris | *Iris virginica* | 1-3 ft | 1-3 ft | Deer, wet soil | Mesic to wet | Seeds, potted plants | Zone 5-9. Full sun. Prefers wet, boggy, acidic, sandy soils. Does not tolerate dry soil. |
| Common rush | *Juncus effusus* | 1-4 ft | 1-4 ft | Clay soil, deer | Mesic to wet | Seeds, potted plants | Full to part sun. Zone 4-9 |
| Cardinal flower | *Lobelia cardinalis* | 1-2 ft | 2-4 ft | Rabbit, deer, wet soil, brief flooding | Mesic to wet | Seeds, plants | Zones 3-9. Full sun to part shade. Showy flowers, attract pollinators. Prefers rich soils. Does not tolerate dry soils. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Bee balm | *Monarda didyma* | 2-3 ft | 2-4 ft | Rabbit, deer, clay soil, wet soil, black walnut | Mesic to wet | Seeds, plants | Zones 4-9. Full sun to part shade. Fragrant, showy flowers, attracts pollinators. Best in rich, moisture-retentive soils; does not tolerate dry soils. |
| Wild bergamot | *Monarda fistulosa* | 2-3 ft | 2-4 ft | Deer, drought, clay soil, shallow-rocky soil, black walnut | Dry to mesic | Seeds, plants | Zones 3-9. Full sun to part shade. Fragrant, showy flowers, attracts pollinators. |
| Switchgrass | *Panicum virgatum (many varietals)* | 2-3 ft | 3-6 ft | Drought, pollution, deer resistant, black walnut | Mesic (well drained) | Potted plants | Controls erosion (roots can reach depths of 10 feet). Food source and cover for birds. Sun to partial shade (best in full sun). Zones 3-9 |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Black-eyed Susan | *Rudbeckia hirta* | 1-2 ft | 1-3.5 ft | Heat, drought, clay soil. Slightly deer resistant | Dry to mesic | Seeds, small pots | Hardiness zones 3-7. Dislikes poorly drained, wet soils (side-slope species). Sun to partial shade. Free seeding. Showy flowers. Attracts pollinators |
| Little bluestem | *Schizachyrium scoparium* | 1.5-2 ft | 2-4 ft | Deer, drought, erosion, black walnut, air pollution, occasional inundation | Dry to mesic | Seeds, potted plants | Many cultivars. Zones 3-9. Full sun (tolerates part shade), |
| Sweet goldenrod | *Solidago odora* | 1-2 ft | 2-5 ft | Deer, drought, clay soil | Dry to mesic | Seed, potted plants | Zone 4-9. Conspicuous yellow flowers. Attracts pollinators. Full sun |
| **Trees** | | | | | | | |
| Serviceberry | *Amelanchier arborea (some cultivars)* | 15-25 ft | 15-25 ft | Tolerant of wide range of soils | Mesic | Potted trees | Zones 4-9. Full sun to part shade. Shrubbier habit if root suckers unpruned. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Red maple | *Acer rubrum* | 30-50 ft | 40-80 ft | Wide range of soil, air pollution. Moderately deer resistant | Mesic to wet by variety | Potted trees | Showy fall color. Fast growing. Sun to partial shade. Zones 3-9 |
| Pawpaw | *Asimina triloba* | 15-30 ft | 15-30 ft | Wet soil, black walnut, deer | Mesic to wet- well drained | Potted trees | Zones 5-9. Full sun to part shade (more fruit production in full sun). Prefers moist, acidic, fertile soils. Showy fall foliage. Spreads by suckers. |
| River birch | *Betula nigra* | 40-60 ft | 40-70 ft | Deer, drought, heat, wet soil, black walnut, air pollution | Mesic to wet | Potted trees, burlapped trees | Full sun to part shade. Zones 4-9. Prefers acidic, fertile soils. |
| Hackberry | *Celtis occidentalis* | 40-60 ft | 40-60 ft | Drought, clay soil, wet soil, dry soil, air pollution, poor soils | Mesic to wet – well drained | Potted trees, burlapped trees | Full sun to part shade. Zones 2-9. Attracts birds and butterflies. Edible fruits. |
| Persimmon | *Diospyros virginiana* | 25-35 ft | 35-60 ft | Drought, clay soil, dry soil, shallow-rocky soil, black walnut, air pollution | Dry to mesic | Potted trees | Full sun to part shade. Zones 4-9. Prefers moist, sandy soils. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Sweetgum | *Liquidambar styraciflua* | 50-75 ft | 60-90 ft | Clay, short duration flooding, rabbits | Mesic to wet | Potted trees | Does not tolerate alkaline soil. Not deer tolerant. Attracts wildlife. Sun to partial shade. Zones 5b-9. Showy fall color |
| Swamp (Sweetbay) Magnolia | *Magnolia virginiana* | 12-30 ft | 12-30 ft | Clay soils, wet soils, shade, flooding, air pollution, salt spray | Mesic to wet | Potted trees | Fragrant white-cream blooms. Attracts birds and wildlife. Sun to partial shade. Zones 5-10. |
| Tupelo gum | *Nyssa aquatica* | 25-50 ft | 50-80 ft | Poorly drained soils, standing water | Mesic to wet | Potted trees | Full sun to part shade. Zones 6-9. Prefers moist, acidic soils. |
| Black gum | *Nyssa sylvatica* | 20-30 ft | 30-50 ft | Wet soil, some standing water, dry soil, black walnut, | Mesic to wet | Potted trees, possibly burlapped trees | Full sun to part shade, Zones 3-9. Prefers moist, acidic soils. |
| Sycamore/ London planetree | *Platanus occidentalis/ Platanus x acerifolia* | 60-100 ft | 75-100 ft | Deer, wet soil, air pollution | Mesic to wet | Potted trees, burlapped trees | Zones 4-9. Full sun. Large tree – best for large areas. Tolerates light shade. Prefers rich, humic, moist soils. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Wild Black cherry | *Prunus serotina* | 30-60 ft | 50-80 ft | Drought, salt spray, black walnut | Dry to mesic | Potted trees | Showy, white flowers. Susceptible to diseases. Not deer tolerant. All parts except fruit are toxic. Attracts pollinators. Zones 3-9 |
| Swamp white oak | *Quercus bicolor* | 50-60 ft | 50-60 ft | Wet soil, drought, | Mesic to wet | Potted trees, burlapped trees | Zones 3-8. Full sun. Prefers acidic soil. Showy fall foliage. |
| Swamp chestnut oak | *Quercus michauxii* | 30-50 ft | 40-60 ft | Erosion, wet soil, part shade, occasional flooding | Mesic to wet | Potted trees, burlapped trees | Zones 5-9. Full sun. Showy fall foliage. Grows best in acidic, moist loams and sandy soils. |
| Pin oak | *Quercus palustris* | 40-60 ft | 50-70 ft | Wet soils, some flooding | Mesic to wet. | Potted trees, burlapped trees | Full sun. Zones 4-8. Does not tolerate very poorly drained soils. Prefers acidic soils. |
| Willow oak | *Quercus phellos* | 25-50 ft | 40-75 ft | Wet soils, clay soil, air pollution, light shade. | Mesic to wet | Potted trees, burlapped trees | Full sun. Zones 5-9. Tolerates some poor drainage. |

| Table P-FIL-05-7 Suggested Native Plants for Use in Bioretention Applications | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Common name** | **Botanical Name** | **Spread** | **Height** | **Tolerances** | **Soil moisture** | **Availability (e.g., seeds, plants)** | **Other notes** |
| Shumard oak | *Quercus shumardii* | 30-40 ft | 40-60 ft | Drought, dry soils, wet soil, air pollution | Dry to mesic – well drained soils | Potted trees, burlapped trees | Full sun. Zones 5-9. Prefers mesic, acidic soils. Moderately fast growing but a smaller oak. Showy fall foliage. |
| Black willow | *Salix nigra* | 30-60 ft | 30-60 ft | Erosion, flooding | Mesic to wet | Potted trees | Zone 4-9. Full sun to part shade. Shallow roots stabilize soil. Intolerant of dry soil and full shade. |
| Bald cypress | *Taxodium distichum* | 20-45 ft | 50-70 ft | Deer, clay soil, wet soil, air pollution, compacted soils. | Mesic to wet | Potted trees, burlapped trees | Full sun. Zones 4-9. Prefers moist, acidic, sandy soils but can tolerate many soils as well as dry soils to standing water. Only native in Coastal Plain of VA. |

#### 5.3 Links for Stormwater BMP and Native Plant Publications

The resources identified in this subsection are listed alphabetically by organization and title.

Chesapeake Bay Landscape Professional (CBLP)

- CBLP Sustainable Landscapes Maintenance Manual – https://certified.cblpro.org/product-category/manuals/
- Native Plants for Stormwater Best Management Practices – https://certified.cblpro.org/product-category/manuals/

Cornell University, School of Integrative Plant Science

- Woody Shrubs for Stormwater Retention Practices: Northeast and Mid-Atlantic Regions – http://www.hort.cornell.edu/uhi/outreach/pdfs/woody_shrubs_stormwater_hi_res.pdf

U.S. Fish and Wildlife Service

- Native Plant Center (interactive online version) – http://www.nativeplantcenter.net/
- Native Plants for Wildlife Habitat and Conservation Landscaping: Chesapeake Bay Watershed. (available at https://dnr.maryland.gov/criticalarea/Documents/chesapeakenatives.pdf)

Virginia Botanical Associates

- Digital Atlas of the Virginia Flora – http://vaplantatlas.org/

Virginia Department of Conservation and Recreation

- Fact Sheets and Brochures: Native Plants for Conservation, Restoration and Landscaping (Coastal Plain, Piedmont Plateau, Mountains, Riparian Forest Buffers, Grasslands) – https://www.dcr.virginia.gov/natural-heritage/factsheets
- Flora of Virginia – http://www.dcr.virginia.gov/natural-heritage/vaflora (describes nearly 3,200 plant species native to or naturalized in Virginia)
- Flora of Virginia – App – https://floraofvirginia.org/
- Native Plants – http://www.dcr.virginia.gov/natural-heritage/nativeplants
- Native Plant Finder – http://www.dcr.virginia.gov/natural-heritage/native-plants-finder

Virginia Department of Forestry

- Common Native Shrubs and Woody Vines of Virginia Identification Guide Book – 2022 – (ID: P00027) –http://www.dof.virginia.gov/edu/index.htm or https://dof.virginia.gov/wp-content/uploads/Common-Native-Shrubs-and-Woody-Vines-ID_pub.pdf
- Common Native Trees of Virginia Identification Guide Book – 2022 – (ID: P00026) – http://www.dof.virginia.gov/edu/index.htm or https://dof.virginia.gov/wp-content/uploads/Common-Native-Trees-ID_pub.pdf

Virginia Native Plant Society – https://vnps.org/

- Virginia Native Plant Guides – https://vnps.org/virginia-native-plant-guides/
  - Regional native plant guides: Accomack and Northampton, Central Rappahannock, Northern Neck, Northern Virginia, Virginia's Capital Region, and Southeast Virginia
  - Piedmont Native Plants: A Guide for Landscapes and Gardens
- Interactive Plant Selectors – https://vnps.org/interactive-plant-finders/

Virginia Tech Extension Publications - www.pubs.ext.vt.edu

- Rain Garden Plants - www.pubs.ext.vt.edu › content › dam › pubs_ext_vt_edu › SPES-57

**5.3.1 Links to Invasive Plant Publications**

The resources identified in this subsection contain information about plants to avoid and are listed alphabetically by organization and title.

U.S. Forest Service

- Nonnative Invasive Plants of Southern Forests: A Field Guide for Identification and Control – https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs062/

Virginia Department of Conservation and Recreation

- Invasive Plant Factsheets – https://www.dcr.virginia.gov/natural-heritage/invspfactsheets
- Virginia Invasive Plant Early Detection Species – https://www.dcr.virginia.gov/natural-heritage/invsp-earlydetection
- Virginia Invasive Plant Species List – https://www.dcr.virginia.gov/natural-heritage/invsppdflist

Virginia Native Plant Society – https://vnps.org/

- Plant Invaders of Mid-Atlantic Natural Areas Field Guide – https://vnps.org/product/plant-invaders-of-mid-atlantic-natural-areas-field-guide/

**5.4 Installation and Maintenance Plan**

Describe the planting sequence, post-nursery care, and initial maintenance requirements. Consider the following recommendations when planting and caring for newly planted vegetation:

- Plant "wet tolerant" (facultative or hydrophytic/obligate) species near the center of the practice and facultative to upland species near the perimeter.
- Plant woody vegetation away from points of inflow.
- Planting densities should be 1 to 1.5 feet on-center for herbaceous vegetation, 5 to 10 feet on-center for shrubs, and 15 feet on-center for trees (or one tree per 250 sq. ft.).
- Trees should not be planted directly above underdrains but instead should be located closer to the perimeter.
- Planting holes for trees should be at least 3 feet deep to provide enough soil volume for the root structure of mature trees. This recommendation applies even if the remaining filter media layer is shallower than 3 feet.
- Temporary or supplemental irrigation may be needed for bioretention plantings in order for plant installers to provide a warranty regarding plant material survival.
- Supplemental irrigation by a rain tank system is recommended (see P-BAS-04 Rainwater Harvesting).

**5.5 Filter Media**

The filter media will be supplied by a vendor and must meet the criteria and test methods in Appendix F. The specification is written for the vendor and is **NOT** intended for contractors to construct this filter media mix on-site unless materials are stockpiled on site and tested before utilization.

- **Soil Filter Media Depth**. The maximum and minimum depths are provided in Table **P-FIL-05-3** for receiving the assigned RR and PR credits. If trees are included in the bioretention planting plan, tree planting holes in the filter bed must be at least 2 feet above the seasonal high-water table or extended water table mound to provide sufficient soil volume and support for the root structure of mature trees. The exception would be Coastal Plain zones where facultative wet, or wetland obligate species are planted.

**5.6 Gravel Layer/Sump**

See Figure P-FIL-05-11 for more information.

**5.6.1 Choker Layer**

Lay a 2- to 4-inch layer of medium-to-coarse sand over a minimum 3-inch layer of choker stone (typically VDOT #8 or #89 gravel. The choker layer is placed beneath the filter media and at the top of the gravel layer, if needed. The choker layer does not count towards TVBMP storage calculations.

**5.6.2 Underdrain (Optional)**

When the $K_{sat}$ of the native soils is less than 0.5 in./hr., an underdrain is required for a Level 1 practice. The underdrain is a perforated pipe laid below the choker layer and is located within the gravel layer. The underdrain conveys water to either the existing storm drain or daylights into an above ground swale, woodland, or stream.

The underdrain should be a minimum 6-inch perforated schedule 40 PVC pipe (or equivalent corrugated HDPE) with 3/8-inch perforations at 6 inches on center. The professional will determine the diameter of the underdrain. Once the slotted portion of the underdrain runs beyond the surface dimensions of the bioretention soil filter media, it transitions to a solid-wall pipe. The underdrain should be sized so that the ponding area and soil media storage fully drain within 48 hours. Multiple underdrains may be necessary for bioretention areas wider than 40 feet, and each underdrain is recommended to be located no more than 20 feet from the next pipe or the edge of the bioretention.

The underdrain is encased in a layer of clean, ASTM D448 No. 57 stone (VDOT #57) that does not extend beyond the surface dimensions of the bioretention filter media. The underdrain pipe should have at least 3 inches of stone above it and at least 6 inches of stone below it, and be sloped at 0.00 ft/ft within the practice. The minimum depth of the gravel layer is 9 inches. This gravel layer may count towards the $TV_{BMP}$ storage calculations using a void ratio of 0.4 to calculate storage volume (see Section 5.1).

### 5.6.3 Underdrain with Liner

An impermeable liner can only be used for Level 1 designs with an underdrain. The liner is used in the following situations:

- Hotspots
- Karst topography
- High groundwater table or bedrock
- Near building foundations, or
- Where deemed necessary by a geotechnical investigation

Impermeable liners may be either clay or geomembrane.

- Clay liners shall meet the specifications in P-SUP-01. The clay liner shall have a minimum thickness of 12 inches.
- If a geomembrane liner is used, it shall have a minimum thickness of 40 mils, be ultraviolet resistant, and comply with the specifications in P-SUP-01.

### 5.6.4 Underdrain with Infiltration Sump/Internal Water Storage (optional)

Design configurations with an infiltration sump or internal water storage (IWS) are for the Level 2 designs and require $K_{sat}$ testing at the location of the practice (Table P-FIL-05-3). The bottom of the infiltration sump or IWS must be at least 2 feet above the seasonally high-water table or projected water mound (if applicable). For sites located on fill or other highly disturbed/compacted soils, geotechnical investigations are required to determine if the use of an infiltration sump or IWS is permissible.

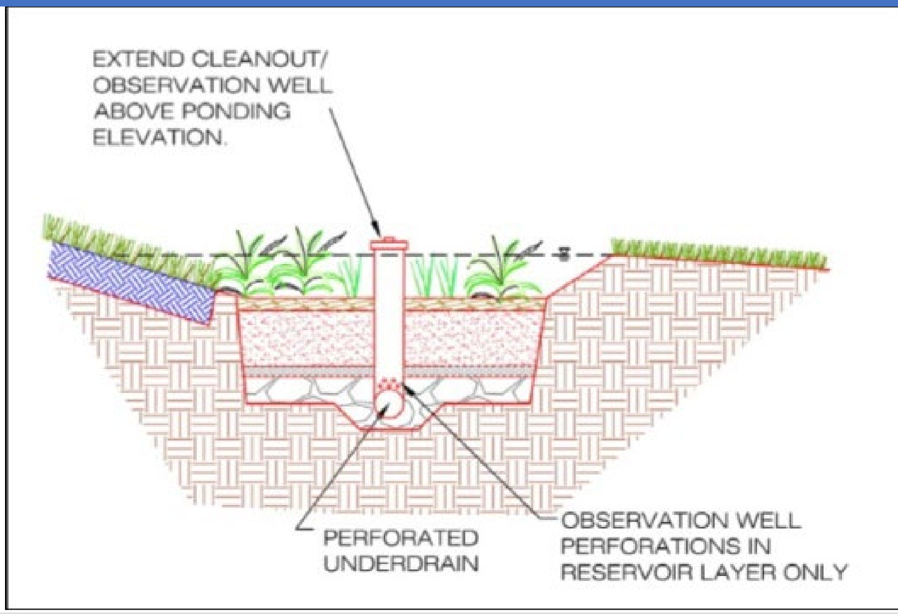
- *Sump:* The infiltration sump is a gravel area located below the underdrain that provides a storage area so the water can exfiltrate into the native soils without impeding drainage from the upper layers. The sump can provide storage to meet $Tv_{BMP}$ requirements and help meet channel and flood protection technical criteria.
- *Internal Water Storage*: As an alternative to the sump, the underdrain can have an "upturned elbow" configuration, also referred to as an internal water storage zone. This configuration places the perforated underdrain at the bottom of the stone reservoir layer, with the outlet elevated to the same elevation as the top of the sump. The IWS is used where limited head is a site constraint (e.g., relatively flat sites).

### 5.7 Observation Wells

All bioretention practices should include at least one observation well. Observation wells extend from above the highest elevation of the ponding area, where it is protected with a vented cap, to the bottom of the gravel layer. The observation well consists of a well-anchored, 4- to 6-inch diameter, rigid schedule-40 PVC pipe, with 3/8-inch perforations at 6 inches on center within the gravel layer and no perforations above the gravel layer (Figure P-FIL-05-6).

For bioretention practices that have an underdrain system, an observation well should be tied into any of the T or Y connections in the underdrain system and must extend upward above the ponding level. These observation wells can also double as cleanouts.

***Figure P-FIL-05-6 Example of typical observation well***




### 5.8 Conveyance and Overflow

There are two basic design approaches for conveying runoff into, through, and around bioretention practices:

1. Off-line: Flow is split or diverted so that only the BMP treatment volume or design flow enters the bioretention area. Larger flows bypass the bioretention treatment.
2. On-line: All runoff from the contributing drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

#### 5.8.1 Off-line Bioretention

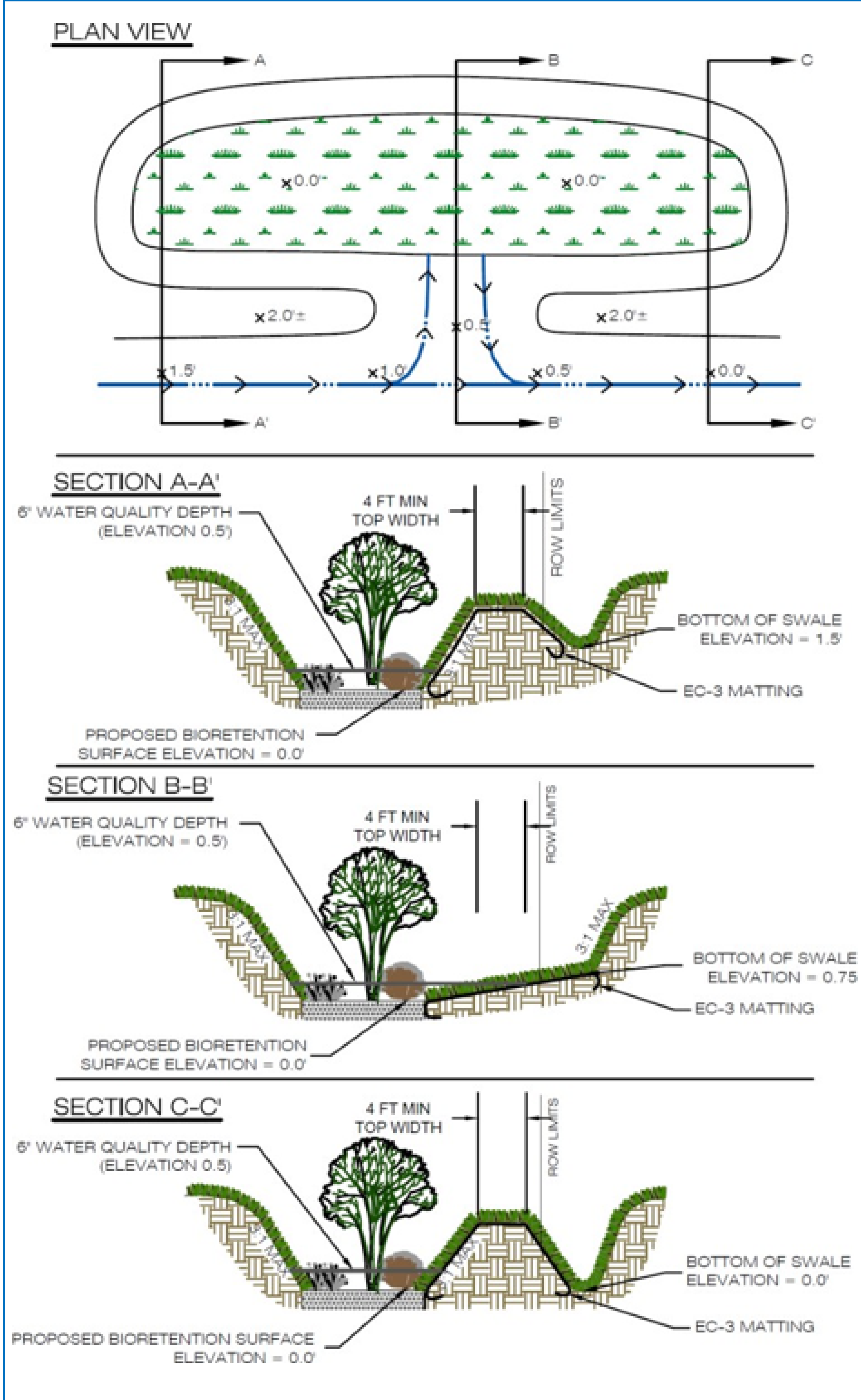
Off-line designs are preferred. If runoff is delivered by a storm drainpipe or is along the main conveyance system, the bioretention area should be designed off-line so that flows do not overwhelm or damage the practice. To determine the discharge that the practice will receive, the $Tv_{BMP}$ will need to be converted. The method to convert the volume to a flow is provided in Appendix F.

| Table P-FIL-05-8 Advantages and Disadvantages of Offline Bioretention | |
|---|---|
| **Advantages** | **Disadvantages** |
| The practice receives, at most, the TvBMP so there may be no need for an overflow device. | Needs a diversion structure to split the flow. |
| All runoff that reaches the practice is treated. | Requires more space to handle diverted flows. |
| When designed properly, runoff enters under non-erosive conditions resulting in fewer issues with erosion within the practice. | |

Two options for creating off-line bioretention facilities are provided below.

- Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the practice (Figure P-FIL-05-7). In this case, the higher flows do not pass over the filter bed and through the practice, and additional flow is able to enter as the ponding water filtrates through the soil filter media.
- Utilize a low-flow diversion, such as a weir, curb opening, or a flow splitter placed at the inlet that allows only the $Tv_{BMP}$ to enter the practice. A bypass channel is needed to handle the remaining flow.

**Figure P-FIL-05-7 Typical details for off-line bioretention**

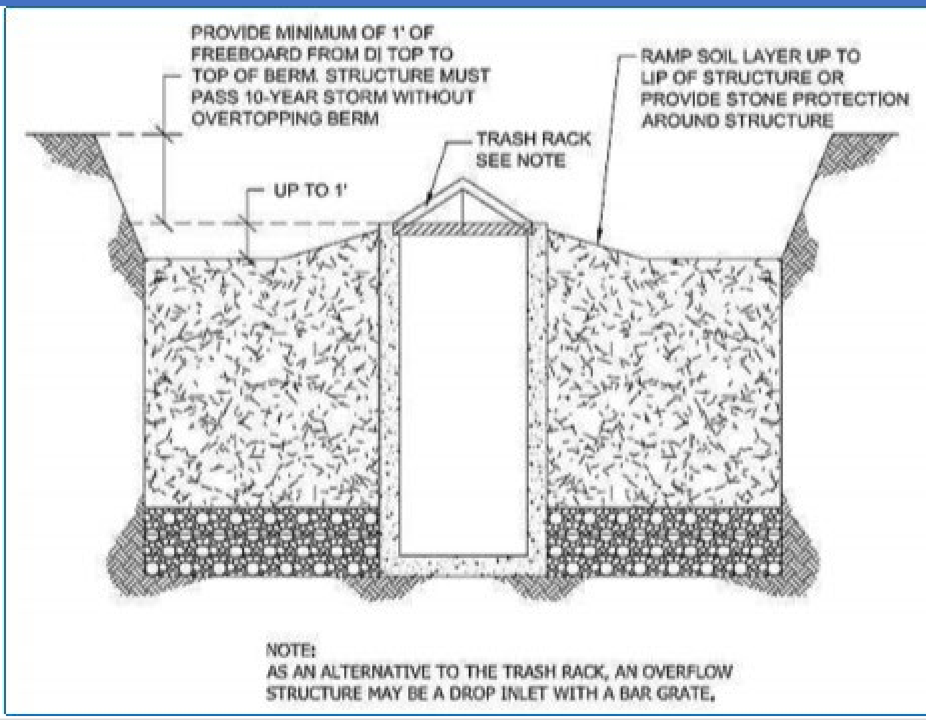



### 5.8.2 On-line Bioretention

All the discharge from the drainage area flows into the practice. On-line designs require attention to safely convey larger flows in adequate conveyances and with adequate freeboard. At no time during a storm event can the maximum head over the design underdrain or soil infiltration depth be more than 4 - 5 ft. Drainage designs should be based on expected peak discharges assuming that upstream practices may fail and/or provide marginal storage during larger events.

Flows that exceed the water quality design capacity exit the practice via an overflow structure. Field experience has shown that soil media immediately around an overflow structure is prone to scouring and erosion and, thus, short circuiting of the treatment mechanism. For example, water can flow straight down through scour holes or sinkholes to the underdrain system (Hirschman et al. 2009). Design options should be used to prevent this type of scouring. One example is shown in Figure P-FIL-05-8.

***Figure P-FIL-05-8 Typical detail of how to prevent bypass or short-circuiting around the overflow structure***




The following criteria apply to overflow structures:

- Inlet velocities for higher return periods need to be quantified in order to prevent erosion and scour from occurring within the practice.
- The ponding surface area should generally be flat so the bioretention area fills up like a bathtub.
- Design the overflow system to control flows associated with the 2- and 10-year design storms so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).
- Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum water surface elevation of the bioretention area, typically 6 to 12 inches above the surface of the filter bed (6 inches is the preferred ponding depth).
- The outlet device should be designed to pass flows greater than the TvBMP discharge and or equal to the 100-year storm event. The outlet structure may be a landscape grate inlet or a commercial-type structure.

- At least 6 inches of freeboard must be provided between the top of the overflow device and the top of the bioretention area to ensure that nuisance flooding will not occur.

### 5.9 BMP Geometry

BMP geometry guidelines for bioretention can be found in Table P-FIL-05-9 below.

**Table P-FIL-05-9 Geometry Guidelines for Bioretention Practices**

| Geometry | Guidelines |
| --- | --- |
| Flow Path | Design internal flow path such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited |
| Inlet flow energy attenuation | Additional emphasis needs to be placed on the peak runoff rate and energy of the inflow when the drainage area has an asymmetric shape or is larger than 2.5 acres |
| Travel Time for concentrated flows | Flows must have an acceptable internal geometry such that the "travel time" from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible |
| Travel Time for non-concentrated/sheet flows | Design the practice so that inflows are distributed as evenly as possible across the entire filter surface area. |

### 5.10 Signage

Bioretention units in highly visible areas (e.g., schools, parks, urban settings, government buildings) should be stenciled or otherwise permanently marked to designate it as a stormwater management practice. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

### 5.11 Regional and Special Design Adaptations

Design criteria for regional and special design adaptation can be found in Table P-FIL-05-10.

| Table P-FIL-05-10 Regional and Special Design Adaptations and Considerations | |
|---|---|
| **Regional/Special Item** | **Consideration and Adaptation** |
| Karst Terrain | Karst regions are found in much of the Ridge and Valley province of Virginia and limited areas of the Coastal Plain, which complicates both land development and stormwater design. Thus, a geotechnical investigation is needed in areas with karst terrain. A geotechnical investigation may not be necessary for a Level 1 practice with a liner and an underdrain. Building setback recommendations should be part of the investigation. For further guidance, please see Appendix E. |
| Coastal Plain * | The flat terrain, low hydraulic head, and high-water table of many Coastal Plain sites can constrain the application of deeper bioretention areas (particularly Level 2 designs). In such settings, the following design adaptations may be helpful:<br><br>A linear approach to bioretention, using multiple cells leading to the ditch system, helps conserve hydraulic head.<br><br>The minimum depth of the soil filter media for a Level 1 design may be relaxed to 18 to 24 inches. It is also useful to limit surface ponding to 6 to 9 inches and avoid the need for additional depth by establishing a turfgrass cover rather than using mulch. The shallower media depth and the turfgrass cover generally comply with the Dry Swale specification, and therefore will be credited with a slightly lower pollutant removal (See BMP P-CNV-02 Dry Swales).<br><br>The minimum depth to the seasonally high-water table or mound from the invert of the system can be 1 foot for a Level 1 design, if the bioretention area is equipped with a large-diameter underdrain (e.g., 6 inches or larger).<br>Maintain at least 0.3% slope in the underdrain to ensure positive drainage. The underdrain should be tied into the ditch or conveyance system.<br>The mix of plant species selected should reflect Coastal Plain plant communities and should be more wet footed and salt tolerant than those used in typical Piedmont applications. |
| Steep Terrain | Land with a slope of up to 10 to 20% may drain to a bioretention area if a two- cell design is used to dissipate erosive energy prior to filtering. The first cell, between the slope and the filter media, functions as a forebay to dissipate energy and settle any sediment that migrates down the slope. Designers may also want to terrace a series of bioretention cells to manage runoff across or down a slope. The drop in slope between cells should be limited to 1 foot and should be armored with river stone or a suitable equivalent. See Figure P-FIL-05-11. |

| Table P-FIL-05-10 Regional and Special Design Adaptations and Considerations | |
|---|---|
| **Regional/Special Item** | **Consideration and Adaptation** |
| Cold Climate and Winter Performance | Bioretention areas may be used for snow storage if an overflow is provided and salt-tolerant, non-woody plant species are used. Tree and shrub locations should not conflict with plowing and piling of snow into storage areas.<br>It should be noted that even though salt-tolerant plants are recommended, chlorides from road salts (and other deicers as may be found on parking lots and sidewalks), have been found to contribute to the export of nutrient washouts from bioretention in following precipitation events. It is recommended that that the use of NaCl deicers be limited to prevent long-term nutrient export.<br>Although several studies have shown that bioretention facilities operate effectively in Pennsylvania and West Virginia winters, extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size to reduce the freezing potential. |
| Linear Highway Sites | Bioretention is a preferred practice for constrained highway right of ways when designed as a series of individual on-line or off-line cells. In these situations, the final design closely resembles that of dry swales. Salt tolerant species should be selected if salt compounds will be used to de-ice the contributing roadway in the winter. |

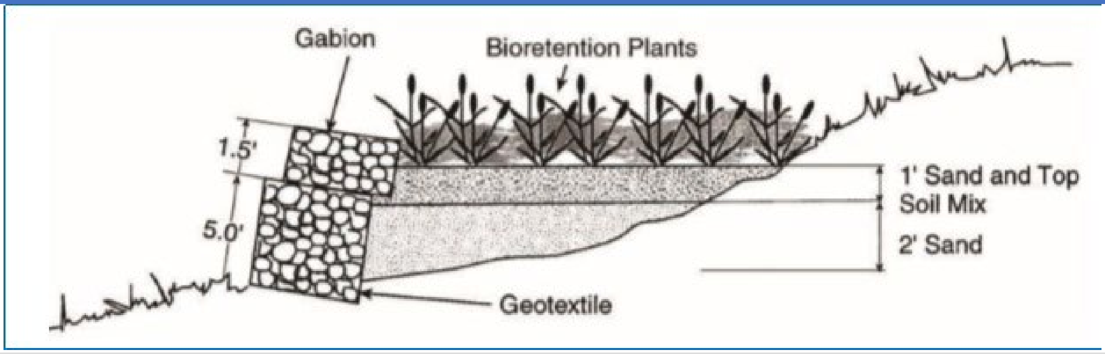
**Notes:**

***** Although these design criteria permit bioretention to be used on a wider range of Coastal Plain sites, it is important to evaluate the specific constraints represented by the site and avoid using bioretention on marginal sites that directly impact the pollutant removal and volume reduction pathways. Other stormwater practices, such as wet swales, ditch wetland restoration, and smaller linear wetlands, are often preferred alternatives for Coastal Plain sites. Earlier restrictions for high $K_{sat}$ (> 10 in/hr) soils from HSG A mapping units should also be addressed.

Refer to additional discussion regarding steep slope suitability for bioretention following this table.

### 5.11.1 Steep Terrain – Additional Consideration and Schematic

**Figure P-FIL-05-11 A bioretention terrace that can be used in sloping terrain (for 10-20% slopes; Source - NCDENR)**




An impermeable or very low permeability geomembrane must be used against the gabions or similar retaining structure to prevent flow from leaving the treatment unit through that surface. An underdrain could be placed at the low point of the filter if the native soil that the unit is built against will not provide adequate infiltration capacity.

## 6.0 Construction Specifications

The basic material specifications for Bioretention are outlined in Table P-FIL-05-11.

**Table P-FIL-05-11 Bioretention Materials Specifications**

| Material | Specification | Notes |
|---|---|---|
| Filter Media Composition (Appendix F) | Filter Media to contain:<br>80% - 90% sand<br>10% - 20% soil fines<br>3% - 5% organic matter | The volume of filter media based on 110% of the plan volume, to account for settling or compaction. See Appendix F. |
| Filter Media Testing | See Appendix F for criteria | The media should be certified by the supplier. |
| Mulch Layer | Use aged (at least 6 months), double- shredded hardwood bark mulch. | Lay a 2- to 3-inch layer on the surface of the filter bed. |
| Alternative Surface Cover | Use river stone or pea gravel, coir and jute matting, or turfgrass cover. | Lay a 2- to 3-inch layer to suppress weed growth. |
| Topsoil For Manage Grass Cover or other intensive vegetation management | Loamy sand or sandy loam texture, with less than 5% clay content; pH corrected to between 6 and 7; and an organic matter content of at least 2%. | 3-inch surface depth. Must meet minimum $K_{sat}$ requirements of underlying media. |
| Geotextile/Liner | Use a non-woven geotextile fabric with a flow rate of > 110 gal./min./sq. ft. (e.g., Geotex 351 or equivalent) | Apply only to the sides and directly above the underdrain. For hotspots and certain karst sites only, use the appropriate liner on the bottom. |

| Table P-FIL-05-11 Bioretention Materials Specifications | | |
|---|---|---|
| **Material** | **Specification** | **Notes** |
| Choking Layer | Lay 2- to 4-inch layer of sand over 3-inch layer of VDOT #8 or #89 washed gravel | |
| Stone Underdrain and/or Storage Layer | VDOT #57 stone | 9 inches for the underdrain;<br>Up to 12 inches for the stone storage layer, if needed;<br>Double washed and clean and free of all fines |
| Underdrains and Cleanouts | Use 6-inch rigid schedule 40 PVC pipe (or equivalent corrugated HDPE for micro-bioretention), with 3/8-inch perforations at 6 inches on center; position each underdrain on a 1% or 2% slope located nor more than 20 feet from the next pipe. | Lay the perforated pipe under the length of the bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system. Install T's and Y's as needed, depending on the underdrain configuration.<br>Extend cleanout pipes to the surface with vented caps at the Ts and Ys. |
| Observation Wells | Use 4- to 6- inch rigid schedule 40 PVC pipe (or equivalent corrugated HDPE for micro-bioretention), with 3/8-inch perforations at 6 inches on center within the gravel layer | Use a closed wall pipe above the gravel layer. Extend observation well pipes to the surface with vented caps |
| Plant Materials | See Section 5.2 and Table P-FIL-05-7 | Establish plant materials as specified in the landscaping plan and the recommended plant list. |

### 6.1 Construction Stage Erosion and Sediment Controls

Bioretention areas should be fully protected by silt fence or construction fencing, particularly if they will rely on infiltration (i.e., have no underdrains). Ideally, bioretention should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Bioretention basin locations may be used as small sediment traps or basins during construction. However, these locations must be accompanied by notes and graphic details on the ESC plan specifying:

1. The maximum excavation depth at the construction stage must be at least 1 foot above the post-construction maximum excavation,
2. The practice must contain an underdrain, and
3. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention practice, including dewatering, cleanout and stabilization.

### 6.2 Bioretention Installation

The following is a typical construction sequence to properly install a bioretention basin. The installation of a bioretention basin will include intermediate inspections at critical stages of construction with inspector sign-off that the elements of the bioretention are constructed according to the approved plans and specifications. As an alternative, if allowed by the VSMP Authority, the contractor may rely on the engineer of record or other qualified individual to conduct the intermediate inspections and certifications of compliance. The construction sequence for micro-bioretention is more simplified. These steps may be modified to reflect different bioretention applications or expected site conditions:

**Step 1.** Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

**Step 2.** The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to the original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

**Step 3.** Temporary erosion and sediment controls are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the construction process.

**Step 4.** Any pre-treatment cells should be excavated first and then sealed to trap sediments.

**Step 5.** Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500 to 1,000 sq. ft. temporary cells with a 10- to 15-foot earth bridge in between, so that cells can be excavated from the side.

**Step 6.** It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration if required $K_{sat}$ testing and/or onsite soil investigation indicates limitations.

**Step 7.** Place geotextile fabric on the sides of the bioretention area with a 6-inch overlap on the sides. If a stone storage layer will be used, place the appropriate depth of #57 stone on the bottom, install the perforated underdrain pipe, pack #57 stone to 3 inches above the underdrain pipe, and add approximately 3 inches of choker stone/pea gravel as a filter between the underdrain and the soil media layer. If no stone storage layer is used, start with 6 inches of #57 stone on the bottom, and proceed with the layering as described above.

**Step 8.** Obtain filter media from a qualified vendor and store it on an adjacent impervious area or plastic sheeting. After confirming that the media meets the specifications, apply the media in 6 to 12-inch lifts until the desired top elevation of the bioretention area is achieved. Add sufficient clean water to facilitate settling (or evaluate after a significant rainfall event) to check for settlement, and add additional media, as needed, to achieve the design elevation. Taking and maintaining an archived air-dried composite sample of the media and mulch materials for at least one year following installation is recommended in case of apparent internal drainage failures.

**Step 9.** Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

**Step 10.** Place the surface cover in both cells (e.g., mulch, river stone or managed grass), depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 9), and holes or slits will have to be cut in the matting to install the plants.

**Step 11.** Install the plant materials as shown in the landscaping plan, and water them initially as required for establishment, particularly if weeks of no rain occur between March and November.

**Step 12**. Install appropriate signage and/or perimeter fencing as/if required.

## 7.0 Operations and Maintenance Considerations

### 7.1 Construction Inspections

Inspections during and immediately after construction are needed to ensure that all the elements of bioretention basins are built in accordance with these specifications. Use a detailed inspection checklist that requires signoffs by qualified individuals at critical stages of construction and to ensure that the contractor's interpretation of the plan is consistent with the designer's intent. The following identifies the critical stages of construction where an intermediate inspection and signoff by a qualified individual is recommended since the items can't be verified after construction is completed. A construction inspection checklist that includes certifications of inspection at critical stages is provided in Section 7.2.

The following represents items that are frequently overlooked during construction inspection but represent important elements for ensuring the success of the bioretention practice during the initial break-in period.

- Verify the proper coverage and depth of mulch, vegetation, or soil matting has been achieved following construction, both on the filter bed and the side-slopes.
- Inspect the pre-treatment forebays and filter strips to verify that they are properly installed, stabilized, and working effectively before opening the practice to runoff.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

Upon final acceptance of the practice, log the practice's GPS coordinates and submit them for entry into the VESMP Authority's BMP maintenance tracking database.

***Figure P-FIL-05-12 An older bioretention area with mature tree growth and shaded areas.***
***Adaptive management is required in areas such as these for continued performance.***

*Photo Credit: Hirschman Water & Environment, LLC*

### 7.2 Sample Construction Inspection Checklist for Bioretention Practices

The checklist for construction inspection of bioretention practices is found along with those for other BMPs in Appendix H and provides a basic outline of the anticipated items for the construction inspection of bioretention practices. This checklist does not necessarily distinguish between all the design variations and differences in construction between the family of practices: bioretention basins, micro-bioretention, urban bioretention, and ultra-urban bioretention. Similarly, the use of an infiltration sump below an underdrain, or an infiltration sump with an "upturned elbow," and other variations between Level 1 and Level 2 bioretention may not be clearly identified in this checklist. Inspectors should review the plans carefully and adjust these items and the timing of inspection verification as needed to ensure the intent of the design is met. Finally, users of this information may wish to incorporate these items into a VESMP Authority Construction Checklist format consistent with the format used for erosion and sediment control and BMP construction inspections.

### 7.3 Pre-Construction Meeting

- Pre-construction meeting with the contractor designated to install the bioretention practice has been conducted.
- Identify the tentative schedule for construction and verify the requirements and schedule for interim inspections and sign-off.
- Subsurface investigation and soils report supports the placement of a bioretention practice in the proposed location.
- Impervious cover has been constructed/installed and area is free of construction equipment, vehicles, material storage, etc.
- All pervious areas of the contributing drainage areas have been adequately stabilized with a thick layer of vegetation and erosion control measures have been removed.
- Area of bioretention practice has not been impacted during construction.
- Stormwater has been diverted around the area of the bioretention practice and perimeter erosion control measures to protect the practice during construction have been installed.

### 7.4 Excavation

- Compare the bioretention surface and invert design elevations with the actual constructed elevations of the inflow and outlet inverts and adjust design elevations as needed.
- Area of bioretention excavation is marked, and the size and location conform to plan.
- If the excavation area has been used as a sediment trap: verify that the bottom elevation of the proposed stone reservoir is lower than the bottom elevation of the existing trap.
- For Level 2 bioretention, ensure the bottom of the excavation is scarified prior to placement of stone.
- Subgrade surface is free of rocks and roots, and large voids. Any voids should be refilled with the base aggregate to create a level surface for the placement of aggregates and underdrain (if required).
- No groundwater seepage or standing water is present. Any standing water is dewatered to an acceptable dewatering device.
- Excavation of the bioretention practice has achieved proper grades and the required geometry and elevations without compacting the bottom of the excavation.
- **Certification of Excavation Inspection:** Inspector certifies the successful completion of the excavation steps listed above.

### 7.5 Choker Layer, Underdrain, and Stone Reservoir Placement

- All aggregates, including, as required, the choker layer, the stone reservoir layer or infiltration sump conform to specifications as certified by quarry.
- Underdrain size and perforations meet the specifications.
- For Level 2 installations: placement of choker layer and initial lift of stone reservoir layer aggregates with underdrain or infiltration sump, spread (not dumped) to avoid aggregate segregation; or
- Impermeable liner, when required, meets project specifications, and is placed in accordance with manufacturers specifications.
- Sides of excavation covered with geotextile, when required, prior to placing stone reservoir aggregate; no tears or holes, or excessive wrinkles are present.
- Placement of underdrain, observation wells, and underdrain fittings (45-degree wyes, cap at the upstream end, etc.) are in accordance with the approved plans.
- Elevations of underdrain and outlet structure are in accordance with approved plans, or as adjusted to meet field conditions.
- Placement of remaining lift of stone reservoir layer as needed to achieve the required reservoir depth.
- **Certification of Choker Layer and Underdrain Placement Inspection:** Inspector certifies the successful completion of the choker layer and underdrain placement steps listed above.

### 7.6 Bioretention Soil Media Placement

- Soil media is certified by supplier or contractor as meeting the project specifications per Appendix F and provides confirmation testing data.
- Soil media is placed in 6- to 12-inch lifts to the design top elevation of the bioretention area. Elevation has been verified after settlement (2 to 4 days after initial placement assuming rain or an initial watering in event).
- Side slopes of ponding area are feathered back at the required slope (no steeper than 3H:1V).
- **Certification of Soil Media Placement Inspection:** Inspector certifies the successful completion of the soil media steps listed above.

### 7.7 Pretreatment and Plant Installation

- Placement of energy dissipators and pretreatment practices (forebays, gravel diaphragms, etc.) are installed in accordance with the approved plans.
- Riser, overflow weir, or other outflow structure is set to the proper elevation and functional; or
- External bypass structure is built in accordance with the approved plans.
- Appropriate number and spacing of plants are installed in accordance with the approved plans.
- All erosion and sediment control practices have been removed.
- Follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all bioretention practice installations on the parcel.

### 7.8 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9 VAC 875) specifies the circumstances under which a maintenance agreement must be executed between the owner and the VESMP Authority, and sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All bioretention practices must include a long-term maintenance agreement consistent with the provisions of the VSMP regulations and must include the recommended maintenance tasks and a copy of an annual inspection checklist.

- When micro-bioretention practices are applied on private residential lots, homeowners should be educated regarding their routine maintenance needs by being provided a simple document that explains their purpose and routine maintenance needs.
- A deed restriction, drainage easement or other mechanism enforceable by the VSMP Authority must be in place to help ensure that rain gardens and bioretention filters are maintained and not converted or disturbed, as well as to pass the knowledge along to any subsequent owners.
- The mechanism should, if possible, grant authority for the VSMP Authority to access the property for inspection or corrective action.

### 7.9 First Year Maintenance Operations

Successful establishment of bioretention areas requires that the tasks outlined below be undertaken in the first year following installation.

**Table P-FIL-05-12 Summary of Essential First-Year Maintenance Operations**

| Activity | Timing |
|---|---|
| Initial Inspections | For the first 6 months following construction, the site should be inspected at least twice after storm events that exceed 0.5 inch of rainfall. |
| Spot Reseeding | Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover. |
| Fertilization | One-time, spot fertilization may be needed for initial plantings. Slow-release nitrogen sources should be utilized whenever possible. |
| Watering | Watering is needed once a week during the first 2 months, and then as needed during the first growing season (March/April-October), depending on rainfall. |
| Remove and replace dead plants | Since significant amounts of the initial planting stock may not survive in the first year, construction contracts should include a care-and-replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction. The typical thresholds below which replacement is required are 85% survival of intended/seeded herbaceous plant material and 100% survival of shrubs and trees. |

### 7.10 Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each bioretention area. The following is a list of some key maintenance inspection items:

- Check to see if 75% to 90% cover (mulch plus vegetative cover) has been achieved in the bed and measure the depth of the remaining mulch.
- Check for sediment buildup at curb cuts, gravel diaphragms or pavement edges that prevents flow from getting into the bed, and check for other signs of bypassing.
- Check for any winter- or salt-killed vegetation and replace it with hardier species.

- Note presence of accumulated sand, sediment and trash in the pre-treatment cell or filter beds and remove it.
- Inspect bioretention side slopes and grass filter strips for evidence of any rill or gully erosion and repair it.
- Check the bioretention bed for evidence of mulch flotation, excessive ponding, dead plants, or concentrated flows, and take appropriate remedial action.
- Check inflow points for clogging and remove any sediment.
- Look for any bare soil or sediment sources in the contributing drainage area and stabilize them immediately.
- Check for clogged or slow-draining soil media, a crust formed on the top layer, inappropriate soil media, excessive plugging by sediments, or other causes of insufficient filtering time, and restore proper filtration characteristics.

Example maintenance inspection checklists for bioretention areas can be accessed in Appendix H.

### 7.11 Routine Maintenance Tasks

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides. A customized maintenance schedule must be prepared for each bioretention practice, since the maintenance tasks will differ depending on the scale of bioretention, the landscaping template chosen, and the type of surface cover. A generalized summary of common maintenance tasks and their frequency is provided in Table P-FIL-05-13.

**Table P-FIL-05-13 Routine Maintenance Tasks**

| Maintenance Tasks | Frequency |
|---|---|
| Mow grass filter strips and bioretention turfgrass cover. | At least 4 times per year |
| Perform spot weeding, erosion repair, trash removal, and mulch raking. | Monthly |
| Add reinforcement planting to maintain desired vegetation density.<br>Remove invasive plants using recommended control methods.<br>Stabilize the contributing drainage area to prevent erosion. | As needed |
| Perform spring inspection and cleanup.<br>Supplement mulch to maintain a 2 to 3-inch layer. Prune trees and shrubs. | Annually as/if needed |
| Remove sediment in pretreatment cells and inflow points. | At least 4 times per year |
| Replace the mulch layer. | Every 2-3 years or if in poor condition |
| Revaluate Ksat via appropriate method for both primary media filter layer and underlying and/or lateral soil infiltration zone (if utilized). | Every 5 years |

### 7.12 Non-Routine Maintenance Tasks

The most common non-routine maintenance problem involves standing water (e.g., insufficient drainage). If water remains on the surface for more than 48 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter (try the easiest things first, as listed below):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and standpipe indicate standing water, then the underdrain must be clogged and will need to be snaked.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 8 to 12 inches of the underlying mineral soil or filter media. Do not simply add sand to the overlying mulch layer.
- Install sand wicks from 3 inches below the surface to the underdrain layer. Sand wicks can be installed by excavating or using an auger (a tree auger or similar soil boring tool) down to the gravel storage zone to create vertical columns that are then filled with a clean open-graded coarse sand material (coarse sand mix like the gradation used for the soil media). Enough wick drains of sufficient dimension should be installed to meet the design dewatering time for the practice. However, this assumes that the underlying zone remains unsaturated and can receive the water.
- Final Measures - remove and replace some or all of the soil media and reconfirm overall filter permeability and underdrain to outlet head drop.

## 8.0 References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## 9.0 Appendix A Micro-bioretention

**Definition**

Micro-bioretention practices, commonly referred to as rain gardens, are designed to treat runoff from small areas, such as individual rooftops, lawns and other commercial or residential on-lot features. Micro-bioretention differs from bioretention primarily in scale, with the micro-bioretention practice receiving stormwater from a much smaller drainage area.

See Table P-FIL-05 A-1 and Table P-FIL-05 A-2 for other differences.

**Purpose and Applicability of Best Management Practice**

The purpose of the micro-bioretention practice is the same as that for general bioretention. Micro-bioretention is typically applicable for treating runoff from small areas, such as sidewalks, driveways, and other on-lot features. Micro-bioretention treats stormwater runoff by simulating native landscape processes and filtering runoff and pollutants via soil biogeochemical processes and plant uptake. Bioretention works by collecting stormwater runoff from a roof, sidewalk, driveway, or other impervious areas that would otherwise go directly to local street or storm drainage. The water temporarily ponds on the surface of the feature and then slowly filters down through the underlying soil media and/or is taken up by plants.

Inflow is typically sheet flow from a nearby sidewalk/driveway or lawn, or can be concentrated flow with energy dissipation, when receiving roof flow from downspouts or other directed drainage. It can be used in both commercial and residential developments.

More than one micro-bioretention practice can be used on a site. For example, they can be used at different points along the runoff pathway, in different pathways, or at different downspouts. Sometimes two or more small micro-bioretention practices are connected and used instead of one large one because of design or space considerations.

Micro-bioretention, as defined here, is also commonly referred to as “rain gardens” and several example configurations are given below in Figure P-FIL-05 A-1 and Figure P-FIL-05 A-2. A list of alternative designs provided by various localities is provided at the end of this Appendix.

**Planning and Considerations**

**Feasibility**

Micro-bioretention can be located anywhere along the natural runoff pathway. Runoff can also be directed into a micro-bioretention practice through pipes or swales. Micro-bioretention practices can be in sun or shade and should be located at least 10 feet away from building foundations, not on steep slopes, not over underground utilities, or a septic field, and not where the water table is high (≤ 24 in). Refer to Table P-FIL-05-3 and others in the primary bioretention specification for feasibility, site selection criteria and regional and special case design adaptions.

**Stormwater Performance Summary**

The typical stormwater functions of an micro-bioretention area with respect to runoff reduction (RR) and pollutant removal (PR) are described in Table P-FIL-05 A-1.

**Table P-FIL-05 A-1 Micro-Bioretention Design Level Performance**

| Pollutant Constituents | Design Level 1 | Design Level 2 |
|---|---|---|
| Total Phosphorus Removal Credit | 40% RR<br>25% PR<br>55% Mass Load* | 80% RR<br>50% PR<br>90% Mass Load* |
| Total Nitrogen Removal Credit | 40% PR<br>64% Mass Load* | 60% PR<br>90% Mass Load* |

| Table P-FIL-05 A-1 Micro-Bioretention Design Level Performance | | |
|---|---|---|
| **Pollutant Constituents** | **Design Level 1** | **Design Level 2** |

**Notes:**

RR = runoff reduction; PR = pollutant removal

*Mass Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2009).

### Design Criteria

A summary of the design elements for micro-bioretention is provided in Table P-FIL-05 A-2. Note certain minor variations for this application vs. Table P-FIL-05-3 in the primary text for general bioretention (e.g. higher minimum $K_{sat}$ for Level 1).

**Table P-FIL-05 A-2 Summary of Design Elements**

| Design Element | Level 1 (RR: 40; TP: 25) | Level 2 (RR: 80; TP: 50) |
|---|---|---|
| Site Selection | Refer to criteria in Section 2.2. Additional criteria may apply depending on the region of the state (see Section 6 Regional and Special Case Design Adaptations). | |
| Contributing Drainage Area | Maximum = 0.5 acres with up to 25% Impervious Cover* | |
| Soil Testing | Perform soil test if no underdrain | One soil test per practice |
| Hydraulic Conductivity of Native Soils | Min > 1 in./hr. to remove the underdrain requirement<br>Max ≤ 10 in./hr.† | Min > 0.25 in./hr.<br>Min > 1 in./hr. to remove the underdrain requirement<br>Max ≤ 10 in./hr.† |
| Surface Area | $Tv_{BMP}$ (cu. ft.) / *ESD* (ft.) Where:<br>$Tv_{BMP}$ (cu. ft.) = (1.0 in.)(Rv)(A)/12 | $Tv_{BMP}$ (cu. ft.) / *ESD* (ft.) Where:<br>$Tv_{BMP}$ (cu. ft.) = (1.25 in.)($R_v$)(A)/12 |
| Drain Time | NA | Ponding Volume ≤ 48 hrs.<br>Design Volume ≤ 72 hrs. |
| Stormwater Quantity | Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the gravel layer/sump to accommodate a larger storm. OR<br>Use the Virginia Runoff Reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment | |
| Ponding Depth | Maximum: 6 inches‡ | |
| Side Slopes | Ponding Storage Area: 3H:1V or flatter | |
| Surface Cover | 2 to 3 inches of mulch or alternative, such as managed approved vegetation in soil media meeting general bioretention media criteria. | |

| Table P-FIL-05 A-2 Summary of Design Elements | | |
|---|---|---|
| **Design Element** | **Level 1 (RR: 40; TP: 25)** | **Level 2 (RR: 80; TP: 50)** |
| Planting Plan | A planting template to include managed turfgrass, herbaceous vegetation, and/or shrubs (min = 1 out of those 3 choices) to cover at least 75% surface area in 2 years. | A planting template to include managed turfgrass, herbaceous vegetation, shrubs, and/or trees (min = 2 out of those 4 choices) to cover at least 90% of the infiltration surface area in 2 years. Turfgrass must be combined with herbaceous perennials, shrubs and/or trees. |
| Filter Media Depth | Min: 18 inches<br>Max: 36 inches§ | Min: 24 inches<br>Max: 36 inches§<br>Min: 36 inches rooting depth for trees** |
| Filter Media | Mixed on-site‖ or supplied by vendor | Supplied and certified by vendor per criteria in Appendix F. |
| Gravel Layer/Sump | Min choker stone layer: 3 in.<br>Min gravel layer with no underdrain: 0 in. Min gravel layer with underdrain: 9 in.<br>Max gravel layer: 12 in.§ | Min choker stone layer: 3 in.<br>Min sump depth with underdrain: 9 in.<br>Max sump depth: 12 in.§ |
| Underdrain | HDPE or equivalent; Clean-outs are not necessary. Use slotted pipe under the filter bed and closed pipe elsewhere. | |
| Observation Wells | Schedule 40 PVC or equivalent closed pipe. | |
| Pre-treatment | External (leaf screens, grass filter strip, energy dissipater, etc.). | External plus a grass filter strip |
| Conveyance and Overflow | Off-line/On-line option | |
| Geometry | Concentrated flow: Locate inlets and outlets as far apart as possible.<br>Non-concentrated flow: Distribute inflow evenly across filter surface area. | |
| Maintenance | Deeded Maintenance Agreement<br>See Section 7 for routine and non-routine maintenance requirements. | |

**Notes:**

RR = runoff reduction (%); TP = total phosphorus reduction (%); NA = not applicable.

* Micro-bioretention can be located at individual downspout locations to treat up to 1,000 sq. ft. of impervious cover (100% IC).

† The native soil must be amended to lower the hydraulic conductivity below 10 inches per hour. See Appendix C.

‡ Incorporate plants that tolerate fluctuating water levels.

§ Additional depth can be added to the filter media and/or gravel layer/sump to help meet water quantity requirements. This additional depth is not used for surface area sizing calculations. See Section 5.1.

**When used in tree planter holes, at least 36” of suitable rooting depth must be maintained. For example, if filter media depth is 24”, at least 12” of non-compacted suitable soil that meets overall media $K_{sat}$ criteria should be employed between the media and the underdrain or soil infiltration zone.

‖ Media mix tested for an acceptable hydraulic conductivity (or permeability) and phosphorus content.

**Figure P-FIL-05 A-1 Micro-bioretention with (a) simple disconnection to downstream practice and/or (b) alternate practice of compost amended filter path**

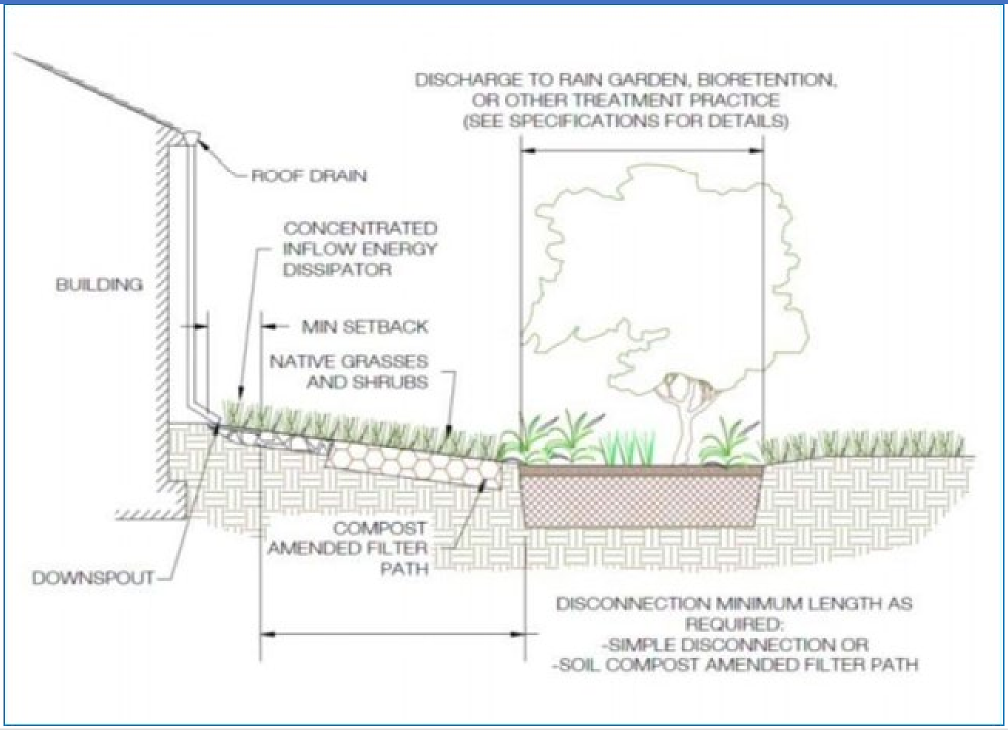
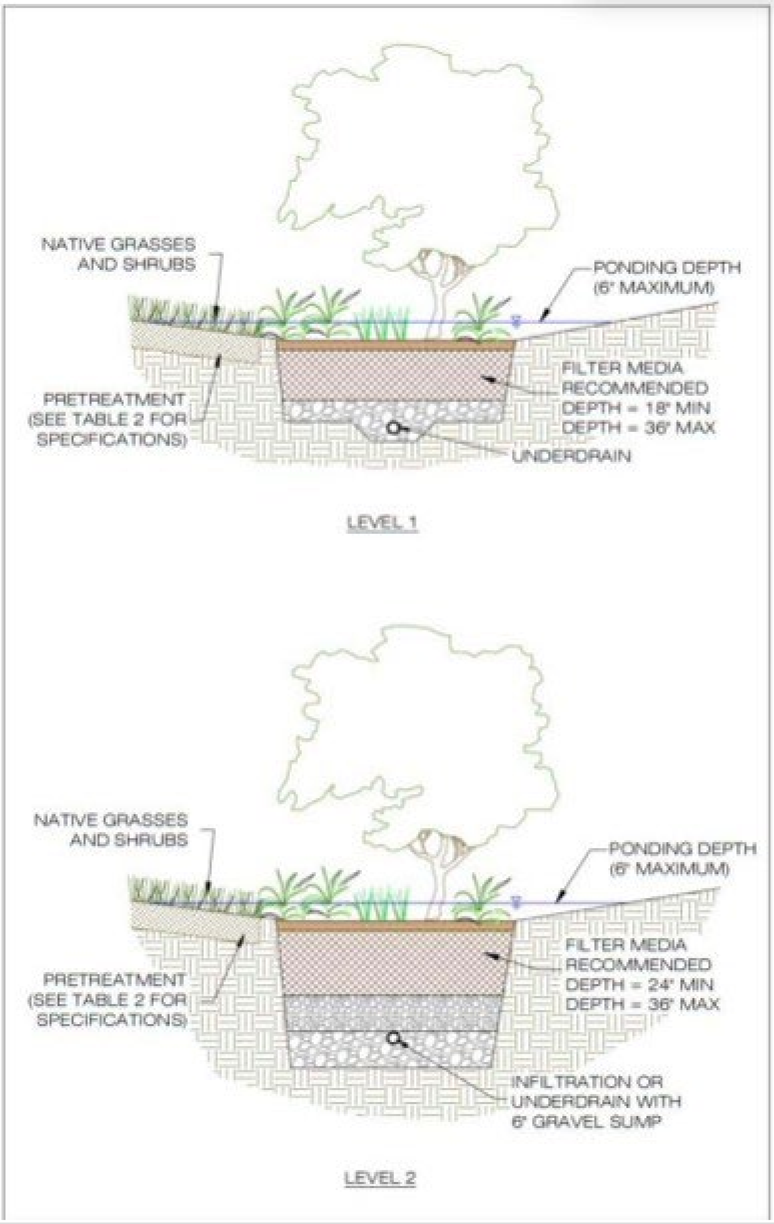


**Figure P-FIL-05 A-2 Typical Micro-bioretention basis with Level 1 vs. Level 2 design**

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## 10.0 Appendix B Ultra-Urban Bioretention

**General Description**

**Stormwater Planters**

**Expanded Tree Pits**

**Stormwater Curb Extensions**

Ultra-urban bioretention practices are similar in function to regular bioretention practices except they are adapted to fit into "containers" or other relatively small, engineered enclosures within urban landscapes. This practice does not include simple "tree planter holes" in urban landscapes that do not contain specified soil media and drainage.

Typically, ultra-urban bioretention is installed within an urban streetscape or city street right-of-way, urban landscaping beds, tree pits and plazas, or other features within an ultra-urban area. Ultra-urban bioretention is not intended for large commercial areas, nor should it be used to treat small sub-areas of a large drainage area such as a parking lot. Rather, ultra-urban bioretention is intended to be a containerized practice incorporated into small, fragmented drainage areas such as shopping or pedestrian plazas within a larger urban development.

Ultra-urban bioretention features hard edges, often with vertical concrete sides, as contrasted with the earthen slopes of regular bioretention. These practices may be open-bottomed to allow some infiltration of runoff into the sub-grade, but they generally are served by an underdrain.

There are three variants of the ultra-urban bioretention practice: stormwater planters, expanded tree pits, and stormwater curb extensions. Each ultra-urban bioretention variant is planted with a mix of trees, shrubs, and grasses as appropriate for its size and landscaping context.

**Stormwater planters** (also known as vegetative box filters or foundation planters) take advantage of limited space available for stormwater treatment by placing soil media in a container located above ground or at grade in landscaping areas between buildings and roadways (Figure P-FIL-05 B-1). The small footprint of foundation planters is typically contained in a precast or cast-in-place concrete vault. Other materials may include molded polypropylene cells and precast modular block systems.

Expanded tree pits are installed in the sidewalk zone near the street where urban street trees are normally installed (Figure P-FIL-05 B-2). The treatment area is increased by using a series of connected tree plantings in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

***Figure P-FIL-05 B-1 Stormwater planters***


***Figure P-FIL-05 B-2 Expanded tree pits***

**Stormwater curb extensions** (also known as parallel bioretention) are installed in the road right-of-way either in the sidewalk area or in the road itself. In many cases, curb extensions serve as a traffic- calming or street-parking control device. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the expanded right- of-way (Figure P-FIL-05 B-3).

*Figure P-FIL-05 B-3 Stormwater curb extensions*

**Performance**

The typical stormwater functions of an ultra-urban bioretention area are described in Table P-FIL-05 B-1.

| Table P-FIL-05 B-1 Summary of Stormwater Functions Provided by Ultra-urban Bioretention Areas | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Annual Runoff Volume Reduction (RR) | 40% | NA |
| Total Phosphorus (TP) EMC Reduction[1] by BMP Treatment Process | 25% | NA |
| Total Phosphorus (TP) Mass Load Removal | 55% | NA |
| Total Nitrogen (TN) EMC Reduction[1] by BMP Treatment Process | 40% | NA |
| Total Nitrogen (TN) Mass Load Removal | 64% | NA |
| Channel and Flood Protection | Use the Virginia Runoff Reduction Method (VRRM) Compliance Spreadsheet to calculate the Curve Number (CN) Adjustment<br>OR<br>Design extra storage (optional; as needed) on the surface, in the engineered soil matrix, and in the stone/underdrain layer to accommodate a larger storm and use NRCS TR-55 Runoff Equations [2] to compute the CN Adjustment. | |

**Notes:**

Sources: CWP and CSN (2008) and CWP (2007)

1. Change in the event mean concentration (EMC) through the practice. The actual nutrient mass load removed is the product of the removal rate and the runoff reduction rate (see Table 1 in the Introduction to the New Virginia Stormwater Design Specifications).
2. NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number (CN) adjustment for larger storm events based on the retention storage provided by the practice(s)

**Design Table**

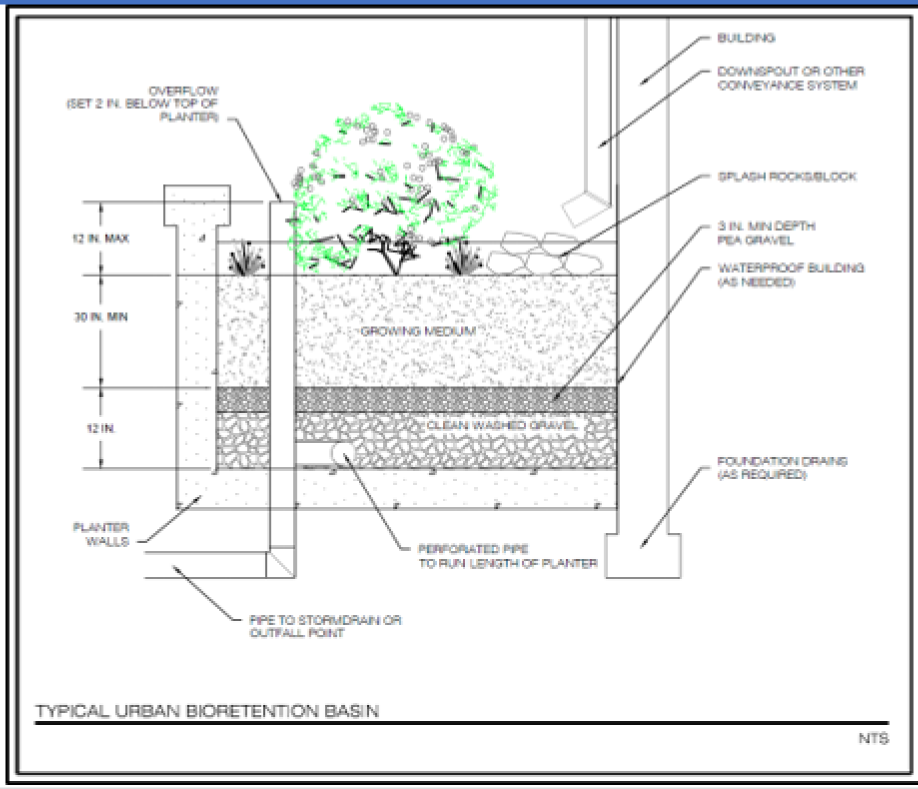
| Table P-FIL-05 B-2 Ultra-Urban Bioretention Design Criteria |
|---|
| **Level 1 Design Only (RR: 40; TP: 25)** |
| Maximum Drainage Area = 2,500 sq. ft.[1] (100% impervious) |
| Sub-soil testing (Refer to the Primary Bioretention Design Specification) |
| Sizing :<br>Tv BMP = [(1)(Rv)(A) / 12] |
| Maximum Ponding Depth = 6 to 12 inches [2] |
| Filter media depth minimum = 18 inches; recommended maximum = 48 inches |
| Media and Surface Cover<br>(Refer to the Primary Bioretention Design Specification) |
| Underdrain = Schedule 40 PVC with clean-outs<br>(Refer to the Primary Bioretention Design Specification) |
| Building setbacks (Refer to Figure P-FIL-05 B-5 below) |
| Inflow = sheetflow (e.g., curb cuts); concentrated flow (e.g., trench drains, roof drains) |
| Deeded maintenance O&M plan (Refer to the Primary Bioretention Design Specification) |

**Notes:**

1. Larger drainage areas may be allowed with sufficient flow controls and other mechanisms to ensure proper function, safety, and community acceptance; however, the urban bioretention filter must then be designed in accordance with the Level 1 bioretention criteria (Table P-FIL-05-3).
2. Ponding depth above 6 inches will require a specific planting plan to ensure appropriate plants (Refer to the Primary Bioretention Design Specification).

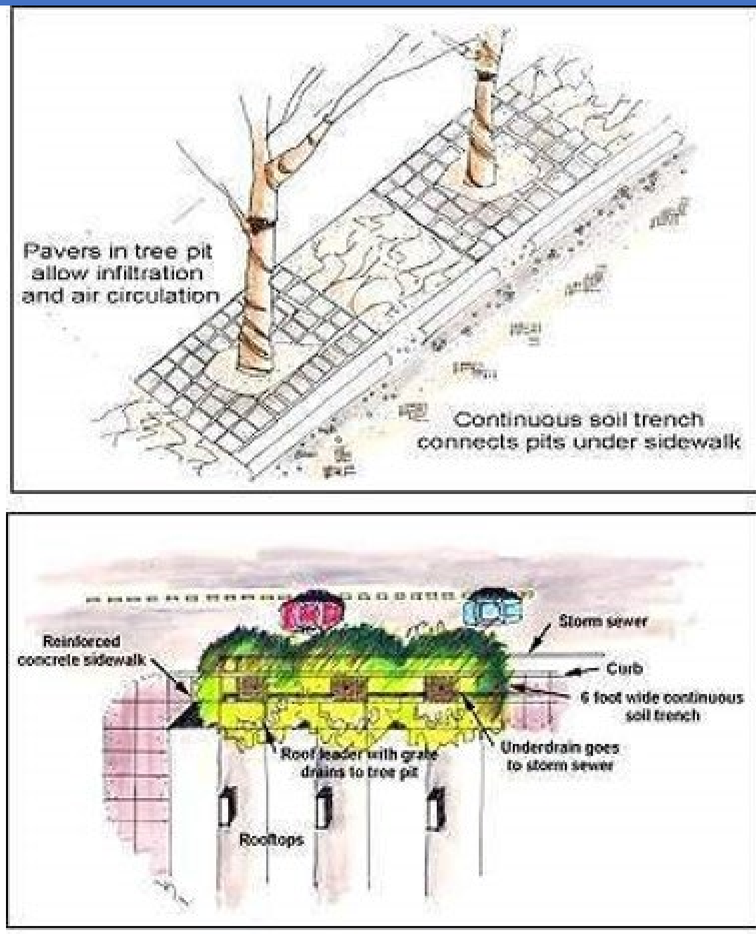
**Typical Details**

## Figure P-FIL-05 B-4 Stormwater planter cross-section




*(Note: To be modified to change min depth = 18")*

**Figure P-FIL-05 B-5 Expanded tree pit details**




### Physical Feasibility & Design Applications

In general, ultra-urban bioretention has the same constraints as regular bioretention, along with a few additional constraints as noted below:

***Contributing Drainage Area.*** Ultra-urban bioretention is limited to 2,500 sq. ft. of drainage area to each unit, and the contributing drainage area is considered to be 100% impervious. Larger drainage areas may be allowed with sufficient flow controls and other mechanisms to ensure proper function, safety, and community acceptance.

***Adequate Drainage.*** Ultra-urban bioretention practice elevations must allow the untreated stormwater runoff to be discharged at the surface of the filter bed and ultimately connect to the local storm drain system.

***Available Hydraulic Head.*** In general, 3 to 5 feet of elevation difference is needed between the downstream storm drain invert and the inflow point of the ultra-urban bioretention practice. This is generally not a constraint, due to the standard depth of most storm drains systems.

***Setbacks from Buildings or Roads.*** If an impermeable liner and an underdrain are used, no setback is needed from the building. Otherwise, the standard 10 foot down-gradient setback applies.

***Proximity to Underground Utilities.*** Ultra-urban bioretention practices frequently compete for space with a variety of utilities. Since they are often located parallel to the road right-of-way, care should be taken to provide utility-specific horizontal and vertical setbacks. However, conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

***Overhead Wires.*** Designers should also check whether future tree canopy heights achieved in conjunction with ultra-urban bioretention practices will interfere with existing overhead telephone, cable communications and power lines.

***Minimizing External Impacts.*** Because ultra-urban bioretention practices are installed in a highly urban settings, individual units may be subject to higher public visibility, greater trash loads, pedestrian use traffic, vandalism, and even vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal deign. When ultra-urban bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates or other measures to prevent damage from pedestrian short-cutting across the practices.

**Design Criteria**

Ultra-urban bioretention practices are similar in function to regular bioretention practices except they are adapted to fit into “containers” within urban landscapes. Therefore, special sizing accommodations are made to allow these practices to fit in very constrained areas where other surface practices may not be feasible.

**Sizing of Ultra-urban Bioretention**

The requirements for sizing an ultra-urban bioretention filter are the same as that of bioretention and micro-bioretention described in the Primary design specification.

**General Design Criteria for Ultra-urban Bioretention**

Design of ultra-urban bioretention should follow the general guidance presented in the main part of this bioretention design specification. The actual geometric design of ultra-urban bioretention is usually dictated by other landscape elements such as buildings, sidewalk widths, utility corridors, retaining walls, etc. Designers can divert fractions of the runoff volume from small impervious surfaces into micro-bioretention units that are integrated with the overall landscape design. Inlets and outlets should be located as far apart as possible. The following is additional design guidance that applies to all variations of ultra-urban bioretention:

- The ground surface of the ultra-urban bioretention cell should slope 1% towards the outlet, unless a stormwater planter is used.
- The soil media depth should be a minimum of 18 inches.
- If large trees and shrubs are to be installed, soil media depths should be a minimum of 4 feet.
- Each individual ultra-urban bioretention unit should be stenciled or otherwise permanently marked to designate it as a stormwater management facility. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.
- All ultra-urban bioretention practices should be designed to fully drain within 24 hours.
- Any grates used above ultra-urban bioretention areas must be removable to allow maintenance access.

- The inlet(s) to ultra-urban bioretention should be stabilized using VDOT #3 stone, splash block, river stone or other acceptable energy dissipation measures. The following forms of inlet stabilization are recommended:
  - Downspouts to stone energy dissipators.
  - Sheet flow over a depressed curb with a 3-inch drop.
  - Curb cuts allowing runoff into the bioretention area.
  - Covered drains that convey flows across sidewalks from the curb or downspouts.
  - Grates or trench drains that capture runoff from the sidewalk or plaza area.
- Pre-treatment options overlap with those of regular bioretention practices. However, the materials used may be chosen based on their aesthetic qualities in addition to their functional properties. For example, river rock may be used in lieu of rip rap. Other pretreatment options may include one of the following:
  - A trash rack between the pre-treatment cell and the main filter bed. This will allow trash to be collected from one location.
  - A trash rack across curb cuts. While this trash rack may clog occasionally, it keeps trash in the gutter, where it can be picked up by street sweeping equipment.
  - A pre-treatment area above ground or a manhole or grate directly over the pre-treatment area.
- Overflows can either be diverted from entering the bioretention cell or dealt with via an overflow inlet. Optional methods include the following:
  - Size curb openings to capture only the Treatment Volume and bypass higher flows through the existing gutter.
  - Use landscaping type inlets or standpipes with trash guards as overflow devices.
  - Use a pre-treatment chamber with a weir design that limits flow to the filter bed area.

**Specific Design Issues for Stormwater Planters**

Since stormwater planters are often located near building foundations, waterproofing by using a watertight concrete shell or an impermeable liner is required to prevent seepage.

**Specific Design Issues for Expanded Tree Pits**

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Extended tree pits designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing a tree pit grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a drop-off from the pavement to the micro-bioretention cell.
- A removable grate capable of supporting typical H-20 axel loads may be used to allow the tree to grow through it.
- Each tree needs a minimum of 400 cubic feet of shared root space.

**Specific Design Issues for Stormwater Curb Extensions**

Roadway stability can be a design issue where stormwater curb extensions are installed. Consult design standards pertaining to roadway drainage. It may be necessary to provide a barrier to keep water from saturating the road's sub-base and demonstrate it is capable of supporting H-20 axle loads.

**Planting and Landscaping Considerations**

The degree of landscape maintenance that can be provided will determine some of the planting choices for ultra-urban bioretention areas. The planting cells can be formal gardens or naturalized landscapes.

In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a "turf and trees" landscaping model. Spaces for herbaceous flowering plants can be included. This may be attractive at a community entrance location.

Native trees or shrubs are preferred for ultra-urban bioretention areas, although some ornamental species may be used. Selected perennials, shrubs, and trees must be tolerant of salt, drought, and inundation. Additionally, tree species should be those that are known to survive well in the compacted soils and polluted air and water of an urban landscape.

**Ultra-Urban Bioretention Material Specifications**

Please consult the primary design specification (Table P-FIL-05-3) for the typical materials needed for filter media, stone, mulch and other bioretention features. The unique components for ultra-urban bioretention may include the inlet control device, a concrete box or other containing shell, protective grates, and an underdrain that daylights to another stormwater practice or connects to the storm drain system. The underdrain should:

- Consist of slotted pipe greater than or equal to 4 inches in diameter, placed in a layer of washed (less than 1% passing a #200 sieve) VDOT #57 stone.
- Have a minimum of 2 inches of gravel laid above and below the pipe.
- Be laid at a minimum slope of 0.5 %.
- Extend the length of the box filter from one wall to within 6 inches of the opposite wall and may be either centered in the box or offset to one side.
- Be separated from the soil media by non-woven, geotextile fabric or a 2-to-3-inch layer of either washed VDOT #8 stone or 1/8 to 3/8 inch pea gravel. Note that the fabric should not cover the entire area of separation between soil media and gravel, but rather be placed just above the perforated underdrain system and extend laterally up to from the centerline of the pipe.

**Construction**

The construction sequence and inspection requirements for ultra-urban bioretention are generally the same as micro-bioretention practices. Consult the construction sequence and inspection guidance provided in the primary design specification. In cases where ultra-urban bioretention is constructed in the road or right-of-way, the construction sequence may need to be adjusted to account for traffic control, pedestrian access, and utility notification.

Ultra-urban bioretention areas should only be constructed after the drainage area to the facility is completely stabilized. The specified growth media should be placed and spread by hand with minimal compaction, to avoid compaction and maintain the porosity of the media. The media should be placed in 6-to-12-inch lifts with no machinery allowed directly on the media during or after construction. The media should be overfilled above the proposed surface elevation, as needed, to allow for natural settling. Lifts may be lightly watered to encourage settling. After the final lift is placed, the media should be raked (to level it), saturated, and allowed to settle for at least one week prior to installation of plant materials.

**Maintenance**

Routine operation and maintenance are essential to gain public acceptance of highly visible ultra-urban bioretention areas. Weeding, pruning, and trash removal should be done as needed to maintain the aesthetics necessary for community acceptance. During drought conditions, it may be necessary to water the plants, as would be necessary for any landscaped area.

To ensure proper performance, inspectors should check that stormwater infiltrates properly into the soil within 24 hours after a storm. If excessive surface ponding is observed, corrective measures include inspection for soil compaction and underdrain clogging. Consult the maintenance guidance outlined in the main part of this design specification (Section 7).

**Design References**

Center for Watershed Protection. 2006. *Urban Watershed Forestry Manual.* Part 2: Conserving and PlantingTrees at Development Sites. Ellicott City, MD**.** Available online at: https://owl.cwp.org/mdocs-posts/urban-watershed-forestry-manual-part-2/

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# P-FIL-06 Filtering Practices

## 1.0 Definition

Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system.

## 2.0 Purpose and Applicability of Best Management Practice

Stormwater filters can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they are clearly the best option (e.g., hotspot runoff treatment, small high-traffic parking lots, ultra-urban areas). Stormwater filters are a versatile option because they occupy very little surface land and have few site restrictions that make it a favorable option for most sites. Additionally, stormwater filters are a useful practice to treat stormwater runoff from small, highly impervious sites.

The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of sand or other filter media.

## 3.0 Planning and Considerations

The feasibility criteria shown in Table P-FIL-06-1 should be evaluated when designing a stormwater filter.

| Table P-FIL-06-1 Filtering Practice Feasibility Criteria | |
|---|---|
| **Feature** | **Criteria** |
| Available Hydraulic Head | The principal design constraint for stormwater filters is available hydraulic head. The hydraulic head that is preferred for stormwater filters can range from 2 to 10 feet, depending on the design variant, making them difficult to employ in extremely flat terrain. Perimeter sand filters can be specified in areas where reduced hydraulic head is a concern. |
| Depth to Water Table and Bedrock | It is preferred that the standard separation distance is at least 2 feet between the seasonally high groundwater table and/or bedrock layer and the bottom invert of the filtering practice. |
| Contributing Drainage Area (CDA) | Stormwater filters are best applied on small sites where the CDA area is as close to 100% impervious as possible to minimize the sediment and organic solids load to the filter. A maximum CDA of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for perimeter or underground filters. Filters can be designed to treat runoff from larger areas; however, the increased hydraulic loading will contribute to greater frequency of media surface clogging and/or maintenance costs. |
| Space Required | The amount of space required for a filter practice depends on the design variant selected. Both sand and organic surface filters typically consume about 2% to 3% of the CDA, while perimeter sand filters typically consume less than 1%. Underground stormwater filters can be placed under parking or open space and generally consume no surface area. This makes stormwater filters well suited to treat runoff from redevelopment of commercial sites or stormwater hotspots. |

There are several design variations of the basic sand filter that enable designers to use filters at challenging sites or to improve pollutant removal rates. The most common design variants include surface, underground, and perimeter sand filters, as described below and depicted on Figure P-FIL-06-1, Figure P-FIL-06-2, through Figure P-FIL-06-3; (detailed drawings are shown on Figure P-FIL-06-4, Figure P-FIL-06-5, Figure P-FIL-06-6, through Figure P-FIL-06-7 within Section 6.1).

**Surface Sand Filters** are normally designed to be off-line facilities to economize the size of the filter components and reduce maintenance costs. However, in some cases they can be installed as a treatment component within the bottom of a dry extended detention pond that has a shallow total ponding depth (see Figure P-FIL-06-5 and BMP P-BAS-03, Extended Detention Pond).

The surface sand filter is applied to sites less than 2 acres in size, and is essentially the same as a bioretention basin (see BMP P-FIL-05, Bioretention), with the following exceptions:

- The bottom is lined with an impermeable filter fabric and always has an underdrain.
- The surface cover is native ground cover.
- The filter media is 100% sand.
- The filter surface is not planted with trees, shrubs or herbaceous materials.
- The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.

The surface sand filter is designed with both the filter bed and pretreatment settling chamber or forebay located at ground level. Both chambers can be constructed with earthen components (see Figure P-FIL-06-5) or pre-cast or cast-in-place concrete (Austin sand filter; see Figure Figure P-FIL-06-2).

**Figure P-FIL-06-1 Sand Filter in a Detention Basin**

**Figure P-FIL-06-2 Austin Surface Sand Filter**

**Underground Sand Filter**. The underground sand filter is modified to install the filtering components underground and is often designed with an internal flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter. Underground sand filters consume very little space and are well suited to ultra-urban areas.

***Perimeter Sand Filter**.* The perimeter sand filter (Figure P-FIL-06-3) also includes the basic design elements of a sediment chamber and a filter bed in a linear configuration allowing the overall system to be relatively small and shallow (see Figure P-FIL-06-7). However, this also serves to limit the CDA since treating a large area becomes very challenging with the linear configuration; (designers will recognize the value of shifting to a traditional underground sand filter or proprietary filter on large drainage areas). Flow enters the system as sheet flow through linear grates, usually at the edge of a small parking lot. The perimeter sand filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by overflowing the internal treatment chamber weir. One major advantage of the perimeter sand filter design is that the smaller scale of the design reduces the required hydraulic head, making it a good option for sites with low topographic relief.

*Figure P-FIL-06-3 Perimeter Sand Filter*

***Organic Media Filter***. Organic media filters are a design variant for the filtering systems described above with an organic filter medium replacing the sand. Two notable examples are the peat/sand filter and the compost filter system. Organic filters achieve higher pollutant removal for metals and hydrocarbons due to the increased cation exchange capacity of the organic media, making them useful for targeting specific hotspot pollutants.

***Proprietary Filters***. Proprietary filters are discussed elsewhere in Chapter 8.

## 4.0 Stormwater Performance Summary

Stormwater filters provide moderate pollutant removal performance and provide no runoff volume reduction credit (see Table P-FIL-06-2); therefore, designers should consider using upgradient runoff reduction practices to decrease the treatment volume (Tv) and the required size of the filtering practice. Filters are usually designed only for water quality treatment.

**Table P-FIL-06-2 Summary of Stormwater Functions Provided by Filtering Practices**

| Stormwater Function | Level 1 Design | Level 2 Design |
|---|---|---|
| Annual Runoff Reduction Volume | 0% | 0% |
| Total Phosphorus EMC Reduction[1] by BMP Treatment Process | 60% | 65% |

| Table P-FIL-06-2 Summary of Stormwater Functions Provided by Filtering Practices | | |
|---|---|---|
| **Stormwater Function** | **Level 1 Design** | **Level 2 Design** |
| Channel Protection | Limited – Runoff diverted off-line into a storage facility for treatment can be supplemented with an outlet control to provide peak rate control. | |
| Flood Mitigation | None. Most filtering practices are off-line and do not materially change peak discharges. | |

**Note:**

1. Change in the event mean concentration (EMC) through the best management practice (BMP).

## 5.0 Design Criteria

This is a water quality BMP that is used to maximize nutrient removal. To this end, designers may choose the baseline design (Level 1) or an enhanced Level 2 design that maximizes nutrient removal. See Table P-FIL-06-3.

| Table P-FIL-06-3 Filtering Practice Design Guidance | |
|---|---|
| **Level 1 Design** | **Level 2 Design[1]** |
| **Runoff Reduction: 0; Total Phosphorous: 60; Total Nitrogen: 30** | **Runoff Reduction: 0; Total Phosphorous: 65; Total Nitrogen: 45** |
| Tv = [(1.0)(Rv)(A)] / 12 – the volume reduced by an upstream BMP | Tv = [(1.25)(Rv)(A)] / 12 – the volume reduced by an upstream BMP |
| One cell design[2] | Two cell design[2] |
| Sand media | Sand media with an organic layer |
| CDA contains pervious area | CDA is nearly 100% impervious |
| Two feet separate from bottom of dry swale and seasonally high groundwater table or bedrock, whichever is encountered first | |

**Notes:**

1. Level 2 runoff reduction may be increased if the second cell is utilized for infiltration in accordance with BMP P-FIL-04, Infiltration Practices, or BMP P-FIL-05, Bioretention. The runoff reduction credit should be proportional to the fraction of the Tv designed to be infiltrated.
2. A pretreatment sedimentation chamber or forebay is not considered a separate cell.

### 5.1 Overall Sizing

Filtering devices are sized to accommodate a specified Tv. The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given Tv, Equation P-FIL-06-1 is used to determine the required filter surface area.

***Equation P-FIL-06-1 Minimum Surface Area for Filtering Practice***

$$Af = (Tv)(df)/(K)(hf + df)(tf)$$

Where:

*Af* = area of the filter surface (square feet).

*Tv* = treatment volume*, volume of storage (cubic feet).

*df* = filter media depth (thickness) = minimum 1 foot (feet).

*K* = coefficient of permeability – partially clogged sande (feet per day) = 3.5 feet per day.

*hf* = average height of water above the filter bed (feet), with a maximum of 5 feet = $h_{max}/2$.

*tf* = allowable drawdown time = 1.67 days.

** Stormwater filters are typically the only practice in a drainage area, or in some cases pretreatment; however, where runoff reduction practices are upstream of the filter, the design TV is reduced by the upstream runoff reduction, or $Tv_{BMP}$.*

The coefficient of permeability (feet/day) is intended to reflect the worst-case situation (i.e., the condition of the sand media at the point in its operational life where it requires replacement or maintenance). Filtering practices are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

***Equation P-FIL-06-2 Required Treatment Volume Storage for Filtering Practices***

$$Vs = 0.75(Tv)$$

Where:

*Vs* = volume of storage (cubic feet).

*Tv* = treatment volume (cubic feet).

A storage volume of a least 75% of the design Tv – including the volume over the top of the filter media and the volume in the pretreatment chamber(s), as well as any additional storage – is required in order to capture the volume from high-intensity storms prior to filtration and avoid premature bypass. The reduced volume of storage (75% of Tv) takes into account the varying filtration rate of the water through the media as a function of a gradually declining hydraulic head.

**5.2 Soil Testing Requirements**

At least one soil boring must be taken at a low point within the footprint of the proposed filtering practice to establish the water table and bedrock elevations and evaluate soil suitability for the proposed structure.

**5.3 Pretreatment**

Adequate pretreatment is needed to distribute flow across the filter surface and capture coarse sediment to facilitate filter media longevity. Sedimentation chambers may be wet or dry but must be sized to accommodate at least 25% of the total design Tv (inclusive). Refer to BMP P-SUP-06, Pretreatment, for design details and specifications for other applicable pretreatment options.

**5.4 Conveyance and Overflow**

Filtering practices should be designed as off-line systems with either an internal or external bypass to divert larger flows around the filter to an outlet chamber. Claytor and Schueler (1996) and the Atlanta Regional Commission (2001, 2016) provide design guidance for flow splitters for filtering practices.

Underground filtering practices with an internal bypass must include design information to indicate how the device will safely pass the full range of design storms (e.g., 10-year event) without resuspending or flushing previously trapped material. All stormwater filters should be designed to drain or dewater within 36 hours (1.5 days) after a storm event to reduce the potential for nuisance conditions.

Stormwater filters are normally designed with an impermeable liner and underdrain system that meet the criteria provided in Table P-FIL-06-4 and Table P-FIL-06-6.

| Table P-FIL-06-4 Filter Media and Surface Cover | |
|---|---|
| **Media** | **Requirement** |
| Type of Media | Sand filter media consists of clean, washed concrete sand with individual grains between 0.02 and 0.04 inch in diameter. Alternatively, organic media can be used, such as a peat/sand mixture or a leaf compost mixture. The decision to use organic media in a stormwater filter depends on which stormwater pollutants are targeted for removal. Organic media may enhance pollutant removal performance with respect to metals and hydrocarbons (Claytor and Schueler 1996). However, some organic media can leach soluble nitrate and phosphorus back into the discharge water, making it a poor choice when nutrients are the pollutant of concern. Designers must provide documentation that the selected media has been tested and verified for use as a stormwater filtering media. |
| Type of Filter | The choice of which sand filter design to apply depends on available space and hydraulic head and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. Surface and perimeter filters are often a more economical choice when adequate surface area is available. |
| Surface Cover | The surface cover for surface sand filters should consist of a 3-inch layer of topsoil; (refer to BMP P-FIL-05, Bioretention) on top of a non-woven filter fabric laid above the sand layer.<br>The surface may also have pea gravel inlets in the topsoil layer to promote filtration. The pea gravel may be located where sheet flow enters the filter, around the margins of the filter bed, or at locations in the middle of the filter bed. Underground sand filters may utilize a mono-filament filter fabric with a high flow rate and a thin layer of pea gravel ballast on top of the pea-gravel helps to prevent biofouling or blinding of the sand surface. The fabric serves to facilitate removing the gravel during maintenance operations. |
| Depth of Media | The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. A minimum filter bed depth from 12 to 18 inches is recommended. Depths greater than 18 inches can be used to facilitate the removal up to 3 inches of sand during maintenance without having to replace the sand upon each scheduled maintenance. |
| Impervious Drainage Area | The CDA should be as close to 100% impervious as possible to reduce the risk that eroded sediments will clog the filter. |

### 5.5 Observation Wells and Cleanouts

The maintenance issues identified in Table P-FIL-06-5 should be addressed during filter design to reduce future maintenance problems.

| Table P-FIL-06-5 Maintenance Concerns | |
|---|---|
| **Feature** | **Requirement** |
| Observation Wells and Cleanouts | Surface filters should include an observation well consisting of a 6-inch diameter non-perforated polyvinyl chloride pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe must be provided for every 2,000 square feet of filter surface area. |
| Access | Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts. |
| Manhole Access (for Underground Filters) | Access to the headbox and clear well of underground filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur. |
| Visibility | Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can easily find them. Adequate signs or markings should be provided at manhole access points for underground filters. |
| Monofilament Fabric and Pea Gravel Ballast | The use of the fabric and ballast should simplify the maintenance of the filter media surface for both underground and surface filters. |
| Confined Space Issues | Underground filters are often classified as an underground confined space; therefore, Occupational Safety and Health Administration rules apply and training is required to protect workers. Required procedures often involve training about confined space entry, venting, and the use of gas probes. |

### 5.6 Filtering Material Specifications

The basic material specifications for filtering practices are outlined in Table P-FIL-06-6. Adaptations for specific environments are identified in Table P-FIL-06-7.

| Table P-FIL-06-6 Filtering Practice Material Specifications | |
|---|---|
| **Material** | **Specification** |
| Sand | Use clean silica based coarse sand (American Association of State Highway and Transportation Officials [AASHTO] M-6/ASTM C-33). |
| Organic Layer | See BMP P-FIL-08, Soil Compost Amendment. |
| Underdrain and Observation Well | See BMP P-FIL-05, Bioretention.<br>Install perforated pipe for the full length of the filtering practice. Observation wells should be installed as stated in BMP P-FIL-05 in a way to facilitate effective monitoring filter media performance. |

| Table P-FIL-06-6 Filtering Practice Material Specifications | |
|---|---|
| **Material** | **Specification** |
| Filter Fabric | See BMP P-FIL-05, Bioretention, and BMP P-FIL-06, Filtering Practices. Choose an appropriate filter fabric for the individual applications. Filter fabric must be impermeable liner or woven fabric. For hotspots and karst sites only: use an appropriate liner on the bottom. |
| Stone Jacket for Underdrain | See BMP P-FIL-05, Bioretention.<br>Use a 9- to 18-inch layer (depending on the desired depth of storage) of 1-inch stone that is Virginia Department of Transportation (VDOT)-compliant aggregate and clean and free of all fines (e.g., VDOT #57 stone). |

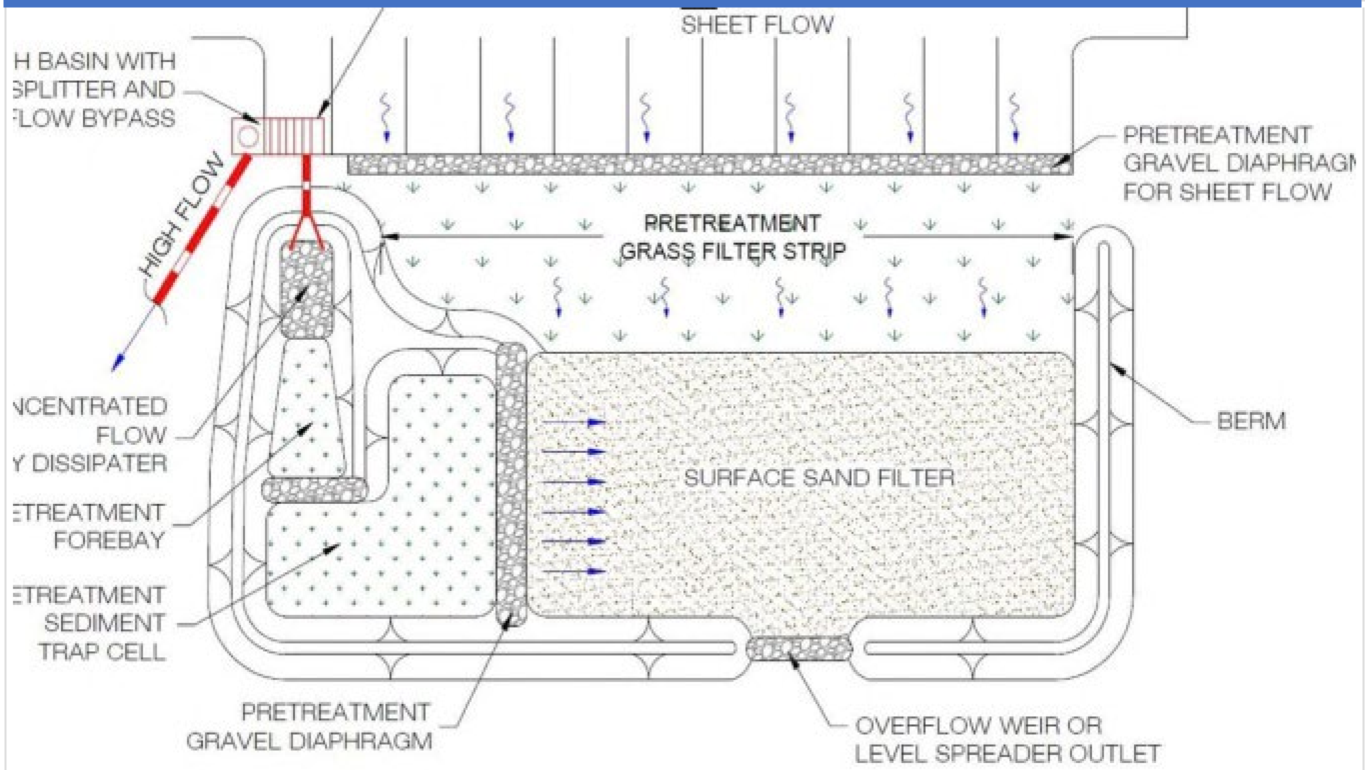
| Table P-FIL-06-7 Regional and Special Case Design Adaptations | |
|---|---|
| **Feature** | **Requirement** |
| Karst Terrain | Stormwater filters are a good option in karst areas, since they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination. Construction inspection should certify that the filters are watertight and that excavation will not extend into a karst layer. |
| Coastal Plain Terrain | The flat terrain, low head, and high-water table of the coastal plain make several filter designs difficult to implement. However, the perimeter sand filter generally has a low head requirement and can work effectively at many small coastal plain sites, subject to the following criteria:<br>• The combined depth of the underdrain and sand filter bed can be reduced to 18 inches.<br>• The designer may wish to maximize the length of the stormwater filter or provide treatment in multiple connected cells.<br>• The minimum depth to the seasonally high groundwater table may be relaxed to 18 inches, as long as the filter is equipped with a large diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the filter bed.<br>• The depth to the seasonally high groundwater can be reduced further if the filter is entirely self-contained to prevent untreated stormwater from entering the groundwater. A geotechnical or structural engineer must verify sufficient support and anchoring to counteract any uplift from hydrostatic pressure.<br>• It is important to maintain at least a 0.5% slope of the underdrain to ensure drainage and to tie it into the receiving ditch or conveyance system. |
| Steep Terrain | The gradient of slopes contributing runoff to sand filters can be increased to 15% in areas of steep terrain, as long as a two-cell terraced design is used to dissipate erosive energy prior to filtering. The drop in elevation between cells should be limited to 1 foot and the slope should be armored with river stone or a suitable equivalent. |

| Table P-FIL-06-7 Regional and Special Case Design Adaptations | |
|---|---|
| **Feature** | **Requirement** |
| Cold Climate and Winter Performance | Surface or perimeter filters may not always be effective during the winter months. The main problem is ice that forms over and within the filter bed. Ice formation may briefly cause nuisance flooding if the filter bed is still frozen when spring melt occurs. To avoid these problems, filters should be inspected before the onset of winter (prior to the first freeze) to dewater wet chambers and scarify the filter surface. Other measures to improve winter performance include the following:<br>• Place a weir between the pretreatment chamber and filter bed to reduce ice formation; the weir is a more effective substitute than a traditional standpipe orifice.<br>• Extend the filter bed below the frost line to prevent freezing within the filter bed.<br>• Oversize the underdrain to encourage more rapid drainage and to minimize freezing of the filter bed.<br>• Expand the sediment chamber to account for road sand. Pretreatment chambers should be sized to accommodate up to 40% of the Tv. |
| Linear Highway Sites | Linear stormwater filters are a preferred practice for constrained highway rights-of-way when designed as a series of individual on-line or off-line cells. In these situations, the final design closely resembles that of dry swales with vegetated filter strip pretreatment. Salt-tolerant grass species should be selected if the contributing roadway will be salted in the winter. |
| Linear Utility Sites | Stormwater filters are generally not suitable to treat runoff within fully vegetated utility rights-of-way or easements because the CDA should be as close to 100% impervious as possible to reduce the risk that eroded sediments will clog the filter. |

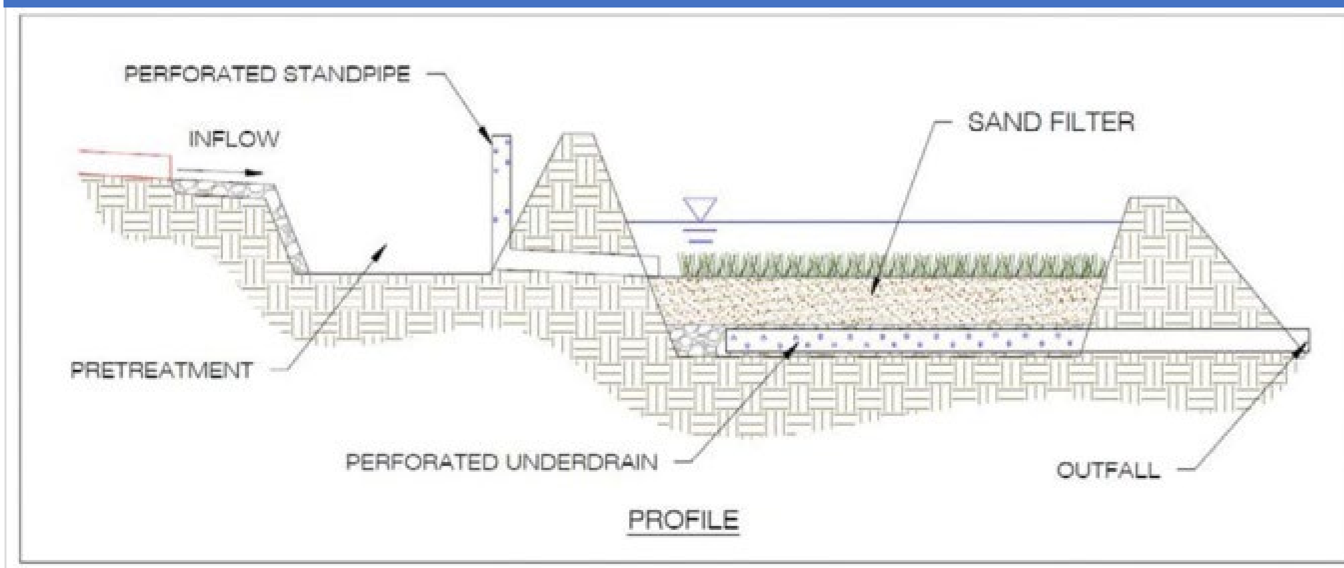
## 6.0 Construction Specifications

Figure P-FIL-06-4 and Figure P-FIL-06-5 provide typical schematics for a surface sand filter and organic filter, respectively. Figure P-FIL-06-6 provides a schematic for an underground sand filter, and Figure P-FIL-06-7 provides a schematic of a perimeter sand filter.

## Figure P-FIL-06-4 Schematic of a Surface Sand Filter




## Figure P-FIL-06-5 Profile of an Organic Filter



## Figure P-FIL-06-6 Underground Filter Schematic

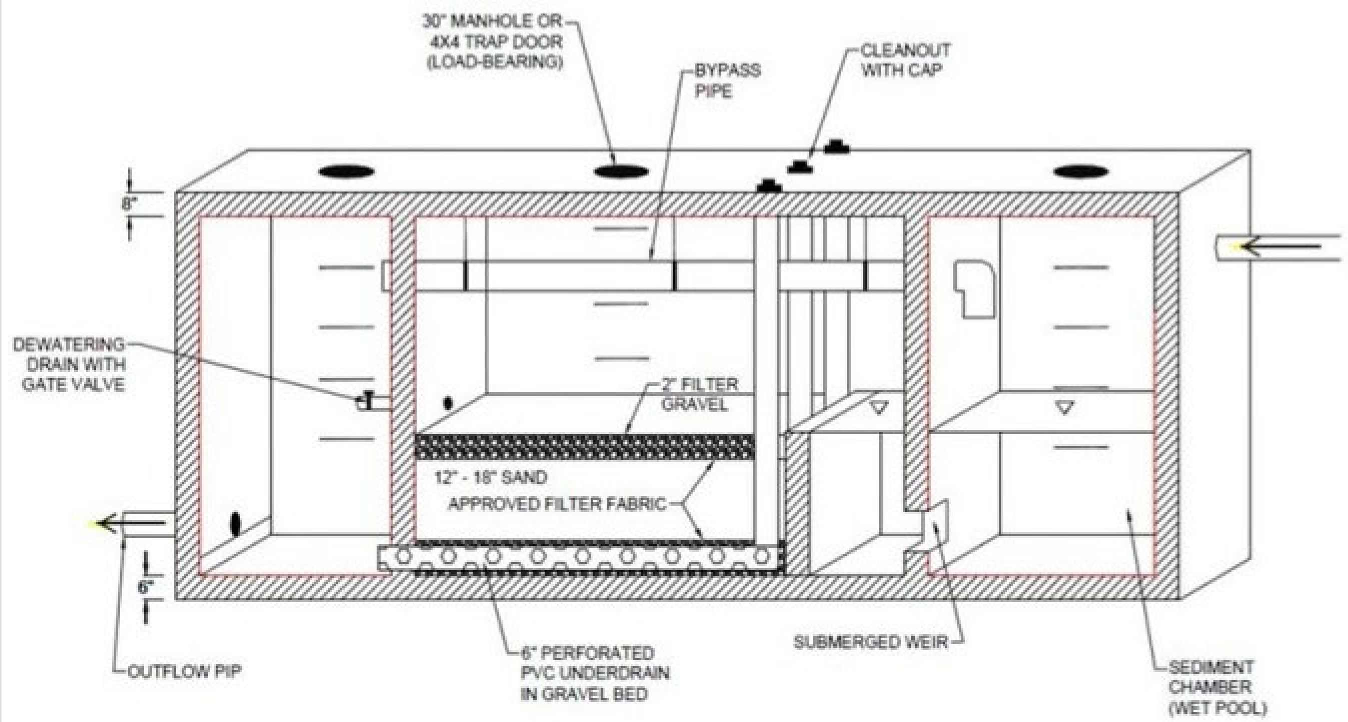
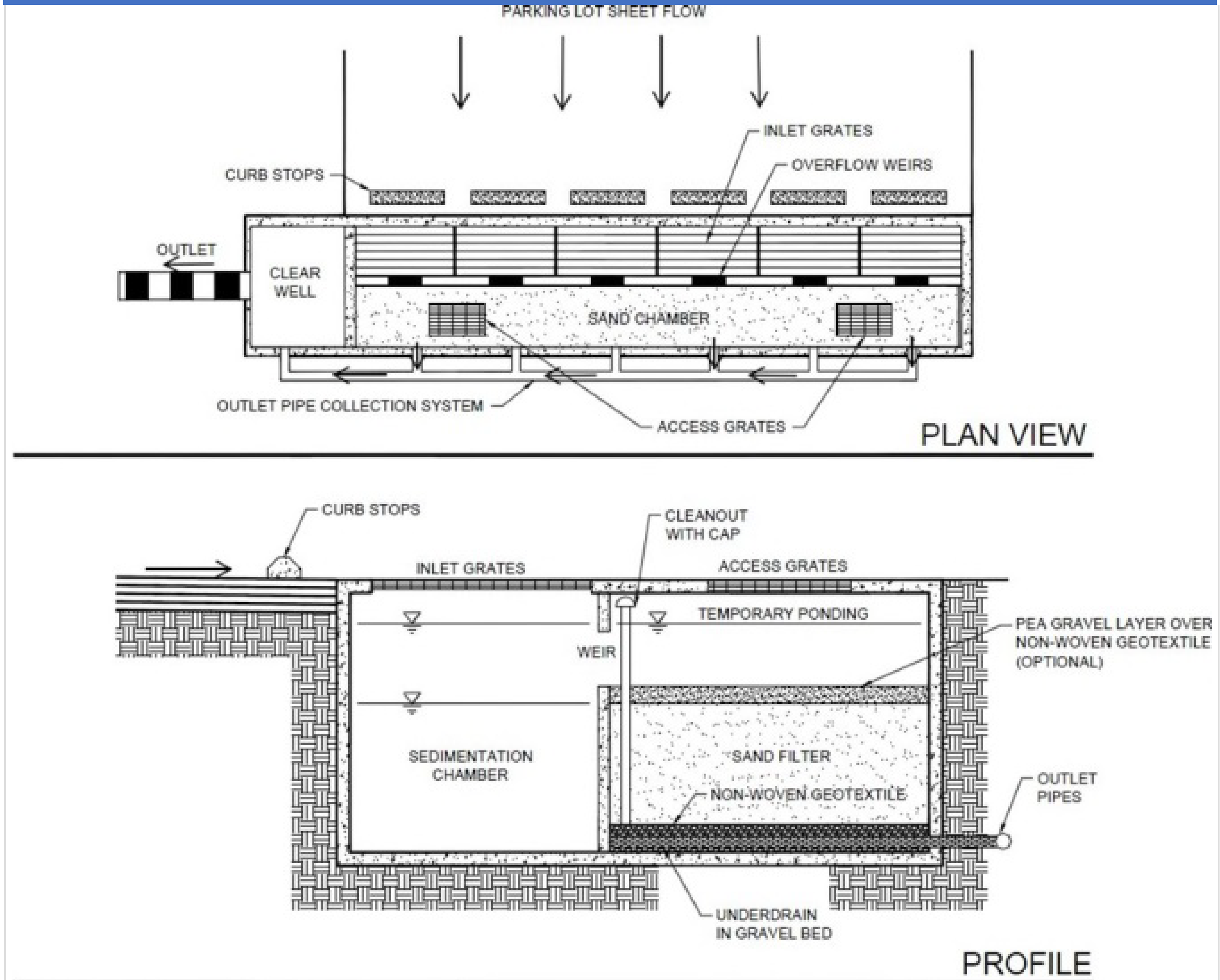


**Figure P-FIL-06-7 Perimeter Filter Plan and Profile Schematic**




### 6.2 Construction Sequence for Filtering Practices

The following is the typical construction sequence to properly install a structural stormwater filter. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity, and configuration of the proposed filtering application.

***Step 1: Use of Filtering Practices as an Erosion and Sediment Control***. The future location of a filtering practice may be used as the site of a temporary sediment basin or trap during site construction, as long as design elevations are set with final cleanout and conversion in mind. The bottom elevation of the filtering practice should be lower than the bottom elevation of the temporary sediment basin. Appropriate procedures should be implemented to prevent discharge of turbid waters when the temporary basin is converted to a filtering practice.

***Step 2: Stabilize Drainage Area***. Filtering practices should only be constructed or opened to runoff after the CDA to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility is to be dewatered, dredged, and regraded to design dimensions for the post-construction filter.

***Step 3: Install Erosion and Sediment Controls for the Filtering Practice****.* Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is extremely important to keep runoff and eroded sediments away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch, or other locally approved method of soil stabilization.

***Step 4: Assemble Construction Materials*** onsite, ensure they meet design specifications, and prepare any staging areas.

***Step 5: Excavate/Grade*** until the appropriate design elevations are achieved for the bottom and side slopes of the filtering practice.

***Step 6: Install the Filter Structure*** and check all design elevations (e.g., concrete vault pipe cut- out holes, bottom of excavation for surface filters).

***Step 7: Ensure Watertight Storage and Filter Structure****.* Upon completion of the filter structure shell, the inlets and outlets should be temporarily plugged and the structure filled with water to the brim to demonstrate watertightness. Maximum allowable leakage is 5% of the water volume in a 24-hour period. If the structure fails the test, repairs must be performed to make the structure watertight before any filter media is installed.

***Step 8: Install Underdrain, and Gravel and Choker Stone Layers****.*

***Step 9: Spread Filter Media Across the Filter Bed*** in 1-foot lifts up to the design elevation. Backhoes or other equipment should deliver the media from outside the filter structure. Sand should be manually raked.

***Step 10: Consolidate the Filter Media****.* Fill the sedimentation and filter media chamber with clean water and allow to drain, hydraulically compacting the sand layers. Verify the depth of filter media meets the design minimum.

***Step 11: Install the Permeable Filter Fabric****.*

- **For Surface Filters** – Install the permeable filter fabric (if specified) over the sand, add a 3-inch topsoil layer with pea gravel inlets diaphragms located with stakes, and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.
- **For Underground Filters** – Install the permeable filter fabric and a thin layer of pea gravel ballast (if specified) over the filter media.

***Step 12: Stabilize Exposed Soils*** on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the ponding area should be permanently stabilized by hydroseeding or seed and straw mulch.

***Step 13:*** Conduct the final construction inspection. Remove excess straw and any unwanted vegetation.

### 6.3 Construction Inspection

Multiple construction inspections during and immediately after construction are critical to ensure that stormwater filters are properly constructed. The following interim verification inspections are recommended during critical stages of construction:

- Conduct pre-construction meetings.
- Verify excavation/grading is to design dimensions and elevations.
- Verify the installation of the filter structure, including the watertightness test.

- Verify the installation of the underdrain and sand filter bed.
- Verify that turf cover is vigorous enough to switch the facility on-line.
- Perform the final inspection after a rainfall event to ensure that it drains properly. Develop a punch list for facility acceptance.
- Log the filtering practice's Global Positioning System (GPS) coordinates and submit them for entry into the Virginia Stormwater Management Program (VSMP) authority's BMP maintenance tracking database.

### 6.4 Sample Construction Inspection Checklist for Filtering Practices

The following checklist provides a basic outline of the anticipated items for the construction inspection of filtering practices. Users may wish to incorporate these items into a VSMP Authority Construction Checklist format consistent with the format used for erosion and sediment control and BMP construction inspections.

- **Certification of Pre-Construction Meeting**: Pre-construction meeting with the contractor designated to install the filtering practice has been conducted.
- Subsurface investigation and soils report supports the placement of a surface or an underground filtering practice in the proposed location.
- Impervious cover has been constructed/installed and area is free of construction equipment, vehicles, material storage), etc.
- All pervious areas of the CDA have been adequately stabilized with a thick layer of vegetation and erosion control measures have been removed.
- Stormwater has been diverted around the area of the filtering practice and perimeter erosion control measures to protect the facility during construction have been installed.

#### 6.4.1 Surface Filter

- Excavation of the filtering practice has achieved proper grades and the required geometry for the filter media placement.
- No groundwater seepage or standing water is present. Any standing water is dewatered to an acceptable dewatering device.
- Installation of the impermeable liner (if required). Liner meets project specifications and is placed in accordance with manufacturers specifications.
- All aggregates, including the reservoir layer around the underdrain, the choker stone layer, and the filter media (sand) conform to specifications as certified by quarry.
- Underdrain size and perforations meet the specifications.
- Placement of the underdrain, observation wells, and underdrain fittings (45-degree wyes, cap at upstream end, etc.) are in accordance with the approved plans.
- **Certification of Excavation and Placement of Liner and Underdrains**: Inspector certifies the successful completion of the previous steps for a surface filter.
- Placement of the stone aggregate, spread (not dumped) around the underdrain, and placement of the layer of the choker stone in accordance with the approved plans.
- Placement of the sand filter media in 1-foot lifts.
- Verify proper depth of filter media.
- Verify surface treatment (vegetation, pea gravel, etc., in accordance with the approved plans.

#### 6.4.2 Underground Structural Filter

- Excavation of the filtering practice has achieved proper grades and the required geometry for the underground structural housing – typically a vault or container made of concrete of other approved material.
- No groundwater seepage or standing water is present. Any standing water is dewatered to an acceptable dewatering device.
- Installation of fabric (if needed) and gravel bedding.
- Placement of the structural housing and verification of internal and external plumbing invert elevations.
- **Certification of Watertightness Test Inspection**: Inspector certifies the successful completion of the watertightness test completed and signed off by contractor or vault supplier.
- Installation of perforated pipes and other piping as required, and filter media to the required depth.
- Connection of inlet and outlet pipes to the site drainage system.

#### 6.4.3 All Filters

- **Certification of Opening of Stormwater Inflow to the Filter Inspection**: Inspector certifies that the CDA(s) are stabilized and erosion and sediment control practices have been removed.
- Follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all filtering practices on the parcel.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of stormwater filtering practices, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- All stormwater filtering practices must include a long-term maintenance agreement consistent with the provisions of the VESMP Regulation and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When stormwater filters are applied on private residential lots, owners should be educated regarding their routine maintenance needs by being provided a document that explains their purpose and routine maintenance needs.
- A deed restriction, drainage easement, or other mechanism enforceable by the VESMP Authority must be in place to help ensure that stormwater filters are maintained and not converted or disturbed, as well as to pass the knowledge along to any subsequent owners.
- The mechanism should, if possible, grant authority for the VESMP Authority to access the property for inspection or corrective action.

### 7.2 Maintenance Inspections

Regular inspections are critical to schedule sediment removal operations, replace filter media, and relieve any surface clogging. Frequent inspections are especially needed for underground and perimeter filters since an organic mat can quickly clog the filter surface. Depending on the level of traffic or the particular land use, a filter system may become clogged within a few months of normal rainfall. Frequent maintenance can quickly establish a routine frequency acclimated to the land use. Maintenance inspections should be conducted within 24 hours following a storm that exceeds 1/2 inch of rainfall in order to evaluate the condition and performance of the filtering practice, including checking for the following:

- Inspect whether sediment accumulation in the sedimentation chamber has exceeded 6 inches. If so, schedule a cleanout.
- Inspect whether inlets and flow splitters are clear of debris and are operating properly.
- Inspect the dry sediment chamber and sand filter bed for any evidence of standing water or ponding more than 48 hours after a storm and take necessary corrective action to restore permeability.
- Dig a small test pit in the sand filter bed to determine whether the first 3 inches of sand are visibly discolored and need replacement.
- Inspect whether the CDA to the filter is stable and not a source of sediment.
- Inspect whether turf on the filter bed and buffer is more than 12 inches high, and schedule necessary mowing operations.
- Inspect the integrity of observation wells and cleanout pipes.
- Inspect concrete structures and outlets for any evidence of spalling, joint failure, leakage, corrosion, etc.
- Ensure that the filter bed is level and remove trash and debris from the filter bed. Sand or gravel covers should be raked to a depth of 3 inches. Filters with a turf cover should have 95% vegetative cover.

The results of the inspection will then determine the level of maintenance required (routine or major – see Table P-FIL-06-8). Example maintenance inspection checklists for filtering practices are included in Chapter 10, BMP Inspection and Maintenance.

### 7.3 Routine Maintenance Tasks

A cleanup should be scheduled at least once per year to remove trash and floating debris that accumulate in the pretreatment cells and filter bed. Sediment cleanouts in the dry and wet sedimentation chambers should be performed as needed to maintain the function and performance of the filter. If the filter treats runoff from a stormwater hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. Testing is not needed if the filter does not receive runoff from a designated stormwater hotspot, in which case the media can be safely disposed by either land application or land filling.

**Table P-FIL-06-8 Suggested Annual Maintenance Activities for Filtering Practices**

| Maintenance Tasks | Frequency |
|---|---|
| Mow grass filter strips and perimeter turf. | At least four times per year |
| Remove blockages and obstructions from inflows. Relieve clogging.<br>Stabilize CDA and side slopes to prevent erosion. | As needed |
| Inspect and clean up. | Annually |

| Table P-FIL-06-8 Suggested Annual Maintenance Activities for Filtering Practices | |
|---|---|
| **Maintenance Tasks** | **Frequency** |
| Clean out wet sedimentation chambers.<br>Remove sediments from dry sedimentation chamber. | Once every 2 to 3 years or as needed |
| Replace top sand layer.<br>Till or aerate surface to improve infiltration/grass cover. | Every 5 years |

## 8.0 References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# P-FIL-07 Sheet Flow to Vegetated Filter Strip or Conserved Open Space

## 1.0 Definition

Filter strips are vegetated areas that treat sheet flow delivered from adjacent managed turf and impervious areas by slowing runoff velocities and allowing sediment and attached pollutants to settle and/or be filtered by the vegetation.

## 2.0 Purpose and Applicability of Best Management Practice

Stormwater must enter the vegetated filter strip or conserved open space as sheet flow. A typical configuration consists of the stormwater runoff from the paved area uniformly entering the practice along a linear edge (such as the edge of a road or parking lot) and draining across the length of the filter strip or open space parallel to the flow. This configuration would be accompanied by a gravel diaphragm or other pretreatment practice to establish a non-erosive transition between the pavement and the filter strip or open space. If the inflow to the filter strip is from a pipe or channel, a level spreader must be designed in accordance with BMP C-ECM-14, Level Spreader, to convert the concentrated flow to sheet flow.

The two design variants of filter strips are: conserved open space and designed vegetated filter strips. The differences in design, installation, and management of these design variants are outlined in this specification.

### 2.1 Conserved Open Space

The most common design applications of conserved open space are on sites that are hydrologically connected to a protected stream buffer, wetland buffer, floodplain, forest conservation area, or other protected lands.

Conserved open space is an ideal component of the "outer zone" of a stream buffer, such as a Resource Protection Area (as is required in some regions), which normally receives runoff as sheet flow. Care should be taken to locate all energy dissipaters or flow spreading devices outside of the protected area.

Designers may apply a runoff reduction credit to any impervious or managed turf cover that is hydrologically connected and effectively treated by a protected conserved open space that meets the following eligibility criteria:

- The goal of establishing conserved open space is to protect a vegetated area contiguous to a receiving system, such as a stream or natural channel, for treating stormwater runoff. Establishing isolated conserved open space pockets on a development site may not achieve this goal unless they effectively serve to connect the surface runoff to the receiving system. Therefore, a locality may choose to establish goals for minimum acreage to be conserved (in terms of total acreage or percentage of the total project site), and the physical location (adjacent to a stream or other criteria) for the cumulative conserved open space to qualify for the runoff reduction credit.
- Minimal disturbance shall occur within the conserved open space during or after construction (i.e., no clearing or grading is allowed except temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation). The conserved open space area shall not be stripped of topsoil. Some minimal grading may be needed at the boundary to establish a level entry into the conserved open space. This shall be accomplished using rubber tracked vehicles to prevent compaction.
- The limits of disturbance shall be clearly shown on all construction drawings and protected by acceptable signage and erosion control measures.
- A long-term vegetation management plan must be prepared to maintain the conserved open space in a natural vegetative condition. Generally, conserved open space management plans do not encourage or even allow any active management. However, a specific plan should be developed to manage the unintended consequences of passive recreation, control invasive species, provide for tree and understory maintenance, etc. Managed turf is not considered an acceptable form of vegetative management, and only the passive recreation areas of dedicated parkland are eligible for the practice (e.g., the actively used portions of ball fields and golf courses are not eligible), although conservation areas can be ideal treatment practices at the edges of turf-intensive land uses.
- The conserved open space must be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure that no future development, disturbance, or clearing may occur within the area.
- The practice does not apply to jurisdictional wetlands that are sensitive to increased inputs of stormwater runoff (e.g., bogs and fens).

### 2.2 Vegetated Filter Strip

Vegetated filter strips are best suited to treat runoff from small segments of impervious cover (usually less than 5,000 square feet) adjacent to road shoulders, small parking lots, and rooftops. Vegetated filter strips may also be used as pretreatment for another stormwater practice, such as a dry swale, bioretention, or infiltration areas. Refer to Support Component: BMP P-SUP-06, Pre-Treatment, for more information regarding pretreatment requirements. If sufficient pervious area is available at the site, larger areas of impervious cover can be treated by vegetated filter strips using a level spreader to recreate sheet flow. Vegetated filter strips are also well suited to treat runoff from turf-intensive land uses, such as the managed turf areas of sports fields, golf courses, and parkland.

Vegetated filter strips can be used in a variety of situations; however, there are several constraints to their use:

- Soil compaction or disturbance in and around the area of a proposed vegetated filter strip should be minimized to the extent practical. If this is unavoidable, the area should be restored by tilling or otherwise re-establishing the soil permeability in accordance with requirements of BMP P-FIL-08, Soil Compost Amendment. The plan-approving authority may require the applicant to verify the restoration of the soils, either through compost amendments or other means sufficient to achieve the goal of treating runoff from upgradient areas.
- The proposed vegetated filter strip shall be shown on the soil erosion and stormwater management plan.
- A vegetation management plan should be developed to maintain the vegetation density of the filter strip. Herbaceous native species with deep roots of several feet for infiltration should be managed to the extent necessary to maintain a healthy cover. However, any fertilizing or other maintenance, such as mowing, should be identified in a management plan as part of the long-term best management practice operation and maintenance plan.
- The vegetated filter strip should be identified and protected in a perpetual easement, deed restriction, or other accepted mechanism that assigns the responsible party to ensure that no future development, disturbance or clearing may occur within the area, except as stipulated in the vegetation maintenance plan. Signage and or markings should be installed to identify the location and extents of vegetated filter strips.

## 3.0 Planning and Considerations

**Table P-FIL-07-1 Feasibility/Limitations**

| | |
|---|---|
| Filter Slopes and Length | Maximum slopes for conserved open space and vegetated filter strips are between 6% and 8%. Minimum lengths (flow path) for conserved open space and vegetated filter strips are dependent on filter strip slope, as specified in Table P-FIL-07-3**.**<br>The maximum length of a filter strip is 100 feet. |
| Soils | Vegetated filter strips are appropriate for all soil types, except fill soils. The runoff reduction rate, however, is dependent on the underlying Hydrologic Soil Groups (HSGs) and whether soils receive compost amendments; (see Table P-FIL-07-2). |
| Contributing Flow Path to Filter | Vegetated filter strips are used to treat small drainage areas of several thousand square feet of contributing drainage area. The limiting design factor is the length of flow directed to the filter. As a rule, the upstream contributing length of sheet flow to a filter strip shall be no more than 100 feet. When flow concentrates, it moves too rapidly to be effectively treated by a vegetated filter strip unless a level spreader or gravel diaphragm is used upstream for the filter strip. |
| Hydraulic Capacity | Sheet flow practices to conserved open space or vegetated filter strips designed as an on-line practice must be checked to verify the increased volumes of sheet flow will not cause or contribute to erosion, sedimentation, or flooding of downgradient properties or resources. Both conserved open space and vegetated filter strips should be designed as an off-line practice by using periodic diversion or overflow structures to take the runoff in excess of the design treatment volume BMP to an alternative conveyance system. |

| Table P-FIL-07-1 Feasibility/Limitations | |
|---|---|
| | |
| Hotspot Land Uses | Filter strips are not recommended to treat stormwater hotspots due to the potential for infiltration of hydrocarbons, trace metals, and other toxic pollutants into groundwater. |
| Turf-Intensive Land Uses | Both conserved open space and vegetated filter strips are appropriate to treat managed turf and the actively used areas of sports fields, golf courses, parkland, and other turf-intensive land uses. |
| Proximity of Underground Utilities | Underground pipes and conduits that cross the vegetated filter strip are acceptable if the previously disturbed soils from trenching are properly restored. |
| Karst Areas | Both conserved open space and vegetated filter strips are preferred BMPs in karst areas. |
| Depth to Water Table | A separation distance of 1 to 2 feet is recommended between the bottom of the vegetated filter strip and the elevation of the seasonally high-water table. |
| Minimum Setbacks | Local ordinances and design criteria should be consulted to determine minimum setbacks from property lines, structures, utilities, and wells. As a rule, filter strips should be at least 10 feet from building foundations, 10 feet from residential structures, 35 feet from septic system fields, and 50 feet from private wells. |

## 4.0 Stormwater Performance Summary

| Table P-FIL-07-2 Summary of Stormwater Functions Provided by Filter Strips | | | | |
|---|---|---|---|---|
| Stormwater Function | Conservation Area | | Vegetated Filter Strip | |
| | HSG A and B | HSG C and D | HSG A | HSG B[4], C and D |
| | Assume no CA[2] in Conservation Area | | No CA[3] | With CA[2] |
| Annual Runoff Reduction Volume | 75% | 50% | 50% | 50% |
| Total Phosphorus EMC Reduction[1] by BMP Treatment Process | 0 | | 0 | |
| Total Phosphorus Mass Load Removal | 75% | 50% | 50% | 50% |
| Total Nitrogen EMC Reduction by BMP Treatment Process | 0 | | 0 | |
| Total Nitrogen Mass Load Removal | 75% | 50% | 50% | 50% |

| Table P-FIL-07-2 Summary of Stormwater Functions Provided by Filter Strips | | | | |
|---|---|---|---|---|
| Stormwater Function | Conservation Area | | Vegetated Filter Strip | |
| | HSG A and B | HSG C and D | HSG A | HSG B[4], C and D |
| | Assume no CA[2] in Conservation Area | | No CA[3] | With CA[2] |
| Channel Protection and Flood Mitigation | Partial. Use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to adjust curve number for each design storm for the contributing drainage area; and Account for a lengthened time-of-concentration flow path in computing peak discharge. | | | |

**Notes:**

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.

CA = compost amended soils

EMC = event mean concentration

HSG = Hydrologic Soil Group

1. There is insufficient monitoring data to assign a nutrient removal rate for filter strips at this time.
2. See BMP P-FIL-08, Soil Compost Amendment.
3. Compost amendments are generally not applicable for undisturbed HSG A soils, although it may be advisable to incorporate them on mass-graded A or B soils and/or filter strips on B soils in order to maintain runoff reduction rates.
4. The plan approving authority may waive the requirement for compost amended soils for filter strips on B soils under certain conditions.

## 5.0 Design Criteria

Conserved open space and vegetated filter strips do not have two levels of design. Instead, each must meet the appropriate minimum criteria outlined in this section to qualify for the indicated level of runoff reduction (see Table P-FIL-07-3). In addition, designers must conduct a site reconnaissance prior to design to confirm topography and soil conditions.

| Table P-FIL-07-3 Filter Strip Design Criteria | | |
|---|---|---|
| **Design Issue** | **Conserved Open Space** | **Vegetated Filter Strip** |
| Soil and Vegetative Cover | Undisturbed soils and native vegetation | Amended soils and dense turf grass cover or landscaped with herbaceous cover, shrubs, and trees |
| Overall Slope and Length[1] | <u>HSG A and B</u><br>1% to 2% Slope – Minimum 25-foot length<br>2% to 4% Slope – Minimum 40-foot length<br>4% to 6% Slope – Minimum 50-foot length<br>6% to 8% Slope – Minimum 60-foot length<br>Maximum length of 100 feet<br><u>HSG C and D</u><br>1% to 2% Slope – Minimum 40-foot length<br>2% to 4% Slope – Minimum 50-foot length<br>4% to 6% Slope – Minimum 65-foot length<br>6% to 8% Slope – Minimum 80-foot length<br>Maximum length of 100 feet | 1% to 2% Slope – Minimum 25-foot length<br>2% to 4% Slope – Minimum 50-foot length<br>4% to 6% Slope – Minimum 75-foot length<br>6% to 8% Slope – Minimum 95-foot length<br>Maximum length of 100 feet |
| Contributing Area | There is no specific maximum contributing drainage area; however, there is a maximum flow length of 100 feet from upstream contributing drainage areas. The contributing drainage area must be uniformly graded, with a shallow enough slope to maintain sheet flow. If concentrated flow is directed to a conserved open space or vegetated filter strip, then a level spreader must be installed upstream of the filter strip. | |
| Level Spreader for dispersing Concentrated Flow | Refer to BMP C-ECM-14, Level Spreader, for design specifications. | |
| Construction Stage | Locate outside the limits of disturbance and manage according to construction BMPs. | Prevent soil compaction by heavy equipment. |
| Typical Applications | Treat adjacent to stream or wetland buffer or forest conservation area. | Treat small areas of impervious cover (e.g., 5,000 square feet) and/or turf-intensive land uses (e.g., sports fields, golf courses) close to source. |
| Compost Amendments2 | No | Yes (HSG B, C, and D soils) |
| Boundary Spreader | Gravel diaphragm at top of filter | Gravel diaphragm at top of filter; Permeable berm at toe of filter |
| On-line or Off-line Practice | Can be installed as either an on-line or off- line practice. | Typically installed as an on-line practice. |

| Table P-FIL-07-3 Filter Strip Design Criteria | | |
|---|---|---|
| **Design Issue** | **Conserved Open Space** | **Vegetated Filter Strip** |

**Notes:**

1. A minimum of 1% slope is recommended to ensure positive drainage.
2. The plan approving authority may waive the requirement for compost amended soils for filter strips on HSG B soils under certain conditions.

### 5.1 Compost Soil Amendments

Compost soil amendments will enhance the runoff reduction capability of a vegetated filter strip when located on HSGs B, C, and D, subject to the following design requirements:

- The compost amendments should extend over the full length and width of the filter strip.
- The amount of approved compost material and the depth to which it must be incorporated is outlined in BMP P-FIL-08, Soil Compost Amendments.
- The amended area will be raked to achieve the most level slope possible without using heavy construction equipment, and it will be stabilized rapidly with perennial grass and/or herbaceous species.
- If filter strip slopes exceed 3%, a protective biodegradable fabric, blankets, or matting should be installed to stabilize the site prior to runoff discharge. Refer to BMP C-SSM-05, Soil Stabilization Blankets and Matting.
- Compost amendments should not be incorporated until the gravel diaphragm and/or level spreader is installed.
- The local plan approval authority may waive the requirement for compost amendments on HSG-B soils in order to receive credit as a filter strip if the following conditions are met:
    - The designer can provide verification of the adequacy of the onsite soil type, texture, and profile to function as a filter strip.
    - The area designated for the filter strip will not be disturbed during construction.

### 5.2 Planting and Vegetation Management

#### 5.2.1 Conserved Open Space

No grading or clearing of native vegetation is allowed within the conserved open space. An invasive species management plan should be developed and approved by the local plan approval authority.

**Reforested Conserved Open Space**. At some sites, the proposed conserved open space may be in turf or meadow cover or overrun with invasive plants and vines. In these situations, a landscape architect or horticulturalist should prepare a reforestation or restoration plan for the conserved open space. The entire area can be planted with native trees and shrubs or planted to achieve a gradual transition from turf to meadow to shrub and forest. Trees and shrubs with deep rooting capabilities are recommended for planting to maximize soil infiltration capacity (PWD 2007). Over-plant with seedlings for fast establishment and to account for mortality.

Plant larger stock at desired spacing intervals (25 to 40 feet for large trees) using random spacing (Cappiella et al. 2006). Plant ground cover or an herbaceous layer to ensure rapid vegetative cover of the surface area. The Virginia Department of Conservation and Recreation's Riparian Buffer Modification and Mitigation Handbook (2003) provides references for planting densities and shrub to tree ratios for reforestation and forested buffer areas. Refer to BMP P-FIL-09, Tree Planting, and Appendix G, Plant Selection, for additional details regarding tree plantings.

#### 5.2.2 Vegetated Filter Strips

Vegetated filter strips should be planted at such a density to achieve a 90% grass/herbaceous cover after the second growing season. Vegetated filter strips should be seeded, not sodded. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Wisconsin Department of Natural Resources 2007). The filter strip vegetation may consist of turf grasses, meadow grasses, other herbaceous plants, shrubs, and trees, as long as the primary goal of at least 90% coverage with grasses and/or other herbaceous plants is achieved. Designers should choose vegetation that stabilizes the soil and is salt tolerant. Vegetation at the toe of the filter, where temporary ponding may occur behind the permeable berm, should be able to withstand both wet and dry periods. The planting areas can be divided into zones to account for differences in inundation and slope.

Refer to BMP C-SSM-10, Permanent Seeding, and Appendix G, Plant Selection, for permanent turf grass and landscaping specifications.

### 5.3 Conveyance and Overflow

#### 5.3.1 On-Line Systems

Conserved open space and vegetated filter strips may be designed as an on-line system. In such cases increased volumes of sheet flow resulting from pervious or disconnected impervious areas, or from physical spreading of concentrated flow through level spreaders, should be identified and evaluated for potential impacts on downgradient properties or resources.

For discharge of sheet flow from pervious or disconnected impervious areas, documentation/computations should be provided demonstrating that increased volumes of sheet flow:

- Will not adversely impact any downgradient property (i.e., cause erosion and/or cause or worsen localized flooding).
- Will not adversely impact any downgradient environmental features (e.g., wetlands, streams).
- Will be conveyed within any downgradient manmade stormwater conveyance system without causing erosion of the system for the 2-year, 24-hour storm AND will be confined within any downgradient manmade stormwater conveyance system without causing or worsening localized flooding for the 10-year, 24-hour storm.
- Will meet the design parameters of any downgradient restored stormwater conveyance system.
- Will be conveyed within any downgradient natural stormwater conveyance system without causing erosion of the system for the 1-year, 24-hour storm AND will be confined within any downgradient manmade stormwater conveyance system without causing or worsening localized flooding for the 10-year, 24-hour storm.
- For discharges of sheet flow from level spreaders, documentation/computations should be provided demonstrating that discharges of sheet flow from level spreaders:
- Will not adversely impact any downgradient property (i.e., cause erosion and/or cause or worsen localized flooding).
- Will not adversely impact any downgradient environmental features (e.g., wetlands, streams).

#### 5.3.2 Off-Line Systems

Conserved open space and vegetated filter strips may also be designed as an off-line system, with a flow splitter or diversion to divert runoff in excess of the design storm to a separate conveyance system.

### 5.4 Support Components

#### 5.4.1 Gravel Diaphragms

Refer to BMP P-SUP-06, Pre-Treatment, for gravel diaphragm design specifications and details.

#### 5.4.2 Permeable Berm

Vegetated filter strips should be designed with a permeable berm at the toe of the filter strip to create a shallow ponding area. Runoff ponds behind the berm gradually flows through outlet pipes in the berm or through a gravel lens in the berm with a perforated pipe. During larger storms, runoff may overtop the berm (Cappiella et al. 2006).

The permeable berm should have the following properties:

- A wide and shallow trench between 3 to 4 inches in width and 6 to 12 inches in depth should be excavated at the upstream toe of the berm, parallel with the contours.
- Media for the berm should consist of 40% sandy loam soil, 40% sand (Virginia Department of Transportation [VDOT] Grade A Fine aggregate per VDOT 2020 Road and Bridge Specifications, Section 202.03), and 20% pea gravel (American Association of State Highway and Transportation Officials [AASHTO] M-43 1/2 inch to 1 inch).
- The berm, 12 to 18 inches high, should be located downgradient of the excavated depression and should have gentle side slopes to promote easy mowing (Cappiella et al. 2006).
- Stone may be needed to armor the top of berm to handle extreme storm events and one or more armored weirs can be sized to allow for nonerosive overflows during large storm events.
- A permeable berm is not needed when vegetated filter strips are used as pretreatment to another stormwater practice.

#### 5.4.3 Engineered Level Spreaders

Refer to P-SUP-08, Permanent Level Spreader, for design specifications and details pertaining to level spreaders designed to convert concentrated flow to sheet flow.

#### 5.4.4 Vegetated Filter Strip Material Specifications

Table P-FIL-07-4 and Table P-FIL-07-5 provide materials specifications and guidance for the primary treatment within filter strips.

**Table P-FIL-07-4 Vegetated Filter Strip Materials Specifications**

| Material | Specification |
|---|---|
| Gravel Diaphragm | See BMP P-SUP-06, Pre-Treatment. |
| Turf Grass and Plantings | See BMP C-SSM-10, Permanent Seeding, and Appendix G, Plant Selection. |
| Engineered Level Spreader | See BMP P-SUP-08, Level Spreader. |
| Erosion Control Blanket | See BMP C-SSM-05, Soil Stabilization Blankets and Matting.<br>Where filter path slope and sheet flow velocities dictate, use woven biodegradable erosion control fabric or mats that are durable enough to last at least two growing seasons. |
| Topsoil | See BMP C-SSM-02, Topsoiling. |
| Compost Amendments | See BMP P-FIL-08, Soil Compost Amendment.<br>Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance program, as outlined in BMP P-FIL-08, Soil Compost Amendment. |

| Table P-FIL-07-5 Additional Design Guidance | |
|---|---|
| **Feature** | **Guidance** |
| Karst Terrain | Conserved open space areas are highly recommended in karst terrain, particularly when storm flow discharges to the outer boundary of a karst protection area; (see CSN 2009).<br>Vegetated filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet). Some communities use wide grass filter strips to treat runoff from the roadway shoulder.<br>In no case should the use of a conserved open space or vegetated filter strip be considered as a replacement for an adequate receiving system for developed- condition stormwater discharges, unless the adequacy of the design has been demonstrated consistent with the Virginia Stormwater Management Handbook. |
| Coastal Plain | The use of conserved open space areas and vegetated filter strips are highly recommended in the coastal plain, particularly when sheet flow (or concentrated flow with an appropriately sized level spreader) discharges to the outer boundary of a shoreline, stream or wetland buffer. Vegetated filter strips can also be used to treat runoff from small areas of impervious cover (e.g., less than 5,000 square feet). In both cases, however, the designer must consider the depth to the water table. In general, shallow water tables may inhibit the function of vegetated filter strips and 1 to 2 feet of separation from the seasonal high-water table should be provided. |
| Linear Highway Sites | Vegetated filter strips are recommended to treat highway runoff if the median and/or road shoulder is wide enough to provide an adequate flow path. |
| Linear Utility Sites | Vegetated filter strips are recommended to treat runoff from utility right-of-ways, given the site is wide enough to provide an adequate flow path. |
| Cold Climate and Winter Performance | Vegetated filter strips can store snow and treat snowmelt runoff when they serve road or parking lot drainage. If roadway salt is applied in their contributing drainage area, filter strips should be planted with salt-tolerant species such as creeping bent grass or switchgrass. Bluegrass should be avoided in areas where salt loading is high. Consult the Minnesota Stormwater Manual (Minnesota Stormwater Steering Committee 2005) for a list of salt-tolerant grass species. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence for Conserved Open Space Areas

The conserved open space must be fully protected during the construction stage of development and kept outside the limits of disturbance designated in the Erosion and Sediment Control Plan prepared for the site.

- No clearing, grading, or heavy equipment access is allowed except minimal, temporary disturbances associated with incidental utility construction, restoration operations, or management of nuisance vegetation.

- The perimeter of the conserved open space shall be protected from construction sediment by super silt fence in accordance with BMP C-PCM-04, Silt Fence.
- The limits of disturbance should be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, and chain link fence, orange safety fence, snow fence or other protective barrier should be used to keep unnecessary construction activity out of the area. Construction of the gravel diaphragm or level spreader shall not commence until the contributing drainage area has been stabilized and perimeter erosion and sediment controls have been removed and cleaned out.
- Some minimal grading may be needed at the conserved open space boundary; tracked vehicles should be used to prevent compaction.
- Stormwater should not be diverted into the conserved open space until the gravel diaphragm and/or level spreader are installed and stabilized.

### 6.2 Construction Sequence for Vegetated Filter Strips

Vegetated filter strips can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, vegetated filter strip boundaries should be clearly marked.
- Only vehicular traffic used for filter strip construction should be allowed within 10 feet of the vegetated filter trip boundary.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- Construction runoff should be directed away from the proposed filter strip site using appropriate erosion control measures and a diversion dike or other measure.
- Construction of the gravel diaphragm or level spreader shall not commence until the contributing drainage area has been stabilized and perimeter erosion and sediment controls have been removed and cleaned out.
- Vegetated filter strips require light grading to achieve desired elevations and slopes; tracked vehicles should be used to prevent compaction. Topsoil and or compost amendments should be incorporated evenly across the filter strip area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater should not be diverted into the filter strip until the turf cover is dense and well established.

### 6.3 Construction Inspection

Inspections during construction are needed to ensure that the filter strip is built in accordance with these specifications.

- Construction inspection is critical to obtain adequate spot elevations and to ensure the gravel diaphragm or level spreader is completely level, on the same contour, and constructed to the correct design elevation.
- As-built surveys should be required to ensure compliance with design standards.
- Inspectors should evaluate the performance of the filter strip after the first rainfall event of 0.1-inch depth or greater to look for evidence of gullies, outflanking, undercutting, or sparse vegetative cover. Spot repairs should be made as needed.

The Global Positioning System (GPS) coordinates should be logged for all filter strips and conserved open spaces, upon acceptance, and submitted for entry into the local BMP maintenance tracking database.

***Sample Construction Inspection Checklist for Sheet Flow to Vegetated Filter Strip or Conserved OpenSpace:*** The following subsections provide a checklist or basic outline of the anticipated items for the construction inspection of sheet flow practices. Users may wish to incorporate these items into a Virginia Stormwater Management Program (VSMP) Authority Construction Checklist format consistent with the format used for erosion and sediment control and BMP construction inspections.

**6.3.1 Sheet Flow to Conserved Open Space Areas**

- Pre-construction meeting with the contractor designated to install the sheet flow practice has been conducted.
- Impervious cover has been constructed/installed and the area is free of construction equipment, vehicles, material storage, etc.
- All pervious areas of the contributing drainage areas have been adequately stabilized and erosion control measures have been removed.
- The area of the conserved open space has been clearly marked and protected from construction traffic with adequate signage and fencing and is in good condition (undisturbed – other than for pruning or other vegetation management needs).
- Area of the conserved open space has been clearly marked and protected from construction runoff and sediment with appropriate sediment control measures (super silt fence, berms, etc.).
- Stormwater has been diverted for the construction of the inflow (level spreader or gravel diaphragm).
- Any light grading required to establish the upper boundary of the conserved open space has been performed with light equipment and minimal impact to the existing vegetation.
- Construction of engineered level spreader for concentrated inflow or a gravel diaphragm or other pretreatment measure for sheet flow has been completed and the area stabilized as needed.
- Stormwater runoff directed into conserved open space after the area at the upper boundary has been stabilized.
- All erosion and sediment control practices have been removed.
- A follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all conserved open spaces on the parcel.

**6.3.2 Sheet Flow to Vegetated Filter Strips**

- Pre-construction meeting with the contractor designated to install the sheet flow practice has been conducted.
- Impervious cover has been constructed/installed and the area is free of construction equipment, vehicles, material storage, etc.
- All pervious areas of the contributing drainage areas have been adequately stabilized and erosion control measures have been removed.
- Area of the vegetated filter strip has been clearly marked and protected from construction traffic with adequate signage and fencing, and is in good condition; or
- Area of the vegetated filter strip has been previously (temporarily) stripped of topsoil during construction is scheduled for restoration and soil amendments (if required).
- Topsoil and/or soil amendments are nearby and certified as meeting the design specifications.
- Proper grades have been achieved with light equipment to avoid compaction to provide the required geometry of the disconnection practice: length, width, and slope, and preparation of the upper boundary has been performed.

- Stormwater has been diverted for the construction of the inflow measures (level spreader or gravel diaphragm).
- Soil amendments, if specified, have been incorporated as specified (thickness of compost material and incorporated to the required depth).
- Construction of engineered level spreader for concentrated inflow or a gravel diaphragm or other pretreatment measure for sheet flow has been completed.
- The entire area of the vegetated filter strip has been stabilized and achieved a dense turf cover prior to diverting runoff into the practice.
- All erosion and sediment control practices have been removed.
- A follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for all vegetated filter strips on the parcel.

### 6.4 Typical Details

Figure P-FIL-07-1 shows a typical approach for sheet flow to a conserved open space (adapted from Cappiella et al. 2006). Figure P-FIL-07-2 illustrates the gravel diaphragm providing pretreatment, and Figure P-FIL-07-3 details a level spreader with a rigid and a vegetated overflow lip. Figure P-FIL-07-4 illustrates the combination of simple disconnection discussed in BMP P-FIL-01, Rooftop Impervious Surface Disconnection, to conserved open space as the downstream practice.

***Figure P-FIL-07-1 Typical Configuration of Sheet Flow to Filter Strip or Conserved Open Space***

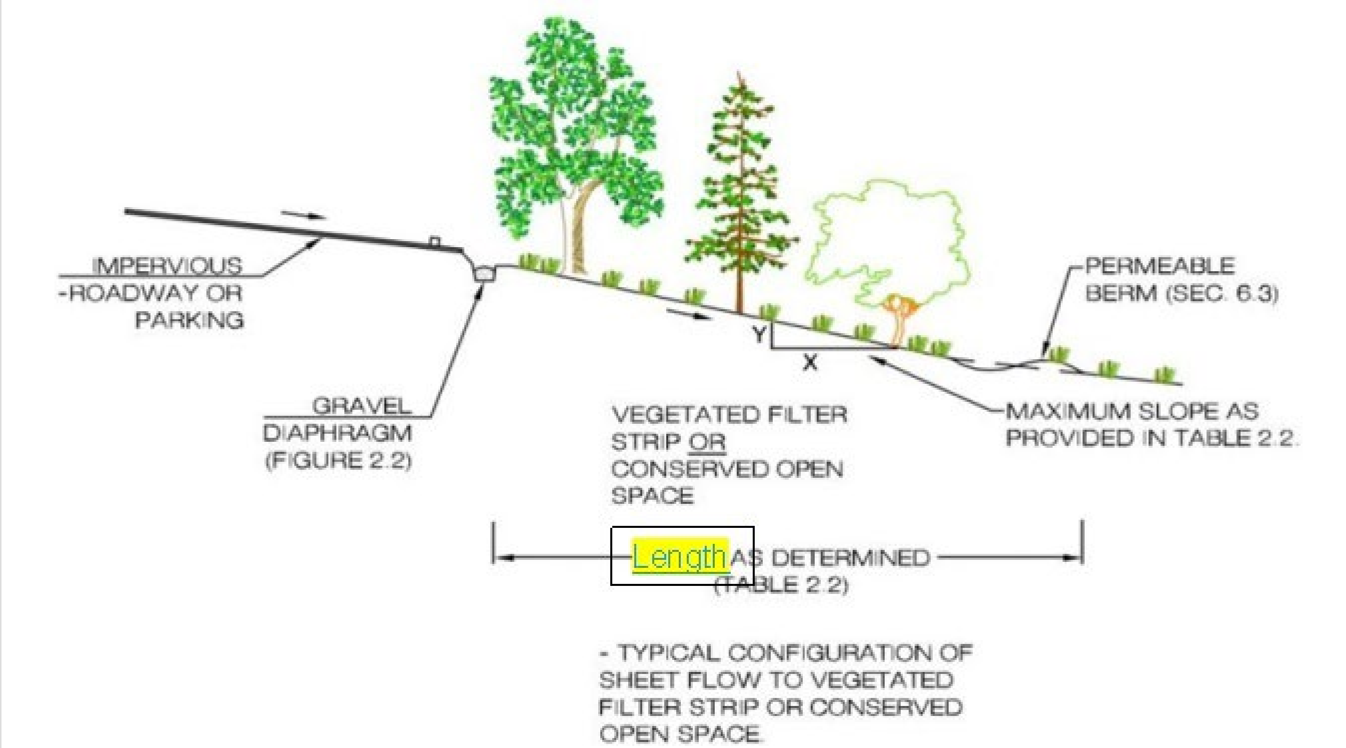


**Figure P-FIL-07-2 Gravel Diaphragm – Sheet Flow Pretreatment**

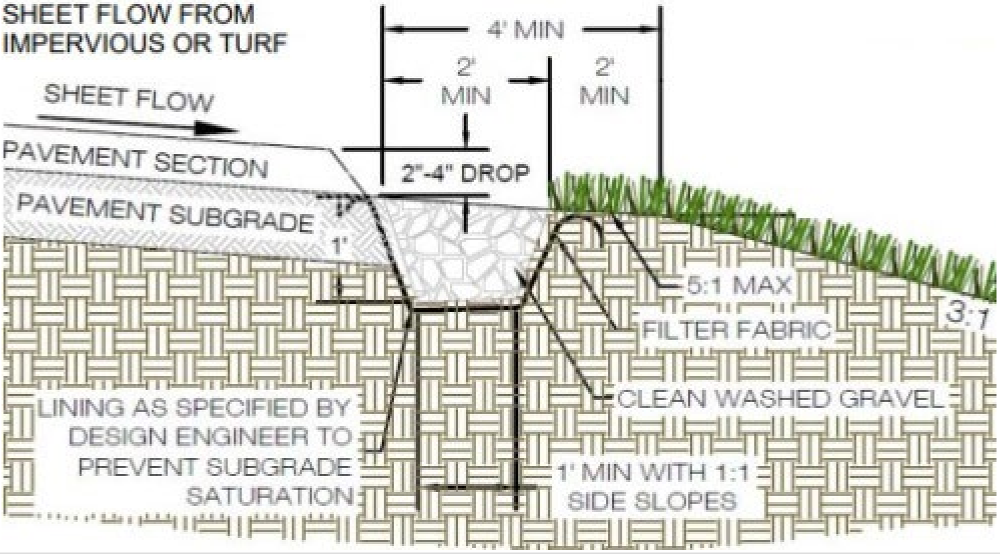



**Figure P-FIL-07-3 Plan View – Level Spreaders (Rigid Lip – top; and Earthen Lip – bottom)**

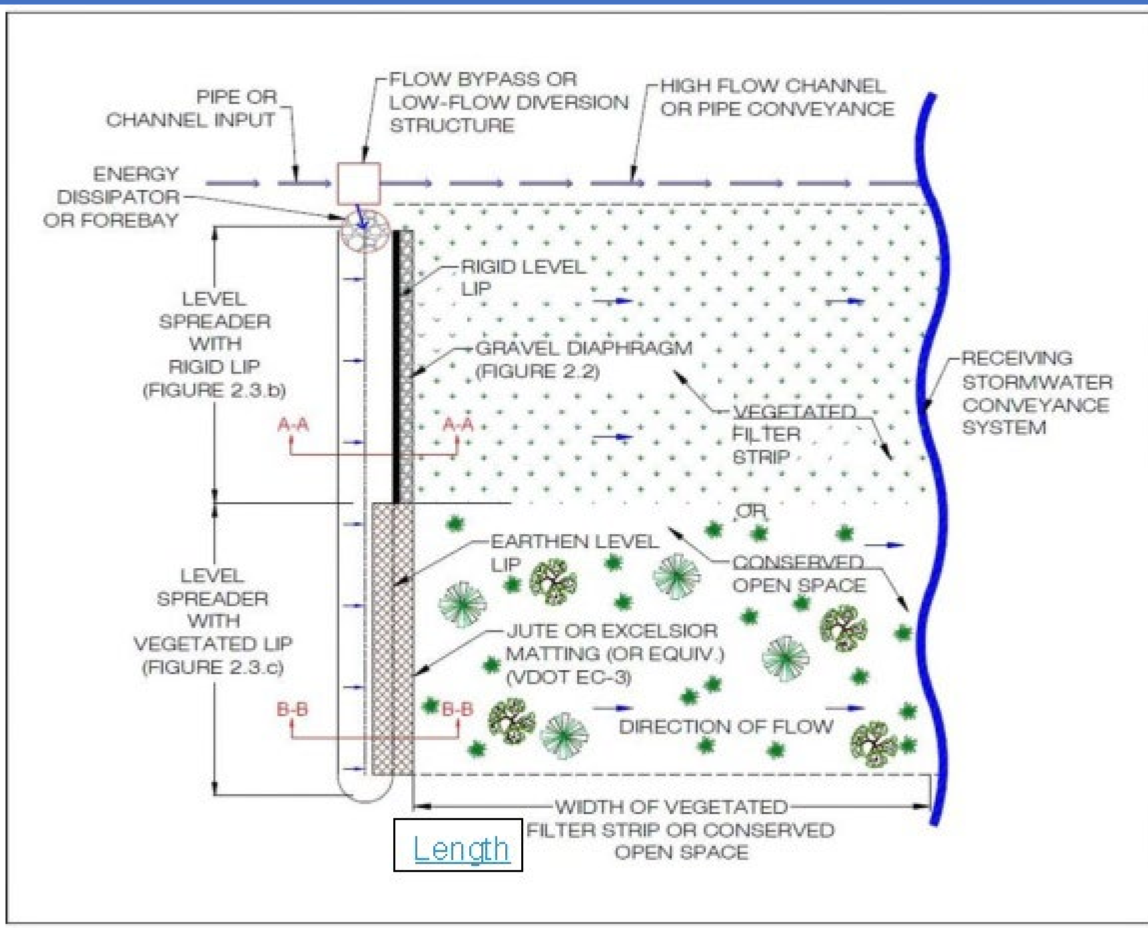
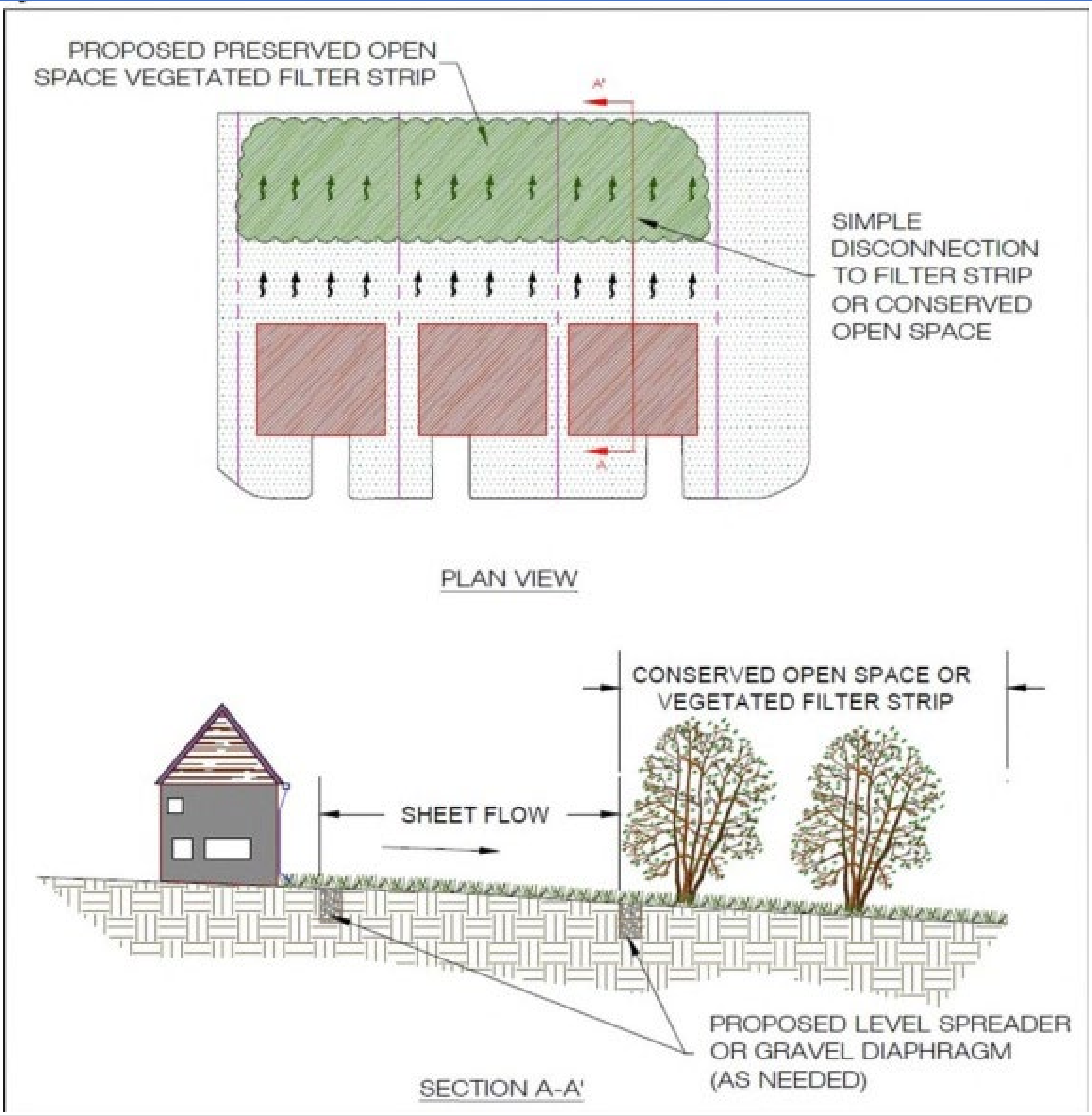


***Figure P-FIL-07-4 Simple Disconnection to downstream Conserved Open Space or Vegetated Filter Strip***




## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of vegetated filter strips, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

| Table P-FIL-07-6 Maintenance Agreements |
|---|
| **Activity** |
| All vegetated filter strips must be covered by a long-term maintenance agreement and drainage easement consistent with the provisions of VESMP Regulation to allow inspection and maintenance. |
| If the vegetated filter strip is located on a residential private lot, the existence and purpose of the filter strip shall be noted on the deed of record. |
| Property owners shall be provided a document that explains the purpose of the filter strip and routine maintenance needs. |
| A deed restriction or other mechanism enforceable by the VESMP Authority must be in place to help ensure that filter strips are maintained. |
| Conserved open space shall be protected by a perpetual easement, deed restriction, or other mechanism enforceable by the VESMP aAuthority that assigns the responsible party to ensure that no future development, disturbance, or clearing may occur within the area, except as stipulated in the vegetation maintenance plan. |
| The existence and purpose of the open space shall be noted on the deed of record, and the owners shall be provided with a simple document that explains the purpose of the open space and routine maintenance needs. |

In cases of both vegetated filter strips and conserved open space, the protective mechanism for ensuring maintenance should grant authority for local agencies to access the property for inspection or corrective action.

### 7.2 Maintenance Inspections

Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation, and level spreader repair. Ideally, inspections should be conducted in the non-growing season when it easier to see the flow path.

Inspections should check to ensure that:

- Flows through the vegetated filter strip do not short-circuit the overflow control section;
- Debris and sediment do not build up at the top of the vegetated filter strip;
- Foot or vehicular traffic does not compromise the gravel diaphragm;
- Scour and erosion do not occur within the filter strip;
- Sediments are cleaned out of level spreader forebays and flow splitters; and
- Vegetative density exceeds 90% cover in the boundary zone or grass filter.

Example maintenance inspection checklists for sheet flow to a vegetated filter strip or conserved open space areas are included in Appendix C, Soil Characterization and Infiltration Testing.

### 7.3 Ongoing Maintenance

Once established, vegetated filter strips have minimal maintenance needs outside of the spring cleanup, periodic mowing, repair of check dams, and other measures to maintain the hydraulic efficiency of the strip and a dense, healthy grass cover. Vegetated filter strips that consist of grass/turf cover should be mowed at least twice per year to prevent woody growth. Turf grass should not be cut shorter than 4 to 6 inches and can be left to grow as tall as 12 inches, depending on aesthetic requirements.

## 8.0 References

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# P-FIL-08 Soil Compost Amendment

## 1.0 Definition

Soil restoration and compost amendment is a technique that enhances compacted soils to improve their porosity and nutrient retention. It includes amending soil with compost to enhance the soil food web (or biological elements of a soil), mechanical aeration, mechanical loosening (tilling), planting dense vegetation, and applying soil amendments.

## 2.0 Purpose and Applicability of Best Management Practice

Soil restoration involves the spreading and mixing of mature compost into disturbed and compacted urban soils. These soil amendments can reduce the generation of runoff from compacted urban lawns and may also enhance the runoff reduction performance of areas that receive runoff such as downspout disconnections, grass channels, and filter strips (Table P-FIL-08-1).

Soil restoration is suitable for any pervious area in which soils have been or are expected to be compacted by grading and construction. This practice is particularly well suited when the pervious area will be used to filter runoff (downspout disconnections, grass channels, and vegetated sheet flow filter strips). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Soil restoration is recommended for sites that will be subject to mass grading, which is the removal and stockpiling of existing topsoil and replacing it on top of the newly graded (and compacted) landscape.

## 3.0 Planning and Considerations

### 3.1 Feasibility/Limitations

Soil restoration and compost amendments are not recommended where:

- Existing soils have high infiltration rates (e.g., Hydrologic Soils Group [HSG] A and B), although compost amendments may be needed at mass-graded HSG B soils in order to maintain runoff reduction rates.
- The water table or bedrock is located within 1.5 feet of the soil surface.
- Slopes exceed 10 percent (compost can be used on slopes exceeding 10 percent if proper soil erosion and sediment control measures are included in the plan). Amendments will not be used on slopes of 3:1 and steeper because an increase in soil moisture may cause slope instability (Virginia Cooperative Extension 2019).
- Existing soils are saturated or seasonally wet.
- Application would harm roots of existing trees (keep amendments outside the tree drip line).
- The downhill slope runs toward an existing or proposed building foundation.
- The contributing impervious surface area exceeds the surface area of the amended soils.
- Amendments and soil restoration can increase infiltration, which may result in groundwater contamination at hot spots such as gas stations.

Compost amendments can be applied to the entire pervious area of a development or only to select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include:

- Reduce runoff from compacted lawns (while also enhancing the long-term viability of the turf) in HSG A-D and in any compacted low permeability soil in HSG B-D.
- Increase runoff reduction for rooftop disconnections directed over otherwise poor soils.
- Increase runoff reduction within a grass channel with HSG C or D soils.
- Increase runoff reduction within a vegetated filter strip with HSG C or D soils.
- Increase the runoff reduction function of a tree cluster or reforested area of the site.
- Increase the runoff reduction function of a natural, vegetated utility right-of-way.

## 4.0 Stormwater Performance Summary

**Table P-FIL-08-1 Stormwater Functions of Soil Compost Amendments**

| Stormwater Function | HSG A and B | | HSG C and D | |
|---|---|---|---|---|
| | No CA[1] | With CA | No CA | With CA |
| Annual Runoff Reduction Volume | | | | |
| Simple Rooftop Disconnection | 50% | NA[2] | 25% | 50% |
| Filter Strip | 50% | NA[2] | NA[3] | 50% |
| Grass Channel | 20% | NA[2] | 10% | 30% |
| Total Phosphorus EMC Reduction[3] by BMP Treatment Practice | 0 | | 0 | |
| Total Phosphorus Mass Load Removal | Same as for annual runoff reduction volume | | Same as for annual runoff reduction volume | |

| Table P-FIL-08-1 Stormwater Functions of Soil Compost Amendments | | | | |
|---|---|---|---|---|
| Stormwater Function | HSG A and B | | HSG C and D | |
| | No CA[1] | With CA | No CA | With CA |
| Total Nitrogen EMC Reduction by BMP Treatment Practice | 0 | | 0 | |
| Total Nitrogen Mass Load Removal | Same as for annual runoff reduction volume | | Same as for annual runoff reduction volume | |
| Channel Protection and Flood Mitigation | Partial. Use the Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet (https://swbmp.vwrrc.vt.edu/vrrm/) to adjust the curve number for each design storm for the contributing drainage area, based on annual runoff volume reduction achieved. | | | |

**Notes:**

Source: Center for Watershed Protection (CWP) and Chesapeake Stormwater Network (CSN) 2008; CWP 2007.

CA = compost amended soils

EMC = event mean concentration

1. See BMP P-FIL-08, Soil Compost Amendment.
2. Compost amendments are generally not applicable for HSG A and B soils, although it may be advisable to incorporate them on mass-graded HSG B soils to maintain runoff reduction rates.
3. Filter strips in HSG C and D soils should use composted amended soils to enhance runoff reduction capabilities. See BMP P-FIL-07, Sheet Flow to Vegetated Filter Strip or Conserved Open Space.

### 4.1 Performance When Used in Conjunction with Other Practices

As referenced in the following specifications, soil compost amendments can enhance the runoff reduction capabilities of allied practices. The specifications for each of these practices contain design criteria for how compost amendments can be incorporated into those designs:

- BMP P-FIL-01, Rooftop Impervious Surface Disconnection;
- BMP P-FIL-02, Vegetated Roof;
- BMP P-FIL-07, Sheet Flow to Vegetated Filter Strip or Conserved Open Space;
- BMP P-CNV-01, Grass Channels;
- BMP P-FIL-09, Tree Planting

## 5.0 Design Criteria

### 5.1 Soil Testing

Soil tests are required during two stages of compost amendment. The first test is conducted to ascertain pre-construction soil properties at proposed amendment areas. The results are used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, pH, salts, and soil nutrients. One test will be conducted for every 5,000 square feet of proposed amendment area. The test results are used to characterize potential drainage problems and determine what, if any, further soil amendments are needed. A representative soil sample consists of a well-mixed composite of 10 subsamples. A soil sample from a single spot, instead of the representative sample described here, could result in inaccurate nutrient recommendations. Collect at least 10 subsamples from the uniform test area and mix them together in a clean container.

### 5.2 Determining Depth of Compost Incorporation

The depth of compost amendment is based on the relationship of the surface area of the soil amendment to the contributing area of impervious cover that it receives. Table P-FIL-08-2 presents some general guidance derived from soil modeling by Holman-Dodds (2004) that evaluates the required depth to which compost must be incorporated. The recommended incorporation depth was adjusted to reflect alternative recommendations of Roa-Espinosa (2006), Balousek (2003), Chollak and Rosenfeld (1998), and others.

**Table P-FIL-08-2 Shortcut Method to Determine Compost and Incorporation Depths**

| Parameter | Contributing Impervious Cover to Soil Amendment Area Ratio [1] | | | |
|---|---|---|---|---|
| | IC/SA = 0 [2] | IC/SA = 0.5 | IC/SA = 0.75 | IC/SA = 1.0 [3] |
| Compost (inches) [4] | 2 to 4 5 | 3 to 6 5 | 4 to 8 5 | 6 to 10 5 |
| Incorporation Depth (inches) | 6 to 10 5 | 8 to 12 5 | 15 to 18 [5] | 18 to 24 [5] |
| Incorporation Method | Rototiller | Tiller | Subsoiler | Subsoiler |

**Notes:**

IC = contributing impervious cover (square feet) and SA = surface area of compost amendment (square feet).

1. For amendment of compacted lawns that do not receive offsite runoff.
2. In general, IC/SA ratios greater than 1 should be avoided.
3. Average depth of compost added.
4. Lower end for HSG B soils, higher end for HSG C/D soils.

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed using an estimator developed by TCC 1997:

***Equation P-FIL-08-1***

$$C = A * D * 0.0031$$

Where:

C = compost needed (cubic yards).

A = area of soil amended (square feet). D = depth of compost added (inches).

### 5.3 Compost Specifications

- Compost will be derived from plant material and meet the general criteria set forth by the U.S. Composting Seal of Testing Assurance (STA) program. See www.compostingcouncil.org for a list of local providers.
- The compost will be the result of the biological degradation and transformation of plant-derived materials under conditions that promote aerobic decomposition. The material will be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost will have a moisture content that has no visible free water or dust produced when handling the material. It will meet the following criteria as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor:
  - 100% of the material must pass through a 0.5-inch screen.
  - The pH of the material will be between 5.5 and 8.5.
  - Manufactured inert material (e.g., plastic, concrete, ceramics, metal) will be less than 0.5 percent by weight.

- The organic matter content will be >35 percent.
- Soluble salt content will be less than 6.0 millimohs per centimeter (mmhos/cm).
- Compost must be mature and stable per the appropriate test(s) as specified by STA.
- Carbon/nitrogen ratio will be less than 25:1.
- Must meet United States Environmental Protection Agency (USEPA) part 503 levels for heavy metals.
- The compost should have an optimum dry bulk density ranging from 40 to 50 lbs/ft3. However, certain fully mature coarse textured composts may be lower.
- Compost should be pesticide-free.

In general, fresh manure should not be used for compost because of high bacteria and nutrient levels. If manure is used, it must be aged (composted) and meet the criteria listed above.

### 5.4 Minimum Design Criteria for Site Reforestation

Several design criteria apply when compost amendments are used as one of the methods to enhance the performance of reforested areas. Site reforestation involves planting trees on existing turf or barren ground at a development site with the explicit goal of establishing a mature forest canopy that will intercept rainfall, increase evapotranspiration rates, and enhance soil infiltration rates. Reforestation areas at larger development sites (and individual trees at smaller development sites) are eligible under the following qualifying conditions.

- The minimum contiguous area of reforestation must be greater than 5,000 square feet.
- A long-term vegetation management plan must be prepared and filed with the local review authority in order to maintain the reforestation area in a natural forest condition.
- The reforestation area must be protected by a perpetual stormwater easement or deed restriction which stipulates that no future development or disturbance may occur within the area.
- Reforestation methods must achieve 75 percent forest canopy within 10 years.
- The planting plan must be approved by the appropriate local forestry or conservation authority including any special site preparation needs.
- The construction contract should contain a care and replacement warranty extending at least three growing seasons to ensure adequate growth and survival of the plant community.
- The reforestation area will be shown on all construction drawings and Erosion and Sediment Control Plans during construction.
- A minimum compost incorporation depth of 18 inches is required for reforestation areas where trees and shrubs are being planted.

### 5.5 Minimum Design Criteria for Linear Utility Site Restoration to a Natural Vegetated State

Several design criteria apply when compost amendments are used to return a disturbed linear utility site to a natural, vegetated state. Site restoration involves restoring the soils to a hydrologically functional state that will mimic the natural, undisturbed condition. Restoration for linear utility projects (not individual utilities included in larger development sites) are eligible to be considered an open space for post-development land cover condition under the following qualifying conditions.

- A long-term vegetation management plan (including being bushhogged no more than four times per year) must be prepared and filed with the local review authority in order to maintain the restored area in a natural, vegetated condition.
- The restored linear utility area must be protected by deeded operation and maintenance agreements and plans, third-party protective easement, deed restriction, or other document approved by the Virginia Stormwater Management Program (VSMP) authority. This component may

include coordination and joint agreement with landowners to ensure the area will remain in a natural, vegetated state until an amended Stormwater Management Plan is approved for the site.

- The construction plans detail the removal and reclamation of all temporary structures, roads, pads, and how those areas will be returned to a hydrologically functional state.
- Restoration methods must achieve 90 percent ground cover with the first year.
- The restoration area will be shown on all construction drawings and Erosion and Sediment Control Plans during construction.

**5.6 Regional and Special Case Design Adaptations**

| Table P-FIL-08-3 Regional and Special Case Design Adaptations | |
|---|---|
| **Condition** | **Details** |
| Karst Terrain | No special adaptations are needed in karst terrain, but the designer should take soil tests to ensure that soil pH is adjusted to conform to pre-existing soil conditions found in limestone dominated areas. |
| Coastal Plain Terrain | Designers should evaluate drainage and water table elevations to ensure the entire depth of soil amendment will not become saturated (i.e., a minimum separation depth of 1.5 feet from groundwater). Compost amendments are most cost-effective when used to boost the runoff reduction capability of grass vegetated filter strips, grass channels, and rooftop disconnections. |
| Steep Terrain | Compost amendments are ineffective when longitudinal slopes exceed 10%; therefore, some terracing may be needed on steeper slopes. Compost amendments should not be used when slopes exceed 3:1. |
| Cold Climate and Winter Performance | Soil restoration is not recommended for areas that will be used for snow storage. |
| Linear Highway Sites | Soil amendments can improve the runoff reduction of grass channels and filter strips in open section of rights-of-way and highway medians. |
| Linear Utility Sites | Soil amendments can restore disturbed areas within utility easements or rights-of- way that are to remain in a natural, vegetated state and be considered “open space” to a functionally hydrologic state. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence for Soil Compost Amendment

The construction sequence for compost amendments differs depending on whether the practice will be applied to a large area or a narrow filter strip such as in a rooftop disconnection or grass channel. For larger areas, a typical construction sequence is as shown in Table P-FIL-08-4.

| Table P-FIL-08-4 Construction Sequence for Soil Compost Amendment | |
|---|---|
| **Step** | **Details** |
| Step 1 | To help minimize compaction, heavy vehicular and foot traffic should be kept out of all restored pervious areas during and after construction. This can typically be accomplished by clearly delineating soil restoration and compost amendment areas on all development plans and, if necessary, protecting them with temporary construction fencing. |
| Step 2 | For large areas of soils to be restored (typically with an IC/SA less than 0.5 ): after the area has been cleared of construction activity, the area should be deep tilled to a depth of 2 to 3 feet using a tractor and subsoiler with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. This establishes a vertical pathway for the compost to influence microbial activity into the adjacent soil. (This step may be omitted when compost is used for narrower filter strips.) |
| Step 3 | Spread the specified compost depth in accordance with Table P-FIL-08 across the surface and incorporate into the soil using a rototiller, tiller, or subsoiler as specified. It is important to have dry conditions at the site prior to incorporating compost. |
| Step 4 | To limit soil erosion and sediment loss, landscaping should be installed immediately after the soil restoration and amendments have been completed. The site should be leveled and seed or sod used to establish a vigorous grass cover. Lime and/or temporary irrigation may initially be needed to help the grass grow quickly. |
| Step 5 | Areas of compost amendments exceeding 2,500 square feet should employ simple erosion control measures, such as silt fence or diversions, to reduce the potential for erosion and trap sediment. |

### 6.2 Construction Inspection

Construction inspection involves digging a test pit to verify the depth of mulch, amended soil, and scarification. A rod penetrometer should be used to establish the depth of uncompacted soil at one location per 10,000 square feet. The test pits will be used to verify that the compost amendments have reached the required incorporation depth.

Upon final inspection and acceptance, log the filtering soil compost amendment practice's global positioning system (GPS) coordinates and submit them for entry into the local best management practice (BMP) maintenance tracking database.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of the BMP, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

The long-term maintenance requirements for soil amendments are minor compared with many other BMPs; however, the following items should be addressed as part of a long-term maintenance program for amended soils:

- When soil amendments are applied on private residential lots, homeowners should be educated on the long-term performance goal and any routine maintenance needs that will ensure continued performance.
- It will be the responsibility of the VESMP Authority to identify through the local ordinance what type of Maintenance Agreement, deed restriction, or other mechanism, if any, will be required where soil amendments are applied across the graded portions of residential lots to reduce runoff at the site scale.
- Where soil amendments are applied to specific runoff reduction practices, the presence and purpose of the soil amendments must be identified within the required Maintenance Agreement, maintenance plan, and applicable enforcement mechanism for those practices.
- In all cases, the mechanism should grant authority for local agencies to access the property for inspection or corrective action, especially where the application of soil amendments has been credited in lieu of a structural BMP.

In cases of soil restoration associated with more than 10,000 square feet of reforestation, a simple Maintenance Agreement, along with a conservation easement and/or deed restriction, which also identifies a responsible party, may be required to make sure the newly developing forest cannot be cleared or developed and appropriate management is accomplished (i.e., thinning, invasive plant removal).

Soil compost amendments within a filter strip or grass channel should be located within a dedicated stormwater or drainage easement or in a public right-of-way as required by the specifications for those individual practices.

### 7.2 First Year Maintenance Operations

In order to ensure the success of soil compost amendments, the tasks outlined in Table P-FIL-08-5 must be undertaken in the first year following soil restoration.

**Table P-FIL-08-5 Operations and Maintenance Schedule**

| Activity | Details |
|---|---|
| Initial inspections | For the first 6 months following the incorporation of soil amendments, the site should be inspected at least once after each storm event that exceeds 0.5 inch of rainfall. |
| Spot Reseeding | Inspections should note bare or eroding areas in the contributing drainage area or around the soil restoration area and ensure that they are immediately stabilized with grass cover. |
| Fertilization | Depending on the findings of a soils test of the amended area, a one-time spot fertilization may be needed in the fall after the first growing season to increase plant vigor. |
| Watering | Water once every 3 days for the first month and then weekly during the first year (April through October) depending on rainfall. |

### 7.3 Ongoing Maintenance

- Dethatch and aerate turf and mulching bed areas to increase permeability as needed.
- Consider temporary irrigation during extreme droughts to keep vegetation healthy.

The owner should also be aware that there are maintenance tasks needed for filter strips, grass channels, and reforestation areas. An example maintenance inspection checklist for an area of soil compost amendments is provided in Chapter 10, BMP Inspection and Maintenance.

## 8.0 References


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# P-FIL-09 Tree Planting

## 1.0 Definition

Tree plantings as a pollution-reduction practice pertain to new, individually planted trees on developed land. Credited area only accounts for precipitation that falls on the tree canopy area. Additionally, this measure does not require a specific soil media be used.

## 2.0 Purpose and Applicability of Best Management Practice

Because of their hydrological and biological functions, tree plantings reduce stormwater runoff and improve local water quality. They perform these functions through interception, throughfall, infiltration, transpiration, and absorption.

Tree plantings provide pollution reduction credit for every new, individually planted tree on developed land. The trees do not need to be planted in a contiguous area and are not intended to produce forest-like conditions.

Trees cannot recieve credit as a best management practice (BMP) when:

- Planted to replace others that are removed through land disturbance;
- Planted to meet planning requirements, or any other local, state, or federal requirements;
- Financed through local, state, and federal programs
- Planted to meet water quality requirements through the Virginia Runoff Reduction Method (VRRM) as forest or mixed open land cover, or as part of other BMPs (e.g., urban bioretention, sheet flow to a vegetated filter strip, manufactured treatment devices).

Regarding treatment trains, when runoff flows through tree plantings flow into downstream practices within the contributing drainage area (CDA), the canopy area should be entered into the VRRM spreadsheets in the tree planting input fields and be excluded from the CDA of the BMP to which they flow. Any remaining runoff volume and nutrient loads will be computed in the treatment train features of the VRRM spreadsheets. Tree plantings cannot be used downstream of other BMPs.

## 3.0 Planning and Considerations

Tree plantings can be used at commercial, institutional, and residential sites. Like bioretention and other post-construction stormwater BMPs, they are typically planted in parking lot islands and edges; road medians, roundabouts, interchanges, and cul-de-sacs; rights-of-way or commercial setbacks; courtyards; and/or residential properties.

## 4.0 Stormwater Performance Summary

There are two subclasses to tree plantings including tree canopy over pervious and tree canopy over impervious. Each new tree planted for this design specification is eligible for a credit area of 144 square feet ($ft^2$), which equals 300 trees per acre.

**Table P-FIL-09-1 Summary of Stormwater Functions Provided by Tree Plantings**

| Stormwater Function | Tree Canopy Over Pervious[1] | | Tree Canopy Over Impervious |
|---|---|---|---|
| | HSG A/B | HSG C/D | |
| Annual Runoff Reduction Volume | 16.0% | 12.0% | 3.5% |
| Total Phosphorus Event Mean Concentration (EMC) Reduction by BMP Treatment Process | 0 | 0 | 0 |
| Total Phosphorus Mass Load Removal | 16.0% | 12.0% | 3.5% |
| Total Nitrogen EMC Reduction by BMP Treatment Process | 0 | 0 | 0 |

| Table P-FIL-09-1 Summary of Stormwater Functions Provided by Tree Plantings | | | |
|---|---|---|---|
| Stormwater Function | Tree Canopy Over Pervious[1] | | Tree Canopy Over Impervious |
| | HSG A/B | HSG C/D | |
| Total Nitrogen Mass Load Removal | 16.0% | 12.0% | 3.5% |

**Notes:**

Source: Adapted from Hynicka and Divers 2016.

See Appendix A, Runoff Reduction Computation Methodology for Tree Planting Over Turf (located at the end of this specification).

## 5.0 Design Criteria

The design criteria for tree planting are summarized in Table P-FIL-09-2. Additional detail is included in the subsequent text.

| Table P-FIL-09-2 Summary of Design Elements for Tree Plantings | |
|---|---|
| **Design Element** | **Design Summary** |
| **Credit** | |
| Credit Area | 1 new tree = 144 $ft^2$ based on the average area under the canopy from the drip line to the tree trunk. No CDA is allowed. |
| **Site Assessment Design Elements** | |
| 1-Site Information | Include information about location, property owner, and current land use. |
| 2-Climate | Determine U.S. Department of Agriculture (USDA) Plant Hardiness Zone, sunlight exposure, and any microclimate features. |
| 3-Topography | Identify steep slopes and low-lying areas within the development site. |
| 4-Tree Inventory | Submit a pre-development tree inventory to the Virginia Stormwater Management Program (VSMP) authority. |
| 5-Soil Testing | Perform soil tests to determine texture, drainage, compaction, pH, soil chemistry, seasonal high-water table, and other soil features. |
| 6-Site Hydrology | Determine runoff to and from the tree planting area (include floodplain connections if in a riparian area). |
| 7-Potential Planting Conflicts | Identify the presence of potential planting conflicts (space limitations, setbacks, hot spots, sight lines, bedrock, etc.). |
| 8-Planting and Maintenance Logistics | Document logistical factors impacting tree survival and future maintenance needs (site access, water source, party responsible for maintenance). |
| 9-Pre-development map | Develop site map that includes features found during the site assessment. |
| **Site Preparation Design Elements** | |
| Soil Amendments | Amend as needed based on soil analysis. |

| Table P-FIL-09-2 Summary of Design Elements for Tree Plantings | |
|---|---|
| **Design Element** | **Design Summary** |
| Species Selection | Refer to a qualified professional such as a Virginia Experienced Forester, Virginia Licensed Landscape Architect, Certified Virginia Nursery and Landscape Association (VNLA) Horticulturalist, or ISA Certified Arborist. Use the findings of the site assessment and consider the space needed by the tree at maturity. |
| Tree Selection | Comply with the American Standard for Nursery Stock (ANSI 2014) minimum of 6 to 8 feet in height and/or 1 to 1½ inches diameter breast height (DBH). |
| Planting Plan | Developed by a VNLA Certified Horticulturalist, Landscape Architect, or Certified Landscape Designer. |
| **Planting Design Elements** | |
| Tree Planting Logistics | Prepare to obtain and/or store trees and associated materials. |
| Substitutions | Substitutions that differ from the approved plan need to be signed off by the professional and resubmitted to the VSMP authority. |
| Planting Techniques | Follow planting procedures of ANSI A300 Part 6 (Planting and Transplanting) and/or American Association of Nurserymen (AAN) standards. |
| Steep Slopes | Stabilize steep slopes until vegetation is established and create terrace for new tree plantings if needed. |
| Soil Enhancement | Add fertilizer or compost to backfill if needed based on the soil analysis. |
| Mulch | Follow mulching procedures of ANSI A300 Part 6 (Planting and Transplanting). |
| Tree Protection | Install tree stakes, fencing, and signage as needed based on AAN standards. |
| **Post-planting Design Elements** | |
| As-Built Requirements | Requires certification to verify BMP install per the approved plan. |
| Inspection | Have qualified professional perform inspections after initial planting. |
| Tree Replacement | Notify the VSMP authority if a tree replacement is needed. |
| Maintenance | Requires a tree maintenance plan. |
| Maintenance Agreement | Requires a deeded maintenance agreement. |

### 5.1 Credit

#### 5.1.1 Credit Area

The drainage area of the tree includes the precipitation that falls within the 144 $ft^2$ delineated tree canopy area.

The water quality credit area for each newly planted tree equals 144 $ft^2$ when planted within pervious landcover. The water quality credit provided does not include stormwater runoff from surrounding areas that flow into the canopy coverage area of the newly planted tree. Credit is not provided for new trees planted to replace trees within the development site that were removed as part of the overall development plan.

Note that water quantity run-on to the canopy land use area (i.e., 144 $ft^2$) must be considered in terms of localized erosion issues and potential overwatering.

**5.2 Site Assessment Design Elements**

To effectively use trees as a stormwater BMP, a site assessment must be performed. The site assessment may be based on the Urban Reforestation Site Assessment (URSA) as described in the Urban Watershed Forestry Manual -- Part 3. Urban Tree Planting Guide. The purpose of performing the assessment is to help determine what tree species will thrive at the site and identify site conditions that need to be improved. The nine site elements of the URSA include:

1. **General Site Information** – Include information about the location, and property owner at the site.

   Location: Describe the site location, being as specific as possible, and using a consistent system for identifying planting sites. The description may include noting the site address, nearest cross streets, GPS coordinates, page and grid of area map, subwatershed name, name of site, specific site identification, or all of these.

   Property Owner: Provide the name of the property owner and contact information.

2. **Climate** – Use climate data to help select tree species.

   USDA Plant Hardiness Zone: Determine the plant hardiness zone, which is based on the average lowest temperatures for the region and can be found using the USDA Plant Hardiness Zone Map (https://planthardiness.ars.usda.gov/).

   Sunlight Exposure: Determine how much sun is received in the planting area during the growing season: full sun (> 6 hours of direct sunlight), partial sun (<6 hours of full sunlight but receives filtered light for most of the day), or shade (<6 hours of filtered light). Identify tall structures that may block sunlight.

   Microclimate Features: Microclimates are fine-scale climate variations, such as windy areas or small heat islands caused by asphalt and concrete. If either of these microclimate factors exist in the planting area, select tree species that are tolerant of drought.

3. **Topography** – Identify local topographic features that may present planting difficulties.

   Steep Slopes: Note the presence of any steep slopes (typically defined as greater than 15%) that can make access difficult for planting and may require special planting techniques. Species planted on slopes should be more resistant to drought, as they will dry out faster. Also, special care should be taken not to disturb slopes during site preparation and planting, to prevent soil erosion.

   Low-Lying Areas: Note the presence of any low-lying areas and mark them on the site map. Trees can be planted in low-lying areas and used to treat stormwater runoff, provided the species selected are tolerant of some standing water.

4. **Tree Inventory** – Conduct a tree inventory.

   The tree inventory should document the trees present on the development site prior to development. For each tree in the inventory, record the species, its DBH (in inches), and height (in feet). Mark the location of each tree on the site map. Indicate which trees will be preserved during construction. Submit the inventory as part of the plan set.

5. **Soil Testing** – Soil testing is required within the planting site. The soil test procedures are available in BMP P-FIL-04, Infiltration Practices.

The results of the soil tests determine if soil amendments or tilling will be needed. The results of the soil test combined with the physical characteristics of the site will be used to select appropriate tree species. Periodic soil testing may be necessary if the health of the tree becomes an issue.

Soil testing is performed to determine porosity (amount of available pore space), permeability (how interconnected pore spaces are), and infiltration rate (how quickly the water moves through the soil). These soil properties affect the amount of air, moisture, and nutrients that are available in the root zone and how much runoff is absorbed into the ground instead of flowing over the ground.

Some soil properties of importance include the following:

- Texture: Soil texture (such as loam, sandy loam, or clay) refers to the proportion of sand, silt and clay sized particles that make up the mineral fraction of the soil.
- Drainage: Evaluate the soil drainage to help select tree species that are tolerant of the site drainage conditions. Soil drainage can generally fall into one of three categories: poor, moderate, or excessive. Soils with grey mottling or have a foul odor are also indicators of poor drainage.
- Compaction: Evaluating soil compaction is necessary to determine if tillage and compost are needed. A bulk soil density test performed in a soiltesting lab can be used to determine soil compaction.
- pH: Evaluating soil pH is important so that tree species that are tolerant of the soil pH may be chosen
- Soil Chemistry: A soil analysis can be used to identify specific nutrient, organic matter, and mineral deficiencies, or confirm soil contamination. Soil samples may be sent to a lab to be analyzed for organic matter content, salt content, and availability of key nutrients such as phosphorus, potassium, calcium, and magnesium.
- Seasonal High-Water Table: Identify if the planting area is in an area with a seasonal high-water table, which will impact species selection.
- Other Soil Features: Record active or severe erosion, potential soil contamination, recent construction or soil disturbance, debris or rubble in soil, or other unusual soil conditions in the planting area. If erosion is present, note the extent and severity of erosion. If a site is suspected of contamination, further investigation should be conducted before proceeding with the project (e.g., research the site history, consult with landowner, conduct an environmental site assessment, pursue cleanup options). If soils are very disturbed, amendments may be needed, or it may be necessary to bring in new soil.

6. **Hydrology** – It is important to understand the hydrological conditions of the development site in its predevelopment condition to determine potential drainage conditions that may impact the proposed planting area(s). Also, understanding the site hydrology is needed for tree selection.

   Site Hydrology: Note whether the planting area is an upland or riparian site.

   Storm Water Runoff to Planting Site: Document any types of stormwater runoff that flow to the planting site. Stormwater may enter the planting site from a pipe, open channel, or as sheet flow.

   Floodplain Connection (Riparian Areas Only): If the planting area is riparian, note the presence of levees or other structures that restrict flood flows onto the floodplain, and the bank height. In such areas, upland species may be more suited to the hydrology of the site than floodplain species.

7. **Potential Planting Conflicts** – Identify the presence of potential planting conflicts to define specific planting locations, select tree species, or identify special methods to improve the growing environment.

   Space Limitations: Note the presence of aboveground or belowground space limitations, such as overhead wires, pavement, structures, signs, lighting, existing trees, or underground utilities.

Local Ordinance Setbacks: Record setbacks between trees and infrastructure that are mandated by local ordinance or utility. Check with local utility companies to determine their clearance requirements.

Hot Spots: The tree canopy area (144 ft2) cannot receive stormwater from hot spot areas.

Sight lines**:** When considering a location for planting, clear lines of sight must be provided.

Bedrock: Tree root growth can be restricted by the presence of bedrock within the planting area.

Other Limiting Factors: Document other potentially limiting factors such as nearby sidewalks or roads that could contribute runoff containing deicing salts and other pollutants, trash piles and debris, animal impacts (deer, beaver), mowing conflicts, presence of wetlands, insects or disease, or heavy pedestrian traffic. These factors will need to be addressed before planting.

8. **Planting and Maintenance Logistics** – Planning needs to include logistical factors that may influence tree survival and future maintenance needs.

Site Access: Determine access to the site for the delivery of planting material and equipment used for planting and maintenance.

Water Source: Note the presence and type of water sources since newly planted trees must be watered regularly the first year or two after planting. The existence of a nearby water source for irrigation makes this critical maintenance task much easier.

Party Responsible for Maintenance: Identify the party responsible for maintenance. They will need to know the maintenance schedule and proper maintenance techniques.

9. **Pre-development Site Map** – The site map should include the following:

- Site boundary, landmark features (e.g., roads, streams) and adjacent land use and cover
- Location of proposed planting area
- Identify climatic features within the proposed planting area, e.g., sun exposure, microclimate.
- Typography: Indicate areas with steep slopes or depressions.
- Current vegetative cover: indicate trees to be removed during development, preserved trees, and invasive species
- Location and results of soil samples
- Flow paths to planting area, location of outfalls
- Above or below ground space limitations (e.g., utilities, structures)
- Other limiting factors (e.g., trash dumping, pedestrian paths)
- Water source and access points
- Scale and north arrow
- Conditions that impact tree species selection,such as pests or other natural factors/diseases (e.g., blight, molds, fungus, insects).

### 5.3 Site Preparation Design Elements

The site preparation phase considers the findings of the site assessment. This phase is important to help with the success of the new tree plantings as a BMP.

- **Soil Amendments** – Soils on developed lands often need to be amended to support healthy trees. Compost is often used to increase soil organic matter, decrease bulk density, improve drainage, provide nutrients, and increase water and nutrient holding capacity. Peat amendments can also increase organic matter and water and nutrient holding capacity, in addition to increasing acidity.

Other amendments include gypsum, which can be added to urban soils to decrease soil sodicity; limestone, which is used to decrease soil acidity; and sulfur, which increases soil acidity. Soil compaction, pH, and drainage should be evaluated at the planting site to determine the need for soil amendments. Refer to BMP P-FIL-08, Soil Compost Amendment, and BMP P-FIL-04, Infiltration Practices.

- **Species Selection** – Tree species selection is dependent upon site conditions as determined in the site assessment. A qualified professional. should select native tree species suitable for the planting site.

  To ensure that the selected tree species is suitable for the available space and desired use of the site at maturity, consider the following:

  - The mature height and spread of trees will not interfere with proposed or developed structures and overhead utilities.
  - The root development will not interfere with walls, sidewalks, driveways, patios, and other paved surfaces or affect water and sewer lines, septic systems, or underground drainage systems.
  - Selected tree species should be tolerant of de-icing salts if there is a chance these will be used near the planting site.
  - Plant native trees, if possible, because they are adapted to growing in local climatic conditions and may require fewer pesticides and fertilizers. To help planners and designers avoid selecting invasive species, the Virginia Department of Conservation and Recreation maintains a list of invasive species on their website at https://www.dcr.virginia.gov/natural-heritage/invsppdflist (DCR 2022).

- **Tree Selection** – All trees must comply with the American Standard for Nursery Stock (ANSI 2014). All new trees shall be a minimum of 6 to 8 feet in height or 1 to 1½ inches DBH. Planting larger tree stock should help attain the desired stormwater management goals more rapidly, although it should be noted larger trees can be more difficult to establish.

  All selected tree stock should be grown within a similar region as the planting site to be adapted to local climate variability.

  Individual trees should be inspected to ensure they are of high quality. The following are important factors in selecting nursery trees:

  - Healthy well-balanced crown
  - Straight trunk or trunks that meet the planting plan specification for single or multi-stem trees
  - No sign of disease or insects
  - No significant wounds or scars from pruning
  - Branches evenly distributed along trunk
  - Minimal to no circling roots

- **Planting Plan** – The planting plan should be prepared by a qualified professional and needs to contain the following elements:
  - Post-development site layout and proposed site grading
  - List of trees to be planted, include common name, botanical name, size and planting location (include allowed substitutions of species)
  - Tree stock to be ordered, sources of trees, when to order trees & plant trees, planting warranty.
  - Post-nursery care and initial maintenance requirements
  - Identification of water source
  - Description of post-planting tree protection

### 5.4 Planting Design Elements

- **Tree Planting Logistics** – The recommended planting season runs from October through March. Container-grown and balled-and-burlapped (B&B) trees can be planted from October through mid-December. However, trees should not be planted when the ground is frozen.

  Determine the best places to purchase plant materials and plan for ordering and purchase. Availability is usually related to the type of plant material and the species. Place orders early to ensure the availability of the species and stock desired. Trees need to be inspected to ensure they are in good condition.

  If trees are not planted immediately, a temporary storage location must be identified. Proper storage and preparation of plant materials before planting is essential to ensure that new trees will establish and thrive. After receiving trees, they should be kept covered, shaded, and moist or watered until placed in the ground. The root balls of B&B stock should be thoroughly watered and kept moist with a covering of peat moss, straw or saw dust until planted. When moving B&B stock and container trees, the root ball should always be supported (never pick it up by the trunk).

- **Substitutions** – The trees that are planted shall be of the species and size specified on the approved plans. If a substitution is necessary that differs from the approved plan, it should be signed off by the professional and resubmitted to the VSMP authority.
- **Planting Techniques** – Follow Part 6 of the American National Standard for Tree Care Operations – Tree, Shrub, and Other Woody Plant Management – Standard Practices (Planting and Transplanting) (ANSI A300).

  Once the plant is placed in the hole, the top of the roots or root ball should be level or slightly above level with the surface of the ground. It is generally better to plant the tree a little high, that is, with the base of the trunk flare 2 to 3 inches above the soil, rather than at or below the original growing level.

  If the soil for backfilling contains too much rock or construction debris, screen soil or replace it with local topsoil. When the hole is about three fourths refilled, straighten and level the tree. Use water to settle the backfill or tamp lightly. Water heavily and fill the hole with backfill to its original level. Remove all wires, or ropes from the stems or trunk to prevent them from strangling the tree as it grows. Trees must be watered well after planting.

- **Steep slopes** – Steep slopes require additional measures to ensure planting success and reduce erosion, especially if the slope receives stormwater runoff from upland land uses. Depending on the steepness of the slope and the runoff volume, rill or gully erosion may occur on these slopes, requiring a twofold approach: controlling the stormwater and stabilizing the slope.

  Erosion control blankets are recommended to temporarily stabilize soil on slopes until vegetation is established. Erosion control fabrics come in a variety of weights and types and should be combined with vegetation establishment such as seeding. Other options for stabilizing slopes include applying compost or bark mulch, or sodding

- **Fertilization** – Fertilization is usually not needed for newly planted trees. If needed, follow the recommendations of the American National Standards Institute (ANSI A300 Part 6). Use only fertilizer that contains the nutrients needed, and do not apply an excess amount of fertilizer.
- **Mulch** – The ground under the canopy area for each newly planted tree needs to be covered with organic mulch. Mulch protects the plants from temperature extremes, maintains soil moisture, prevents erosion, increases infiltration, helps control weeds, and adds organic matter. If planting a cluster of trees, mulch the entire planting area. Use slow-decomposing organic mulches, such as shredded bark, compost, leaf mulch, or wood chips (grass clippings and sawdust are not recommended for use as mulch). Mulch should be applied near, but not touching, the trunk and spread out to the perimeter of the planting. Refer to ANSI A300 (American National Standard for

Tree Care Operations – Tree, Shrub, and Other Woody Plant Management –Standard Practices [Part 6: Planting and Transplanting]) for specifics on proper mulching techniques.

- **Tree Protection** – Follow the procedures outlined in the American National Standards Institute (ANSI A300 Part 6: Planting and Transplanting).
    - Stakes: Trees may require temporary support from stakes and guy-lines, but this support should only be utilized with top-heavy trees, in windy environments, or when recommended by an arborist. If staking is necessary for support, use three stakes in conjunction with a flexible tie material to hold the tree upright while minimizing injury to the trunk. Keep slack in the tie material to provide flexibility. To prevent damage to the root ball, stakes should be placed in undisturbed soil beyond the outer edges of the root ball. Remove support staking and ties within a year of planting.
    - Fencing: Fencing can be used to help prevent damage from animals (deer, beavers) and mowers. Use fencing material with openings that are sufficient to prevent unwanted access to the tree. Fencing should be at least 3' high to protect trees from beavers and will need to be higher to prevent deer browsing. Place fencing an appropriate distance from the tree trunk as needed to meet the desired purpose.
    - Signage: Development sites in highly visible areas (e.g., school yards, parks, urban settings, government buildings) that utilize newly planted trees as a BMP should have a marker to indicate the water quality purpose. The sign should also state that the trees are not to be disturbed except for authorized maintenance.

### 5.5 Post-Planting Design Elements

- **As-Built Requirements** – After the new trees have been planted, the owner/developer must have an as-built certification. The as-built certification verifies that the BMP was installed per the approved plan. Supporting documents such as invoices and compost certification should be provided.
- **Inspection** – Tree inspections are to be performed by professionals who can diagnose tree health. An inspection schedule should be created for each site.

Initial planting inspection: Each tree should be inspected for proper planting and post-planting protection immediately after initial planting. New trees must have a species identification tag from the nursery at the time of inspection. Tags shall be removed after inspection to prevent girdling. The initial planting inspection should consider the quality of the woody plant material, planting installation, and growing conditions. Ensure trees are correctly spaced and planted according to the planting plan and are free from conflicts, etc. Address points from the Initial Inspections column in Table P-FIL-09-3 below.

Short-term Inspection (3 months-1 year): After the initial planting, trees should be inspected at least once before the warranty period expires. Trees should be inspected after major storm events to check for any damage that may have occurred. The inspection should assess points from the Short- and Long-term Inspections column in Table P-FIL-09-3 below.

| Table P-FIL-09-3 Inspection Checklists | |
|---|---|
| **Initial Inspection** | **Short- and Long-term Inspections** |
| Assess tree health. | Assess tree vigor and overall health. |
| Determine that planted tree species are those in the planting plan. | Determine if pruning is needed for damaged, dead, or diseased branches. |
| Ensue trees are spaced and planted according to the planting plan. Inspect that trees are planted at the correct height. | Inspect trees for signs of insect damage and disease. |
| Ensure stakes are installed properly (if needed). | Evaluate if additional mulch is needed. |
| Assess that mulch has been properly applied around trees. | Determine if stakes need to be adjusted or removed. |
| Check that trees have been well watered. | |
| Assess that trees are free from conflicts. | |
| Source: Adapted from Cappiella et al. 2006. | |

- **Tree Replacement** – If a tree is dying or dies, notify the VSMP authority. A new tree needs to be planted during the next appropriate planting period (spring/fall) from the time of death and needs to be planted in an appropriate location. Perform an assessment to determine the reason for the decline in health and use this information when selecting the new replacement tree.
- **Maintenance** – Regular maintenance will help ensure establishment and success of newly planted trees as a BMP. Maintenance includes activities such as watering, removing temporary supports, controlling weeds and pests, and pruning. A potential source of water would include a rain tank system (*See* BMP P-BAS-04 Rainwater Harvesting). Watering is generally needed for the first three years and then only during periods of drought. All pruning of branches should be done according to proper American National Standards Institute recommendations (ANSI A300 Part 1: Tree, Shrub, and Other Woody Plant Maintenance – Standard Practice, Pruning).

| Table P-FIL-09-4 Example Inspection and Maintenance Schedule | | | | | |
|---|---|---|---|---|---|
| **Inspection and Maintenance Activity** | **Year 1** | | **Year 3** | | **Year 5+** |
| Regularly inspect tree health and survival. | X | X | X | X | X |
| Water trees. | X | X | X | | |
| Remove any supporting stakes and guywires. | | X | | | |
| Implement invasive species and noxious weed control as needed. | X | X | X | X | X |
| Prune damaged, dead, or diseased branches. | | X | X | X | X |
| Implement integrated pest management methods as needed. | X | X | X | X | X |
| Remove trash and fallen branches from area. | X | X | X | X | X |
| Remove any limbs damaged in storms that might pose a danger. | X | X | X | X | X |
| Source: Adapted from Cappiella et al. 2006; originally derived from Hairston-Strang (2005) and Palone and Todd (1998). | | | | | |

- **Maintenance Agreement** - The Virginia Stormwater Management regulations (9 VAC 875) specify the circumstances under which a maintenance agreement must be executed between the owner and the VSMP Authority, and sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.
- All tree plantings must include a long-term maintenance agreement consistent with the provisions of the VSMP regulations and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When tree plantings are applied on private residential lots, homeowners should be educated regarding their routine maintenance needs by being provided a simple document that explains their purpose and routine maintenance needs.
- A deed restriction, drainage easement or other mechanism enforceable by the VSMP Authority must be in place to help ensure that new tree plantings are maintained and not converted or disturbed, as well as to pass the knowledge along to any subsequent owners. The mechanism should, if possible, grant authority for the VSMP Authority to access the property for inspection or corrective action.

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Vermont Manual (https://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/Permitinformation/2017%20VSMM_Rule_and_Design_Guidance_04172017.pdf

New trees should be planted following appropriate procedures (e.g., the International Society of Arboriculture's Planting New Trees, http://www.treesaregood.com/treecare/resources/New_TreePlanting.pdf).

Planting shall only be performed when weather and soil conditions are suitable for planting.

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## 7.0 Appendix A Runoff Reduction Computation Methodology for Tree Planting Over Turf

Hynicka and Divers (2016) provide the basis for the runoff reduction values and pollutant removal efficiencies for the Tree Planting BMP. However, where other VRRM BMPs base the mass phosphorus removal efficiency on runoff reduction, Hynicka and Divers (2016) base phosphorus reduction on leachate removal. To ensure consistency among VRRM BMPs, this design specification calculates pollutant removal efficiencies through the following methodology.

1. Hydrologic Soil Group (HSG) A/B soils have a greater storage capacity than C/D soils. Based on the volumetric runoff coefficient ($R_v$) for turf, the average A/B $R_v$ is 0.175, and the average C/D $R_v$ is 0.235. Dividing the A/B $R_v$ by the C/D $R_v$ yields 0.75. This indicates that runoff is approximately 75% lower for A/B vs. C/D soils. The runoff reduction (RR) capacity ratio can be approximated by the inverse of this value, 1/.75=1.333.
2. Item 1 above implies, for turf, that the runoff storage capacity of A/B soils is 1.333 times greater than C/D soils.
3. Knowing item 2, above, an equation can be created that approximates the runoff reductions of A/B and C/D soils using both the above information and knowledge regarding the breakdowns of the various HSG soils groups throughout the Chesapeake Bay watershed:

$$X_{AB}(0.64) + X_{CD}(0.36) = RR_{TOTAL}$$

$$X_{AB} = 1.33(XCD)$$

Where:

$X_{AB}$ = runoff reduction percentage of AB soils.

$X_{CD}$ = runoff reduction percentage of CD soils.

0.64 = proportion (64%) of Chesapeake Bay watershed made up of A and B soils.

0.36 = proportion (36%) of Chesapeake Bay watershed made up of C and D soils.

$RR_{TOTAL}$ = runoff reduction proportion (not percentage) as indicated in Hynicka and Divers 2016.

A direct solution to the above equation with RRTOTAL= 0.29 yields XCD = ~0.24, or 24% and XAB = ~0.32, or 32%.

Because leaves affect runoff reduction and pollutant removal efficiencies, the values are reduced to account for foliage cover. A six-month growing season would extend from May 1 to October 31. Therefore, annual percent values are reduced by half.

Although nominal 1.5% and 4% nitrogen and phosphorus removals were suggested in the study due to uptake and entrapment in woody biomass, those credits were not included in Table P-FIL-09-1 due to relatively high uncertainty in values and overall low magnitude improvements.

# P-SUP-01 Earthen Embankment

## 1.0 Definition

An earthen embankment is a raised impounding structure made from compacted soil. The embankment is the feature of pond-type practices that causes the impoundment of water.

## 2.0 Purpose and Applicability of Best Management Practices

An earthen embankment is appropriate for any facilities that detain or retain water.

The design procedures presented in this section may not apply to small embankments or to storm drainage outfall structures with embankments less than 3 feet high. The review and approval of such structures should be based on sound engineering practices and supporting calculations that verify a stable outfall for the 10-year storm, at a minimum.

Similarly, this section does not apply to embankments with a height of 25 feet or more and a maximum storage capacity of 50 acre-feet or more as measured from the top of the embankment. Such structures may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.).

The height of an earthen embankment is the vertical distance from the natural bed of the stream or watercourse, measured at the downstream toe of the embankment, to the top of the embankment. If the embankment does not span a stream or watercourse, the height is the vertical distance between the lowest elevation, measured at the outside limit of the embankment, and the top of the embankment.

## 3.0 Design Criteria

Earthen embankments are complex structures that must be designed and constructed considering: (a) specific site and foundation conditions, (b) construction material characteristics, (c) purpose of the impoundment, and (d) hazard potential associated with the site and/or impoundment.

The hazard potential associated with an impoundment is defined in the Virginia Dam Safety Regulations. It is based on the potential for loss of life and/or economic loss due to facility failure. While stormwater management embankments are typically much smaller than those regulated under the Virginia Dam Safety Program, the potential for significant property damage and loss of life may still be present. The engineer is responsible for analyzing potential downstream impacts and for determining if more stringent analyses are required.

Minimum guidelines for those facilities not covered under Virginia's Dam Safety Regulations are provided in this handbook.

### 3.1 Embankment Types

The type of embankment selected will depend on the purpose of the stormwater facility (e.g., detention, extended-detention, retention) and the available soil material for construction. The two general types are listed below:

1. A homogeneous embankment is composed of one kind of material (excluding slope protection). The material used must be sufficiently impervious to provide an adequate water barrier, and the slopes must be moderately flat for stability and ease of maintenance (see Figure P-SUP-01-1).

2. A zoned embankment contains a central impervious core flanked by zones of more pervious material called shells. These shells enclose, support, and protect the impervious core. Typically, a zoned embankment requires an internal drain or filter between the impervious zone and the downstream shell and between the shell and the foundation (see Figure P-SUP-01-1).

### 3.2 Soils Investigation

A soils investigation or geotechnical study should be completed before designing any earthen embankment covered in this section. The scope of such a study will vary from site to site based on the size of each project. Recommended minimum guidelines for a geotechnical study are provided below.

Refer to U.S. Department of Interior (USDI), Design of Small Dams, latest edition, for additional information.

### 3.3 Geotechnical Guidelines

The following discussion presents minimum recommended criteria for the planning and design of earthen embankments. The designer is responsible for determining which of the guidelines apply to the specific project and for determining if any additional investigations are required.

The validity of the design depends on the thoroughness of the site investigation, the adequacy of the testing program, and the soundness of the designer's judgment. Design components based on quantitative soil tests, such as analyses of slope stability, seepage, and settlement, are not discussed herein, but they are necessary to designing large dams. Such analyses will logically follow the selection of a preliminary design. Even for small earth dams that have a low hazard potential, the following criteria should be considered in a geotechnical report.

A geotechnical engineering study should evaluate the stability of the proposed embankment and should consist of (1) a site investigation, (2) laboratory testing, and (3) an engineering analysis.

1. A field investigation should include the review of available soils information and a subsurface exploration. Test borings, test pits, or both, should be used to evaluate the foundations, abutments, borrow materials, reservoir area, embankment design, and any other pertinent geological considerations. In karst areas, a subsurface profile using seismic or sonar technology should be considered to verify that there are no subsurface anomalies. This type of subsurface investigation may also be recommended in areas known to have been previously mined for mineral extractions.
2. Laboratory testing should be completed to evaluate the various soils. At a minimum, an index property test should be completed to classify the soils following the Unified Soil Classification System. Shear strength, compressibility, and permeability testing may be required depending on the size and complexity of the embankment and the nature of the site's subsurface conditions.
3. A geotechnical engineer should conduct an engineering analysis and present his or her findings, recommendations, and comments on items such as: foundation materials and preparation, design of interior drainage features and filters, and geotechnical design of conduits/structures through the embankment including seepage and stability analyses. The engineer should also provide a summary describing the soil types and rock strata encountered and explaining the laboratory tests and their results.

### 3.4 Stream Diversions

The design of some earthen embankments will require provisions for stream diversions around or through the embankment site during construction. A stream diversion can be accomplished by a variety of acceptable means including open channels, conduits, coffer dams, and pumping. Occasionally, stream diversions may be required to meet additional requirements and/or to be permitted by agencies such as the U.S. Army Corps of Engineers, the Virginia Department of Environmental Quality, and/or the Virginia Marine Resources Commission. Refer to The Virginia Stream Restoration & Stabilization Best Management Practices Guide for additional guidance on stream diversions.

To establish design water surface elevations and spillway capacity for earthen embankments, various hydrologic design methods and spillway storm frequencies may be used. Factors that affect their selection include: (a) the purpose of the stormwater facility: flood control, water quality enhancement, and/or channel erosion control, (b) the contributing watershed size, and (c) local regulations. Despite the design method selected or the frequency storm is used, the embankment should always be analyzed to ensure safe passage of the maximum spillway design storm while maintaining its structural integrity and stability. Furthermore, the embankment height should be set such that runoff from the spillway design storm can safely pass through one of the following spillways without overtopping the embankment:

- A natural or constructed spillway;
- A principal spillway; or
- A combination of a principal spillway and an emergency spillway.

Hydrologic and hydraulic methods are described in Appendix A Hydrologic and Hydraulic Methods and Computations.

Local ordinances or watershed conditions may require a more stringent analysis of the embankment concerning overtopping or spillway capacity. The U.S. Department of Agriculture (USDA) Natural Resource Conservation Service's (NRCS) National Engineering Handbook and the Virginia Dam Safety Regulations provide a classification of dams based on the potential hazard from failure. A dam failure analysis, or breach analysis, may be required to learn the extent of the potential hazard. Any dam breach analysis should use a method similar to the Army Corps of Engineers Hydrologic Engineering Center River Analysis System (HEC-RAS), NRCS Technical Release 210-60 Earth Dams and Reservoirs, National Weather Service River Mechanics Suite, or that specified by the local authority.

### 3.5 Embankment Stability

An earthen embankment must be designed to be stable against any force condition or combination of force conditions that may develop during the life of the structure. Other than overtopping caused by inadequate spillway capacity, the three most critical conditions that may cause failure of the embankment are:

1. Differential settlement within the embankment or its foundation due to a variation in materials, a variation in embankment height, or compression of the foundation strata. Differential settlement may subsequently cause the formation of cracks through the embankment that are roughly parallel to the abutments. These cracks may concentrate seepage through the dam and lead to failure by internal erosion.
2. Seepage through the embankment and foundation. This condition may cause piping within the embankment, the foundation, or both.
3. Shearing stresses within the embankment and foundation due to the weight of the fill. If the shearing stress force exceeds the strength of the materials, the embankment or its foundation may slide, resulting in the displacement of large portions of the embankment.

The stability of an embankment and its side slopes depends on: (1) construction materials, (2) foundation conditions, (3) embankment height and cross section geometry, (4) normal and maximum pool levels, and (5) purpose of best management practice (BMP): retention, detention, or extended detention. The embankment cross section should be designed to provide an adequate factor of safety to protect against sliding, sloughing, or rotation in the embankment or foundation. USDA NRCS's TR-60 publication provides guidelines for slope stability analysis when required. The most important factors in determining the stability of an embankment are:

1. **Physical characteristics of the fill materials:** Soil classification for engineering uses are detailed in the USDA NRCS Engineering Field Manual Chapter 4, and other references listed at the end of this section.
2. **Configuration of the site:** The height of the embankment may vary considerably throughout its length; therefore, the total settlement of any given section of the embankment may differ from that of adjacent sections. The length of the embankment and slope of the abutments profoundly influence the degree of differential settlement between adjacent sections of the embankment. As the length shortens and the abutments become steeper, differential settlement becomes more likely. (P-SUP-02 Principal Spillways discusses the use of a concrete cradle to protect the spillway barrel sections from separating due to the forces of differential settlement.)
3. **Foundation materials:** The character and distribution of the foundation material must be considered for its shear strength, compressibility, and permeability. Occasionally, the shear strength of the foundation may govern the choice of embankment slopes. Permeability and stratification of the foundation may dictate the need for a zoned embankment. Often, foundations contain compressible soils that settle under the weight of the embankment, although the shear strength of these soils is satisfactory. When such settlement occurs in the foundation, the embankment settles. This settlement is rarely uniform over the basal area of the embankment. Therefore, fill materials used on such sites must be sufficiently plastic to deform without cracking. (P-SUP-02 Principal Spillways discusses the use of a concrete cradle to protect the spillway barrel sections from separating due to the forces of differential settlement.)

A foundation composed of homogeneous soil is simple to evaluate; however, this condition rarely occurs in natural soil deposits. Most often, a stratified deposit composed of layers of several soil types is encountered. To determine the suitability of such a foundation, the following information becomes very important: (1) the geologic history of the site, (2) the degree of stratification, and (3) the order in which materials occur within the stratification. A complex, stratified foundation containing plastic or compressible soil should be investigated by an experienced engineer or geologist.

### 3.5.1 Foundation Cutoff

A foundation cutoff trench of moderately impervious material should be provided under the embankment. The cutoff trench should be installed at or upstream of the dam's centerline and should extend up the abutments to the 10-year water surface elevation.

The bottom of the cutoff trench should be wide enough to accommodate excavation, backfill, and compaction equipment. The trench's minimum width and depth should be 4 feet, and the side slopes should be no steeper than 1H:1V (refer to Figure P-SUP-01-1, Figure P-SUP-01-2, and Figure P-SUP-01-3).

### 3.5.2 Rock Foundations

The presence of rock in the embankment foundation area triggers specific design and construction recommendations (provided in the geotechnical engineering analysis) to ensure a proper bond between the foundation and the embankment.

Generally, no blasting should be permitted within 100 feet of the foundation and abutment area. If blasting is essential, it should be carried out under controlled conditions to reduce adverse effects on the rock foundation such as over-blasting and opening fractures. This is especially critical in areas of karst topography.

**3.5.3 Embankment Zoning and Seepage**

The stability of an embankment slope and the seepage pattern through it are greatly influenced by the zoning of the embankment. (Refer to Embankment Types above.) The position of the saturation line within a homogeneous embankment is theoretically independent of the type of soil used in it. Although soil permeabilities vary greatly, even the tightest clays are porous and cannot prevent water from seeping through. The rate of seepage through an embankment depends on the consistency of the reservoir level and the permeability of the embankment or core material.

The upper surface of seepage is called the phreatic surface (zero pressure). In a cross section, it is called the phreatic line. The position of the phreatic line in a retention basin embankment can be assumed to begin at the normal pool elevation on the upstream slope and extend at a 4H:1V slope downward through the embankment. This assumption is based on the presence of a permanent pool. For detention and extended detention facilities with no permanent pool, many designers assume that the embankment will not impound water long enough for a phreatic surface to occur. This assumption, however, is based on a properly designed, constructed, and maintained embankment. Many jurisdictions, therefore, have chosen a conservative design approach by requiring that the phreatic line start at the 10-year design stormwater surface elevation, regardless of the presence of a permanent pool.

For most stormwater management facilities, determining the location of the phreatic surface will often suggest the need to install seepage collars on the barrel. (Refer to P-SUP-02 Principal Spillways for a discussion on seepage control along conduits.) For larger stormwater facilities, especially those with a permanent pool, the location of the phreatic surface may trigger additional design considerations such as an internal drain.

If the saturation line intersects the downstream slope of the embankment at a point above the toe, then seepage will exit the embankment along the downstream face and toe. Typically, the quantity of seepage is so slight that it does not affect the slope's stability. However, sometimes the saturation of the toe will cause sloughing or serious reduction of the shear strength in the downstream section of the embankment.

Seepage control should be included in the design if:

- Pervious layers in the foundation are not intercepted by the cutoff.
- Possible seepage from the abutments may create a wet embankment.
- The phreatic line intersects the downstream slope.
- Special conditions require drainage to ensure a stable embankment.

For seepage collar design, it is recommended that the phreatic line start at the 10-year design stormwater surface elevation and extend through the embankment at a 4H:1V slope. If the phreatic line intersects the downstream slope, a qualified soil scientist should be consulted to decide if additional controls are needed. The location of the phreatic surface, therefore, may have a significant impact on the design of the embankment.

Seepage may be controlled by:

- Foundation, abutment, or embankment drains;
- A downstream drainage blanket,
- A downstream toe drain, or
- A combination of these measures (see Figure P-SUP-01-2).

Foundation drains may control seepage encountered in the cutoff trench during construction. These drains must be downstream of the embankment centerline and outside the limits of the proposed cutoff trench.

Including a toe drain in the design of most homogeneous embankments may be desirable. Embankments built on pervious foundations or constructed of materials that exhibit susceptibility to piping and cracking should always be protected by adequate toe drainage. Toe drains may be constructed of sand, gravel, or rock depending on the nature of the embankment fill material. Whenever a rock toe drain is installed, a graded filter should be placed between the fill and the drain. Often, a 12-inch layer of well-graded, stream-run, sandy gravel will satisfy this requirement. Filter and drainage diaphragm design criteria are presented in the references listed as USDA NRCS Soil Mechanics Notes No. 1 and No. 3 at the end of this section.

### 3.5.4 Piping

The contact areas between the embankment soils, foundation material, abutments, and conduits are the most susceptible locations for piping failures. Piping results from the variation in materials at contact points and the difficulty in compacting the soil in these areas. Compaction is especially difficult next to and under conduits and seepage collars. Therefore, it is highly recommended that all utility conduits, except the principal spillway, be installed away from the embankment. When utility conduits through the embankment cannot be avoided, they should meet the requirements for spillways (e.g., watertight joints, no gravel bedding, restrained to prevent joint separation due to settlement).

Seepage along pipe conduits that extend through an embankment should be controlled by:

- Anti-seep collars, or
- Filter and drainage diaphragms.

Refer to P-SUP-02 Principal Spillways for additional information on the use of anti-seep collars. Filter and drainage diaphragms are presented in USDA Soil Conservation Service (SCS) Soil Mechanics Notes No. 1 and No. 3, available upon request from Virginia Department of Environmental Quality (DEQ) or USDA SCS. When filter and drainage diaphragms are used, their design and construction should be supervised by a registered professional engineer.

### 3.5.5 Embankment Geometry

1. **Height:** The height of an earthen embankment is based on the freeboard requirements relative to the maximum water surface elevation during the 100-year frequency storm event. An embankment with an emergency spillway must provide at least **1 foot of freeboard** from the maximum 100-year stormwater surface elevation (WSE) to the lowest point on the top of the embankment (excluding the emergency spillway). (Note that the spillway design storm WSE, if specified, may be used instead of the 100-year elevation.)

   An embankment without an emergency spillway must provide at least **2 feet of freeboard** from the maximum 100-year storm WSE to the lowest point on the top of the embankment. (Note that the spillway design storm WSE, if specified, may be used instead of the 100-year elevation.)

2. **Top Width:** The top of an earthen embankment should be shaped to provide positive drainage. The top width is based on the following table:

**Table A-1 Embankment Top Widths**

| Total Height of Embankment (ft) | Minimum Top Width (ft) |
|---|---|
| 14 or less | 8 |
| 15-19 | 10 |
| 20-24 | 12 |

| Table A-1 Embankment Top Widths | |
|---|---|
| **Total Height of Embankment (ft)** | **Minimum Top Width (ft)** |
| 25 or more | 15 |

### 3.5.6 Compacted Fill

Using the Unified Soil Classification System, as covered in the geotechnical analysis, should specify the soil types.

The compaction requirements should include the percent of maximum dry density for the specified density standard, allowable range of moisture content, and maximum loose lift thickness. Refer to Construction Specifications for Earthen Embankments later in this standard. In general, the design of an embankment should account for approximately 10 percent settlement unless otherwise specified by a geotechnical report based on the embankment foundation and fill material. The top of the embankment must be level to avoid possible overtopping in one location in cases of extreme storms or spillway failure.

Compaction tests should be performed regularly during embankment construction, typically at a frequency of one test per 5,000 square feet on each layer of fill or as directed by the geotechnical engineer. Generally, one of two compaction tests will be specified for embankment construction: the Standard Proctor Test (ASTM D698) or the Modified Proctor Test (ASTM D1557). For the construction of earth dams, the Modified Proctor Test is likely to be more appropriate (Terzaghi and Peck 1948). This is due in part to the unconfined nature of the earth fill for dam construction. A new Proctor test is required if the material changes from that previously tested.

### 3.5.7 Embankment Construction

A geotechnical or construction inspector should be onsite during embankment construction. Inspectors should be required to conduct more than just test fill compaction (e.g., observe foundation preparation, pipe installation, riser construction, filter installation).

A vertical trench through the embankment material should not be allowed under any circumstances to place the spillway pipe. Trench side slopes should be laid back in steps at a 2:1 slope, minimum.

### 3.6 Maintenance and Safety

Embankment slopes should be no steeper than 3H:1V if possible, with a maximum combined upstream and downstream slope of 5:1 (3:1 downstream face and 2:1 upstream face). For embankments exceeding 15 feet in height, a 6- to 10-foot-wide bench should be provided at intervals of 10 to 15 feet of height, particularly if slopes are steeper than 3H:1V.

The following design considerations are provided to help reduce the long-term maintenance burden on the owner(s):

1. *Internal drainage systems in embankments (e.g., drainage blankets, toe drains)* should be designed such that the collection conduits discharge downstream of the embankment at a location where access for observation is possible by maintenance personnel.
2. *Adequate erosion protection* is recommended along the contact point between the face of the embankment and the abutments. Runoff from rainfall concentrates in these areas and may reach erosive velocities depending on the gutter slope and embankment height. Although a sod gutter will be satisfactory for most small embankments, an evaluation should be made to decide if another type of gutter protection is required. For most embankments, a riprap gutter is preferred to a paved concrete gutter.
3. *Trees, shrubs, or any other woody plants should not be planted on the embankment* or adjacent areas extending at least 25 feet beyond the embankment toe and abutment contacts.

4. *Access should be provided to all areas of an impoundment that require observation or regular maintenance*. These areas include the embankment, emergency spillway, basin shoreline, principal spillway outlet, stilling basin, toe drains, riser structure, extended drawdown device, and likely sediment accumulation areas.

## 4.0 Construction Specifications

The construction specifications for earthen embankments outlined below should be considered minimum guidelines, with the understanding that more stringent specifications may be required depending on individual site conditions as evaluated by the geotechnical engineer. Final construction specifications should be included on the construction plans. In general, widely accepted construction standards and specifications for embankments, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed.

Further guidance is provided in the USDA-NRCS Engineering Field Manual and National Engineering Handbook. Specifications for the embankment work should conform to the methods and procedures indicated for installing earthwork, concrete, reinforcing steel, pipe, water gates, metal work, woodwork, and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy all requirements of the local government.

### 4.1 Site Preparation

Areas designated for borrow sites, embankment construction, and structural work should be cleared, grubbed, and stripped of topsoil. All trees, vegetation, roots, and other objectional material should be removed.

All cleared and grubbed material should be disposed of outside and below the limits of the embankment and reservoir as directed by the owner or representative. When specified, a sufficient quantity of topsoil should be stockpiled in a suitable location for use on the embankment and other designated areas.

### 4.2 Earth Fill

| Parameter | Details |
|---|---|
| Material | Fill material should be taken from an approved, designated borrow area. It should be free of roots, stumps, wood, rubbish, stones greater than 6 inches, and frozen or other objectionable materials. Fill material for the center of the embankment and the cutoff trench should conform to Unified Soil Classification GC, SC, or CL. The use of other materials in the embankment may be considered based on the recommendations of a geotechnical engineer who supervises the design and construction. |
| Placement | Areas on which fill is to be placed should be scarified before its placement. Fill material should be placed in layers a maximum of 8 inches thick (before compaction), which should be continuous over the entire length of the fill. The most permeable borrow material should be placed in the downstream portions of the embankment. The principal spillway must be installed concurrent with fill placement and not excavated into the embankment. |

| Parameter | Details |
|---|---|
| Compaction | Fill material should be compacted with appropriate equipment such as a sheepsfoot, rubber-tired, or vibratory roller. The number of required passes by the compaction equipment over the fill material may vary with soil conditions. Fill material should contain sufficient moisture such that the required degree of compaction will be obtained with the equipment used.<br>The minimum required density is 95% of maximum dry density with a moisture content within 2% of the optimum, unless otherwise specified by the engineer. Each layer of the fill should be compacted as necessary to obtain minimum density and the engineer should certify, at the time of construction, that each fill layer meets the minimum density requirement. All compaction is to be determined by either Standard Proctor Test (ASTM D698) or the Modified Proctor Test (ASTM D1557) as directed by the geotechnical engineer based on site and soil conditions and the size and type of structure being built. |
| Cutoff Trench | The cutoff trench should be excavated into impervious material along or parallel to the centerline of the embankment as shown on the plans. The equipment used for excavation should govern the bottom width of the trench, with the minimum width being 4 feet. The depth should be at least 4 feet below existing grade or as shown on the plans. The side slopes of the trench should be 1H:1V or flatter. The backfill should be compacted with construction equipment, rollers, or hand tampers to ensure maximum density and minimum permeability. |
| Topsoil | The surface layer of compacted fill should be scarified before placement of at least 6 inches of topsoil. The topsoil will be stabilized in accordance with BMP C-SSM-09 and BMP C-SSM-10. |

#### 4.3 Structure and Conduit Backfill

Backfill that is beside pipes or structures should be of the same type and quality as specified for the adjoining fill material. The fill should be placed in horizontal layers not to exceed 4 inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material should fill all spaces under and beside the pipe. During the backfilling operation, equipment should not be driven closer than 4 feet, as measured horizontally, to any part of a structure. Also, equipment should **NEVER** be driven over any part of a structure or pipe, unless compacted fill has been placed to a depth specified by the structural live load capacity of the structure or pipe to adequately distribute the load.

#### 4.4 Filters and Drainage Layers

To achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface. The filter material should be placed in lifts of no more than 12 inches.

Up to 4 feet of embankment material may be placed over a filter material layer before excavating back down to expose the previous layer. After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above until the top of the adjacent fill is reached.

#### 4.5 Impermeable Liner to Prevent Infiltration

In instances where it has been determined that infiltration is not desirable, an impermeable clay or geomembrane liner pursuant to the following specifications may be used.

- All clay liners should have a minimum thickness of 12 inches and meet the specifications of Table P-SUP-01-1 below.
- A layer of compacted topsoil (minimum thickness 6 to 12 inches) should be placed over the liner before seeding in accordance the seeding specifications for the selected BMP.

**Table P-SUP-01-1 Clay Liner Specification**

| Property | Test Method (or equal) | Unit | Specifications |
|---|---|---|---|
| Permeability | ASTM D-2434 | cm/sec | 1 x 10-6 |
| Plasticity Index of Clay | ASTM D-423 & D-424 | % | Not less than 15 |
| Liquid Limit of Clay | ASTM D-2216 | % | Not less than 30 |
| Clay Particles Passing | ASTM D-422 | % | Not less than 30 |
| Clay Compaction | ASTM D-2216 | % | 95% of Standard Proctor Density |

Where a geomembrane liner is used, it should have a minimum thickness of 40 mils and be ultraviolet resistant. The geotextile fabric for protection of the geomembrane shall meet the specifications in Table P-SUP-01-2.

**Table P-SUP-01-2**

| Property | Test Method | Unit | Specification |
|---|---|---|---|
| Unit Weight | | oz./Sq. Yd. | 8 (minimum) |
| Filtration Rate | | in/sec. | 0.08 (minimum) |
| Puncture Strength | ASTM D-751 (Modified) | lb. | 125 (minimum) |
| Mullen Burst Strength | ASTM D-751 | psi | 400 (minimum) |
| Tensile Strength | ASTM D-1682 | lb. | 300 |
| Equivalent Opening Size | US Standard Sieve | No. | 80 (minimum) |

## 5.0 Operations and Maintenance Considerations

A thick, healthy grass cover, free of trees and brush, should be maintained on the embankment. Such a cover will help stabilize the surfaces of the embankment and will simplify inspections.

The maintenance and inspection guidelines presented below are not all-inclusive. Specific facilities may require other measures not discussed here. It is the designer's responsibility to decide if additional measures are necessary.

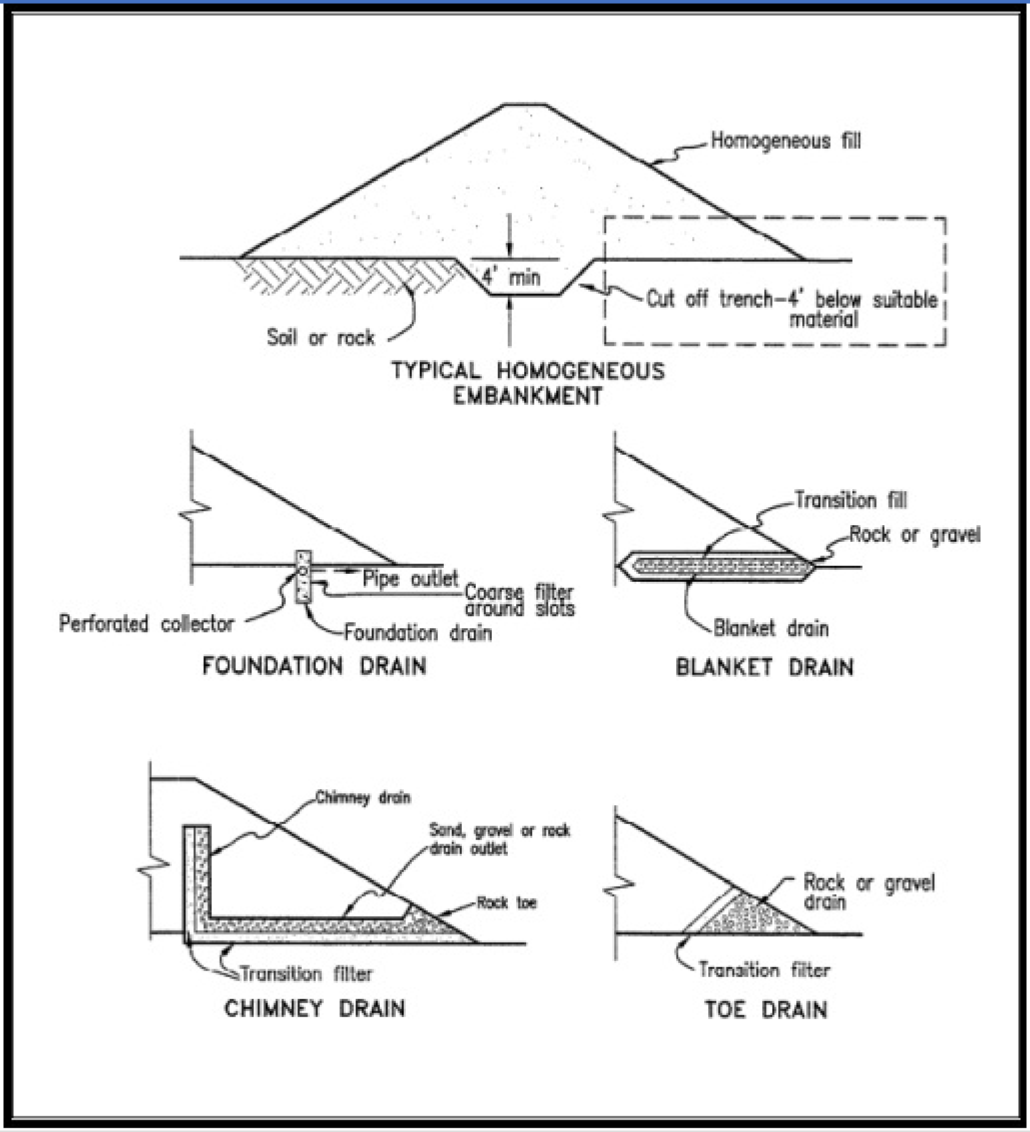
1. The embankment should be mowed periodically during the growing season, ensuring that the last cutting occurs at the end of the season. The grass should not be cut less than 6 to 8 inches high.

2. The embankment should be inspected for subsidence/sinkhole formation, especially along the side slopes and at the toes of slopes. Subsidence is a criterion of failure, and the sinkhole should be repaired promptly using the appropriate sinkhole repair techniques.
3. If necessary, the embankment should be limed, fertilized, and seeded in the fall after the growing season. Lime and fertilizer application rates should be based on soil test results. The type of seed should be consistent with that originally specified on the construction plans.
4. All erosion gullies noted during the growing season should be backfilled with topsoil, reseeded, and protected (mulched) until vegetation is established.
5. All bare areas and pathways on the embankment should be properly seeded and protected (mulched) or otherwise stabilized to eliminate the potential for erosion.
6. All animal burrows should be backfilled and compacted, and burrowing animals should be removed from the area.
7. All trees, woody vegetation, and other deep-rooted growth, including stumps and associated root systems, should be removed from the embankment and adjacent areas extending to at least 25 feet beyond the embankment toe and abutment contacts. The root systems should be extracted, and the excavated volume replaced and compacted with material similar to the surrounding area. All seedlings should be removed at the first opportunity. Similarly, any vine cover and brush should be removed from the embankment to allow for inspections.
8. The embankment should be visually inspected for evidence of any springs, boils, or wet areas with or without wetland vegetation, which may be an indication of uncontrolled seepage and should be investigated further to determine if repairs are necessary.
9. Any repairs made to the principal spillway (riser or barrel) should be reviewed by a professional engineer. Vertical trenching to expose the barrel should not be allowed under any circumstances.

   The trench side slopes should be stepped back at a 2:1 slope, minimum.

## 6.0 Typical Details

***Figure P-SUP-01-1 Homogenous Embankments w/Seepage Controls***




*Source: SCS Engineering Field Manual*

**Figure P-SUP-01-2 Zoned Embankment**

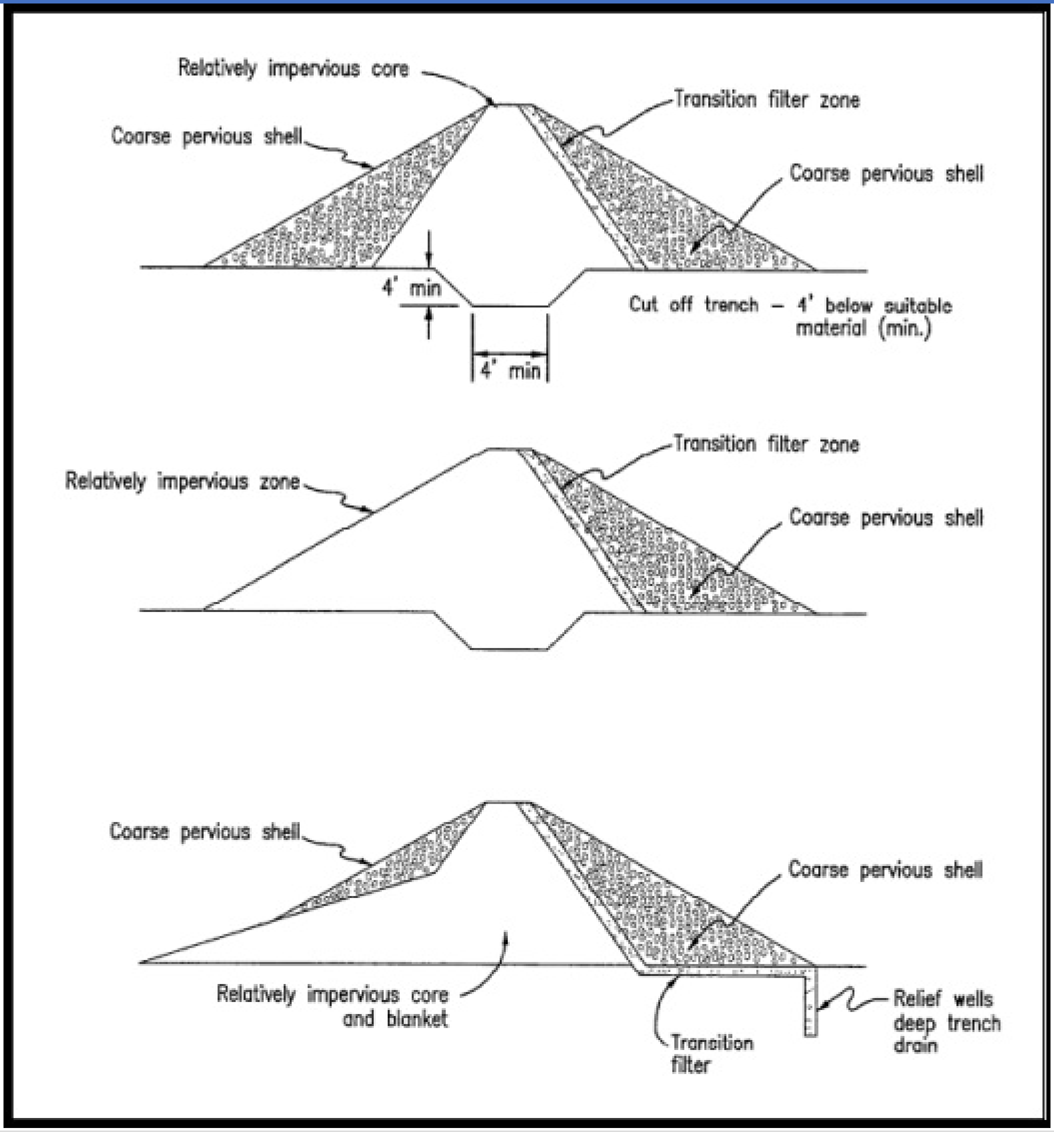


**Figure P-SUP-01-3 Profile Along Centerline of Embankment**

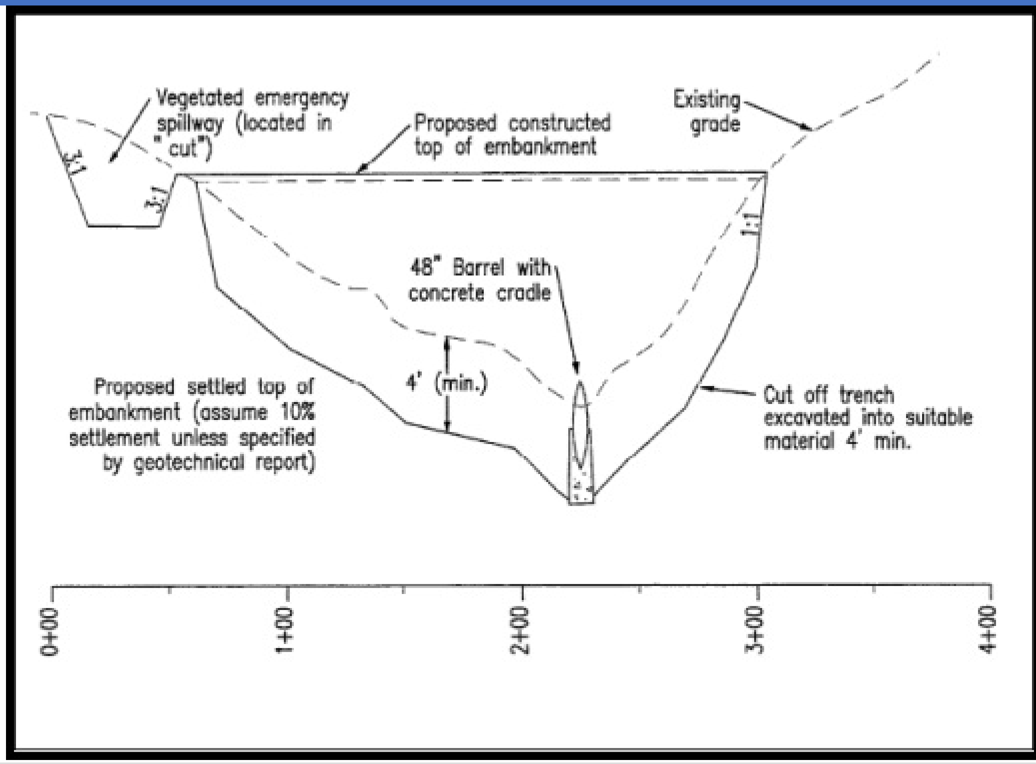
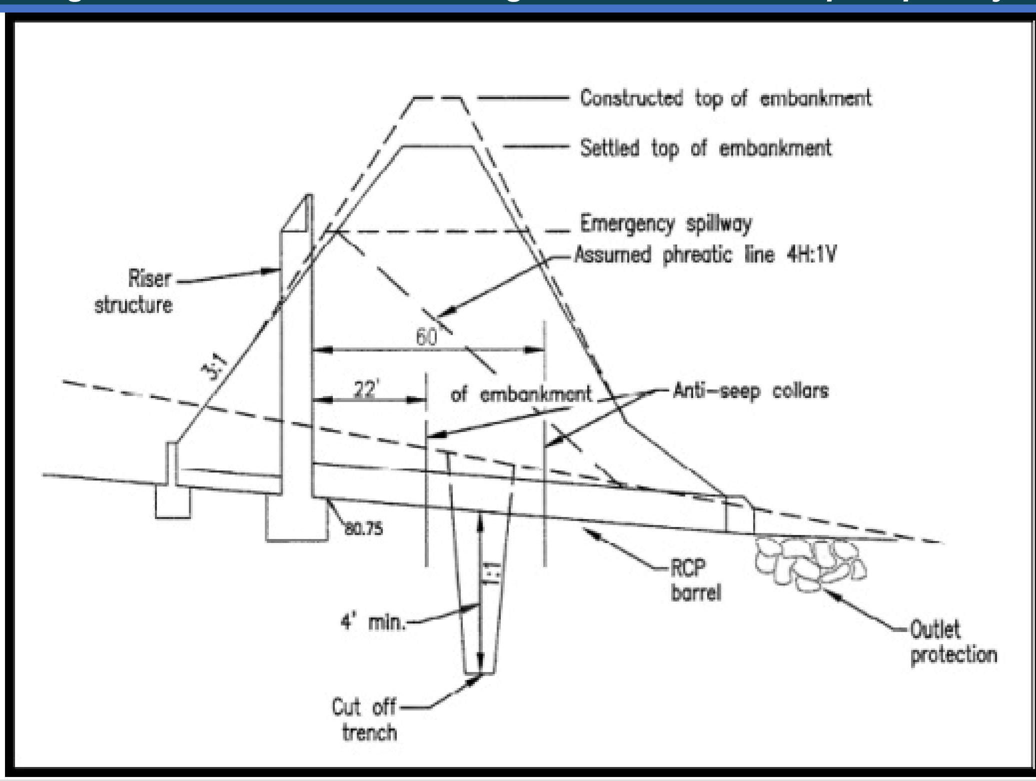



**Figure P-SUP-01-4 Profile Along Centerline of Principal Spillway**




## 7.0 References

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USDA Natural Resource Conservation Service. Engineering Field Manual.

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- SM Note No. 1, Guide for Determining the Gradation of Sand and Gravel Filters.
- SM Note No. 2, Light Weight Piston Sampler for Soft Soils and Loose Sands.
- SM Note No. 3, Soil Mechanics Considerations for Embankment Drains.
- SM Note No. 4, Preparation and Shipment of Undisturbed Core Samples.
- SM Note No. 5, Flow Net Construction and Use.
- SM Note No. 6, Glossary, Symbols, Abbreviations, and Conservation Factors.
- SM Note No. 7, The Mechanics of Seepage Analysis.
- SM Note No. 8, Soil Mechanics Testing Standards.
- SM Note No. 9, Permeability of Selected Clean Sands and Gravels.
- SM Note No. 10, The Static Cone Penatrometer: The Equipment and Using the Data.

USDA Natural Resource Conservation Service, Technical Releases:

- TR 709. Dimensioning of Filter-Drainage Diaphragms for Conduits According to TR-60.
- TR 026. The Use of Soils Containing More Than 5% Rock Larger Than the No.4 Sieve.
- TR 027. Laboratory and Field Test Procedures for Control of Density and Moisture of Compacted Earth Embankments.
- TR 028. Clay Minerals.
- TR 071. Rock Materials Field Classification Procedure.
- TR 60. Earth Dams and Reservoirs

U.S. Department of the Interior. Design of Small Dams. 1987.

U.S. Department of the Interior, Bureau of Reclamation. Guidelines for Controlling Seepage Conduits through Embankment.

Virginia Erosion and Sediment Control Handbook. Richmond, Virginia: 1992.

# P-SUP-02 Principal Spillways

## 1.0 Definition

A principal spillway is a primary outlet device for a stormwater impoundment.

## 2.0 Purpose and Applicability of Best Management Practice

A principal spillway is used on any impoundment best management practice (BMP) including retention, extended detention, and detention facilities. It may also be used with constructed wetlands and infiltration measures.

A principal spillway typically consists of either a riser structure combined with an outlet conduit or a weir control section cut through the embankment. The purpose of a principal spillway is to provide a primary outlet for storm flows, usually up to the 10- or 25-year frequency storm event. The principal spillway is designed and sized to regulate the allowable discharge from the impoundment facility at pre-determined release rates.

## 3.0 Planning and Considerations

A principal spillway typically consists of a multi-stage riser structure and an outlet conduit or a weir that allows flow to pass over a control section of the embankment. The shape and geometry of the weir, as well as that of the riser structure, can be manipulated to meet the needs of the specific facility. The use of a weir as the principal spillway prevents the barrel from projecting through the embankment. This and the associated piping and seepage control represent not only significant material and construction costs, but also potential trouble spots for long-term maintenance and repair.

The most common type of riser structure is a drop inlet spillway, which usually consists of a rectangular or other shaped riser structure containing one or more openings sized to control one or more discharge rates. The barrel shape or geometry and size through the embankment is based on the required flow capacities and availability of materials.

For aesthetic or safety concerns, the drop inlet riser structure may be installed in the embankment with only its top showing. The discharge openings may be extended to the design water surface elevations with pipe.

### 3.1 Safety Considerations

When sizing trash racks and debris control structures, they should prevent entry by children. Fencing or other barriers should be considered around spillway structures that have open or accessible drops of more than 3 feet. A locking manhole cover on the riser may also be prudent to prevent unauthorized access. Check the locality for other safety feature requirements, such as fencing, safety benches, and minimum depths, which are usually documented in a drainage or design manual.

## 4.0 Stormwater Performance Summary

Not applicable.

## 5.0 Design Criteria

The purpose of this section is to provide minimum design recommendations and guidelines for principal spillway systems (riser structure and barrel). The designer is responsible for determining aspects applicable to the facility being designed and for determining if any additional design elements are required to ensure the long-term functioning of the system.

In general, all principal spillways should be constructed of a non-erosive material. The selected material should have an anticipated life expectancy similar to that of the stormwater management facility. Pre-cast riser structures cannot be substituted if plans call for a cast-in-place structure unless approved by the design engineer and the plan approving authority. Sections of pre-cast structures must be anchored together for stability and flotation requirements. A structural engineer should evaluate shop drawings for pipe, pre-cast structures, or other fabricated appurtenances before fabrication or installation. Cinder block and masonry block structures should not be used.

The crest elevation of the principal spillway must be at least 1 foot below the crest of the emergency spillway.

### 5.1 Drop Inlet Spillways

Drop inlet spillways (riser and barrel system) should be designed such that:

a. Full flow is established in the outlet conduit and riser at the lowest head over the riser crest as is practical, and

b. The facility operates without excessive surging, noise, vibration, or vortex action at any stage.

To meet these two requirements, the riser must have a larger cross sectional area than the outlet conduit.

The basic hydraulic calculation procedures needed to design the spillway riser and barrel system are described in the Appendix A Hydrologic and Hydraulic Methods and Calculations.

### 5.2 Headwall/Conduit Spillways

Headwall spillways consist of a pipe extending through an embankment with a headwall at the upstream end. The headwall is typically oversized to provide an adequate surface against which to compact the embankment fill and to prevent erosion at the inlet.

### 5.3 Weir Spillways

A weir spillway, when used as a principal spillway, should be armored with concrete or other non-erosive material because it usually carries water during every storm event. At the spillway, armoring should extend from the upstream face of the embankment to a point downstream of the spillway toe. The downstream impact of the drainage flowing over the weir should be considered, as it spills onto the exit channel for erosion.

### 5.4 Combined Principal and Emergency Spillways

An emergency spillway, separated from the principal spillway, is generally recommended. However, using an overland emergency spillway at the embankment abutments may not be practical due to site limitations such as:

- Topographic conditions (e.g., abutments are too steep);
- Land use conditions (e.g., existing or proposed development imposes constraints);
- Other factors (e.g., roadway embankments are used as a dam, basins are excavated).

Under these conditions, a combined principal/emergency spillway (a single spillway structure that conveys both low flows and extreme flows such as the 100-year frequency flow) may be considered. The combined spillway may take the form of a drop inlet spillway, a weir spillway, a headwall/conduit spillway, or any other spillway type.

A primary design consideration for a combined principal/emergency spillway, particularly if it is a drop inlet spillway, is protection against clogging.

### 5.5 Perforated Risers

Perforated risers are special orifices used in extended detention and sediment basins. These risers are small-diameter vertical pipes with equally spaced round holes. An orifice plate is installed at the bottom of the riser to restrict flow if needed. Perforated risers should be used when the low-flow orifice diameter is 3 inches or less. The perforated riser is packed with clean aggregate to prevent clogging. The top of the pipe has a screw cap for access to accomplish inspection and cleaning.

### 5.6 Conduits/Structures through Embankments

The contact point for the embankment soil, the foundation material, and the conduit is the most likely location for piping to occur due to the discontinuity in materials and the difficulty in compacting the soil around the pipe. Piping is the flow of drainage around and along the conduit from the face of dam through the downstream face of embankment. Therefore, special attention must be given to the design of any conduit that penetrates an embankment. See Section 5.5.1 below for additional detail and preventive measures.

It is highly recommended that the designer limits the number of conduits that penetrate through an embankment. Whenever possible, utility or other secondary conduits should be located outside of and away from the embankment. When additional conduits cannot be avoided, they should meet the requirements for spillways (e.g., watertight joints, no gravel bedding, encasement in concrete or flowable fill, restrained to prevent joint separation due to settlement).

Many embankment failures occur along the principal spillway because of the difficulty in compacting soil along a pipe. To help alleviate this concern, designers should consider the use of a weir as a control structure.

An additional cause of embankment failure is the separation of pipe joints due to differential settlement and pipe deflection. The contractor and project inspector should verify that the pipe materials in the manufacturer's certification that accompanies the pipe shipment comply with the plan material specifications including connections and gaskets. Note that some localities prohibit the use of corrugated metal pipe due to soil conditions, such as acid sulfate soils, which would deteriorate the metal at a much higher rate, making it prone to failure.

Watertight joints are necessary to prevent infiltration of embankment soils into the conduit. All joints must be constructed as specified by the pipe manufacturer. "Field joints," at which the ends of the pipes are cut off in the field, should not be accepted. See the manufacturer's specifications and the design plans. The construction specifications should define the parameters for all aspects of the pipe system including material, class and thickness, joint materials, joint assembly, and sizing.

All pipe gaskets should be properly lubricated with the material provided by the pipe manufacturer. Use of an incorrect lubricant may cause deterioration of gasket material.

### 5.6.1 Conduit Piping and Seepage Control

Seepage or piping along a pipe conduit that extends through an embankment should be controlled by use of anti-seep collars or a filter or drainage diaphragm. Concrete cradles, as discussed in item 3 below, may also be used.

Seepage control will not be required on pipes less than 6 inches in diameter.

1. Anti-Seep Collars: These collars lengthen the percolation path along the conduit, subsequently reducing the exit gradient, which helps to reduce the potential for piping. While this works well in theory, the required quality of compaction around the collars is very difficult to achieve in the field.

   Anti-seep collars, when used, should be installed around all conduits through earth fills according to the following criteria:

   a. Enough collars should be placed to increase the seepage length along the conduit by a minimum of 15 percent. This percentage is based on the length of pipe in the saturation zone.
   b. The assumed normal saturation zone should be determined by projecting a line through the embankment with a 4H:1V slope from the point at which the normal water elevation meets the upstream slope to a point at which it intersects the invert of the conduit. This line, referred to as the phreatic line, represents the upper surface of the zone of saturation within the embankment. For stormwater management basins, the phreatic line starting elevation should be the 10-year storm pool elevation (see P-SUP-01 Earthen Embankment).

c. Maximum collar spacing should be 14 times the minimum projection above the pipe. The minimum collar spacing should be five times the minimum projection.

d. For pipes with concrete cradles, the projection will be measured from the cradle (MD).

e. Anti-seep collars should be placed within the saturation zone. Where the spacing limit will not allow this, at least one collar should be in the saturation zone.

f. All anti-seep collars and their connections to the conduit should be watertight and made of material compatible with the conduit.

g. Collar dimensions should extend a minimum of 2 feet in all directions around the pipe.

h. Anti-seep collars should be placed a minimum of 2 feet from pipe joints unless flanged joints are used.

i. The calculation procedure for sizing anti-seep collars is presented in Appendix A Hydrologic and Hydraulic Methods and Calculations.

2. Filter and Drainage Diaphragms: Anti-seep collars extend the flow path along the conduit and, therefore, discourage piping. In contrast, filter and drainage diaphragms do not eliminate or discourage piping; rather, they control the transport of embankment fines, which is the major concern in piping and seepage. Rather than trying to prevent seepage or increase its flow length, these devices channel the flow through a filter of fine-graded material, such as sand, which traps any embankment material being transported. The flow is then conveyed out of the embankment through a perforated toe drain or other acceptable technique.

   While filter and drainage diaphragms require careful design, the procedure is straightforward. The grain size distribution of the embankment fill and foundation material must be determined so that the filter material grain size distribution can be specified. If the specified filter material is not available on the site, it must be imported. The design procedure for filter and drainage diaphragms is documented in the following references:

   - U.S. Department of Agriculture (USDA)- Natural Resources Conservation Service (NRCS) TR-60;
   - USDA-NRCS Technical Note No. 709; and
   - USDA-NRCS Soil Mechanics Notes 1 and 3 (Available upon request from Virginia Department of
   - Environmental Quality [DEQ] or NRCS)

   There are some distinct advantages to using filter diaphragms instead of anti-seep collars:

   - Eliminating the obstructions created by anti-seep collars allows heavy compaction equipment to more thoroughly compact the embankment fill material adjacent to the conduit.
   - The labor-intensive formwork associated with anti-seep collar construction is eliminated.
   - Cracks that form in the fill along the conduit will be terminated by the filter and will not propagate completely through the dam.

   A geotechnical engineer should supervise the design of filter and drainage diaphragms. The critical design element is the grain size distribution of the filter material compared with that of the embankment fill and foundation material.

   Overall, the following criteria apply to the use of filter and drainage diaphragms:

   a. The diaphragm should consist of sand, meeting the specifications of Virginia Department of Transportation (VDOT) Grade A fine aggregate, or ASTM C33.

   b. The diaphragm should be a minimum of 3 feet thick and should extend vertically upward, horizontally at least three times the pipe diameter, and vertically downward at least 24 inches beneath the barrel invert, or to rock, whichever is encountered first (SCS Tech. Note 709).

c. The diaphragm should be placed immediately downstream of the cutoff trench, approximately parallel to the centerline of the dam.

d. In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface. The filter material should be placed in lifts of no more than 12 inches.

e. Up to 4 feet of embankment material may be placed over a filter material layer before excavating back down to expose the previous layer. After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above until the top of adjacent fill is reached.

f. The diaphragm should be discharged at the downstream toe of the embankment. The opening sizes for slotted and perforated pipes in drains must be designed according to the filter criteria. A second filter layer may be required around the drainpipe in order to alleviate the need for many very small openings. Fabric should not be used around the perforated pipe, as it may clog, rendering the perforations impenetrable by water.

Whatever measures are taken to control seepage, proper construction techniques and inspection are critical to a successful project. The contractor should ensure that backfill material meets the specifications for quality, lift thickness, placement, moisture content, and dry unit weight. In addition, special care should be taken in the placement and compaction of the embankment material beside the barrel. Compaction along this conduit must extend away from the pipe enough to overlap with the compaction of the embankment. The use of filter and drainage diaphragms will ease this effort while providing greater protection against the damaging effects of piping and seepage.

During construction, it is recommended that a qualified professional inspect filter and drainage diaphragms. Inspection logs should be submitted along with any as-built plans.

3. Concrete Pipe Bedding: If the embankment fill material under the spring line of the conduit is inadequately compacted, piping may result. This problem is magnified if the conduit is not designed with flexible watertight joints; differential settlement of the embankment and foundation materials may pull the conduit joints apart, allowing the stormwater to escape into the surrounding soil, greatly adding to the piping condition. Installation of a concrete cradle will help to reduce the risk of piping under the barrel and the subsequent failure of the embankment resulting from differential settlement.

   Cradles not only provide conduit support but also provide a better condition for the placement and compaction of backfill by helping to prevent piping along conduit and providing a 90-degree bedding angle for the loading support of the conduit.

   The concrete cradle may not be necessary along the entire length of the conduit to prevent piping, but it is recommended. This will eliminate a sudden change in the support provided under the conduit. The load distribution of the conduit is assumed to be the same as the typical load distribution characteristics of reinforced concrete pipe (RCP). The external loading capacity of RCP depends on a bedding condition that provides equal support around the base of the pipe. General pipe culvert installation specifications call for the placement of gravel under the pipe to distribute the load evenly. However, gravel bedding under an embankment conduit is never appropriate unless it is designed as a filter or drainage diaphragm. Therefore, if the external load on the barrel is enough to warrant provision for its maximum supporting strength, then a concrete cradle should be installed along the conduit's entire length. Note that external loads on the barrel may be due to the height of the embankment fill, the anticipated construction traffic, or the weight of the compaction equipment.

4. Single Conduits**:** All conduits penetrating dam embankments should be designed using the following criteria:

- Conduits and structures penetrating an embankment should have a smooth surface without protrusions or indentations that will hinder compaction of embankment materials.
- All conduits should be circular in cross section except cast-in-place reinforced concrete box culverts.
- Conduits should be designed to withstand the external loading from the proposed embankment without yielding, buckling, or cracking, all of which will result in joint separation.
- Conduit strength should not be less than the values for corrugated steel, aluminum, and polyvinyl chloride (PVC) pipes and the applicable ASTM standards for other materials. The manufacturer should submit certification that the pipe meets plan requirements for design load, pipe thickness, joint design, and other parameters.
- Inlet and outlet flared-end sections should be made from materials that are compatible with the pipe.
- All pipe joints should be made watertight using flanges with gaskets, coupling bands with gaskets, bell and spigot ends with gaskets, by welding, or any other equivalent designed mechanism.

5. Multiple Conduits**:** Where multiple conduits are used, each conduit should conform to the requirements for single conduits listed above. In addition, sufficient space between the conduits and the installed anti-seep collars should be provided to allow for backfill material to be placed between the conduits with earth-moving equipment and to allow for easy access by hand-operated compaction equipment. The distance between conduits should be equal to or greater than one half of the pipe diameter but not less than 2 feet.

### 5.7 Cathodic Protection

In some areas of Virginia, sedimentary layers may be very acidic. This is particularly common in the Coastal and Piedmont Regions east of the fall line or roughly east of Interstate 95. Cathodic protection should be provided for coated welded steel and galvanized corrugated metal pipe when soil and resistivity studies indicate the need for a protective coating. Cathodic protection may also be provided when additional protection and longevity are warranted. Check with the locality regarding any material limitations.

### 5.8 Outlet Protection

Outlet protection should be used on the downstream toe of a spillway structure to help dissipate the high-energy flow through the spillway and to prevent excessive erosion in the receiving channel. Riprap at the endwall or end section of an outlet conduit or a designed hydraulic jump with impact blocks can be used.

The type of outlet protection depends on the flow velocities associated with the spillway design flood and energy dissipation required.

Outlet protection should be designed in accordance with C-ECM-15 Outlet Protection.

### 5.9 Trash Racks and Debris Control Devices

Most basins will collect trash and debris from incoming flows. Floating debris, such as grass clippings, tree limbs, leaves, trash, construction debris, and sediment bed load from upstream watersheds, are common. Therefore, all control structures, including detention, extended-detention and retention basin low-flow weirs, and orifices, should have a trash rack or debris control device. The following are recommended design criteria for these devices:

1. Openings for trash racks should be no larger than one half of the minimum conduit dimension, and to discourage child access, bar spacing should be no greater than 1 foot apart. The clear distance between the bars on large storm discharge openings should generally be no less than 6 inches.

2. Flat grates for trash racks are not acceptable. Inlet structures that have flow over the top should have a non-clogging trash rack, such as a hood-type inlet, that allows passage of water from underneath the trash rack into the riser or a vertical or sloped grate. The designer should verify that the surface area of the vertical perimeter of a raised grate equals the area of the horizontal top opening. This will allow adequate flow passage should the top horizontal surface become clogged.
3. Metal trash racks and monitoring hardware should be constructed of galvanized or stainless steel metal.
4. Methods to prevent clogging of extended detention orifices in dry extended detention basins should be carefully designed because these orifices are usually very small and located at the invert or bottom of the basin, see P-BAS-03 Extended Detention Pond.

#### 5.10 Anti-Vortex Device

All drop inlet spillways designed for pressure flow should have adequate anti-vortex devices. An anti-vortex device is not required if weir control is maintained in the riser through all flow stages including the maximum design storm or safety storm.

An anti-vortex device may be a baffle or plate installed on top of the riser or a headwall set on one side of the riser.

#### 5.11 Drainpipes and Valves

Stormwater management facilities that have permanent impoundments may be designed so that the permanent pool can be drained to simplify maintenance and sediment removal. The draining mechanism will usually consist of a valve or gate attached to the spillway structure and an inlet pipe projecting into the reservoir area with a trash rack or debris control device. The typical configuration of a drainpipe will place the valve inside the riser structure with the pipe extending out to the pool area. This configuration results in the drainpipe being pressurized by the hydraulic head associated with the permanent pool. Pressurized drainpipes should consist of mechanical joints in order to avoid possible leaks and seepage resulting from this condition. In all cases, valves should be secured to prevent unauthorized draining of the facility.

Basin drains should be designed with sufficient capacity to pass the 1-year frequency design storm with limited ponding in the reservoir area, such that sediment removal or other maintenance functions are not hampered.

An uncontrolled or rapid drawdown of a stormwater basin could cause a slide in the saturated upstream slope of the dam embankment or shoreline area. Therefore, the design of a basin drain system should include specific operating instructions for the owner. Generally, drawdown rates should not exceed 6 inches per day. For embankments or shoreline slopes of clay or silt, drawdown rates as low as 1 inch per week may be required to ensure slope stability (FPFM 1994). Contact a geotechnical engineer for additional site-specific information.

#### 5.12 Anti-Floatation

The design of a principal spillway riser structure should include a flotation or buoyancy calculation.

When the ground around the riser is saturated and the water surface elevation in the basin is higher than the riser footing, then the riser structure behaves like a “vessel” floating in water. Such flotation forces on the riser can lead to failure of the connection between the riser and barrel, and any other rigid connections.

The downward force of the riser and footing (assuming the riser is attached firmly to the footing) is the structure weight. To maintain adequate stability, this weight must be at least 1.25 times greater than the upward force, or buoyant force, acting on the riser.

An anti-flotation calculation procedure is presented in Appendix A Hydrologic and Hydraulic Methods and Computations.

## 6.0 Construction Specifications

The construction specifications for principal spillways outlined below should be considered as minimum guidelines. More stringent requirements may be needed depending on individual site conditions. Overall, widely accepted construction standards and specifications, such as those developed by the USDA NRCS or the U.S. Army Corps of Engineers, should be followed.

Further guidance is provided in the USDA-NRCS Engineering Field Manual for the work should conform to the methods and procedures specified for installing earthwork, concrete, reinforcing steel, pipe water gates, metal work, woodwork, and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy all requirements of the local government. Final construction specifications should be included on the construction plans.

### 6.1 Corrugated Metal Pipe

The following criteria apply to corrugated metal pipe used in the BMP:

#### 6.1.1 Materials

Corrugated metal pipe may be steel, aluminum-coated steel, or aluminum.

Steel Pipe: This pipe and its appurtenances should be galvanized and fully bituminous-coated and should conform to the requirements of American Association of State Highway and Transportation Officials (AASHTO) Specification M-190 Type A with watertight coupling bands. Any bituminous coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound. Steel pipes with polymeric coatings should have a minimum coating thickness of 0.01 inch (10 mils) on both sides of the pipe. Coated corrugated steel pipe should meet the requirements of AASHTO M-245 and M-246.

- *Aluminum Coated Steel Pipe*: This pipe and its appurtenances should conform to the requirements of AASHTO Specification M-274 with watertight coupling bands or flanges. Any aluminum coating damaged or otherwise removed should be replaced with cold-applied bituminous coating compound.
- *Aluminum Pipe*: This pipe and its appurtenances should conform to the requirements of AASHTO Specification M-196 or M-211 with watertight coupling bands or flanges. Aluminum surfaces that are to be in contact with concrete should be painted with one coat of zinc chromate primer. Hot-dipped galvanized bolts may be used for connections. The pH of the surrounding soils should be between 4 and 9.

#### 6.1.2 Coupling Bands, Anti-Seep Collars, End Sections, and Other Components

All connectors must be composed of the same material as the pipe. Metals must be shielded from dissimilar materials with rubber or plastic insulation at least 24 mils thick.

#### 6.1.3 Connections

All connections to pipes must be completely watertight. The drainpipe (or barrel) connection to the riser should be welded all around when both are metal. Anti-seep collars should be connected to the pipe so that they are completely watertight.

A rubber or neoprene gasket should be used when joining pipe sections. The end of each pipe should be re-rolled by enough corrugations to fit the bandwidth. The following connection types are acceptable for pipes less than 24 inches in diameter: flanges with gaskets on both ends of the pipe, a 12-inch-wide standard lap-type band with a 12-inch-wide by 0.5-inch-thick closed-cell circular neoprene gasket, and a 12-inch-wide hugger-type band with O-ring gaskets having a minimum diameter of 0.375 inch greater than the corrugation depth. Pipes 24 inches in diameter and larger should be connected by a 24-inch-long annular corrugated band using rods and lugs and a 24-inch-wide by 0.375-inch-thick closed-cell circular neoprene gasket. Helically corrugated pipe should have either continuous welded seams or lock seams with internal caulking or a neoprene bead.

All pipe gaskets must be properly lubricated with the material provided by the pipe manufacturer and tensioned. Flat gaskets must be factory-welded or solvent-glued into a circular ring, with no overlaps or gaps.

#### 6.1.4 Bedding

The pipe should be firmly and uniformly bedded along its entire length. Where rock or soft, spongy, or other unstable soil is encountered, it should be removed and replaced with suitable earth that is subsequently compacted to provide adequate support. See construction specifications or consult a geotechnical engineer. Under no conditions should gravel bedding be placed under a conduit through the embankment.

#### 6.1.5 Backfill

All backfill material and placement should conform to Structure Backfill specifications in P-SUP-01 Earthen Embankment.

### 6.2 Reinforced Concrete Pipe

The following criteria apply to RCP used in this BMP:

#### 6.2.1 Materials

RCP should have bell and singular spigot joints with rubber gaskets and should equal or exceed ASTM Designation C-443. See design and manufacturer's specifications.

#### 6.2.2 Bedding

All RCP conduits should be laid in a concrete bedding for their entire length. This bedding should consist of high-slump concrete placed under the pipe and up the sides of the pipe for at least 25 percent of its outside diameter, and preferably to the spring line, with a minimum thickness of 3 inches or as shown on the drawings.

#### 6.2.3 Laying pipe

Bell and spigot pipe should be placed with the bell end upstream. Joints should be made per recommendations from the manufacturer. After the joints are sealed for the entire run of pipe, the bedding should be placed so that all spaces under the pipe are filled. Care should be taken to prevent any deviation from the original line and grade of the pipe.

#### 6.2.4 Backfill

All backfill material and placement should conform to Structure Backfill specifications in P-SUP-01 Earthen Embankment.

### 6.3 Polyvinyl Chloride Pipe

The following criteria apply to PVC pipe used for this BMP:

#### 6.3.1 Materials

PVC pipe should be PVC-1120 or PVC-1220 conforming to ASTM D-1785 or ASTM D-2241.

### 6.3.2 Connections

Joints and connections to anti-seep collars should be completely watertight.

### 6.3.3 Bedding

The pipe should be firmly and uniformly bedded along its entire length. Where rock or soft, spongy, or other unstable soil is encountered, it should be removed and replaced with suitable earth that is subsequently compacted to provide adequate support.

### 6.3.4 Backfill

All backfill material and placement should conform to Structure Backfill specifications in P-SUP-01 Earthen Embankment.

### 6.4 Filters and Drainage Layers

In order to achieve maximum density of clean sands, filter layers should be flooded with clean water and vibrated just after the water drops below the sand surface. The filter material should be placed in lifts of no more than 12 inches.

Up to 4 feet of embankment material may be placed over a filter material layer before excavating back down to expose the previous layer. After removing any unsuitable materials, the trench may be filled with additional 12-inch lifts of filter material, flooded, and vibrated as described above until the top of adjacent fill is reached.

Filter fabrics should not be used in lieu of sands and gravel layers within the embankment.

### 6.5 Concrete

Concrete should meet the requirements of the VDOT Road and Bridge Specifications, latest edition.

### 6.6 Outlet Protection

### 6.7 Trash Rack and Debris Control Devices

All trash rack and debris control components should be stainless steel or galvanized metal per the VDOT specifications or rigid plastic. Trash racks attached to a concrete spillway structure should be secured with stainless steel anchor bolts.

## 7.0 Operations and Maintenance Considerations

This section presents general operation, maintenance, and inspection guidelines for principal spillways and components. However, these guidelines are not intended to be all-inclusive. Specific structures may require special measures not discussed here. The engineer is responsible for determining what, if any, additional items are necessary. Guidelines include:

- Spillway structures should be cleared of debris periodically and after any significant rainfall event where inspection reveals a significant blockage.
- During low water conditions, concrete spillway structures should be inspected to decide if water is passing through any joints or other structure contacts and to identify any cracks, spalling, broken, or loose sections. Any cracked, spalled, broken, or loose sections should be cleaned and refilled with an appropriate concrete patching material. A professional engineer should be consulted to repair extensive leakage, spalls, or fractures.
- Outlet protection (stilling basins) and discharge channels should be cleared of brush at least once per year. Ensure outlet protection is functioning in accordance with the approved plans.
- Trash racks and locking mechanisms should be inspected and tested periodically to make sure they are intact and operating.

- All sluice gates (or other types of gates or valves used to drain an impoundment) should be operated periodically to ensure proper function. The gate and stem should be periodically lubricated, and all exposed metal should be painted to protect it from corrosion.
- Any repairs made to the principal spillway (riser or barrel) should be reviewed by a professional engineer. Vertical trenching to expose the barrel should not be allowed under any circumstances. The trench side slopes should be stepped back at a 2:1 slope, minimum.

## 8.0 References


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# P-SUP-03 Vegetated Emergency Spillway

## 1.0 Definition

A vegetated emergency spillway is an open channel, usually trapezoidal in cross-section, that is constructed adjacent to or on an embankment. It consists of an inlet channel, a control section, and an outlet channel, and is lined with erosion-resistant vegetation.

## 2.0 Purpose and Applicability of Best Management Practice

A vegetated emergency spillway is to be used when the required maximum design flood volume may exceed the capacity of the principal spillway system. They are designed to convey a pre-determined design flood discharge without excessive velocities and without overtopping the embankment.

The details of the vegetated emergency spillway (such as channel dimensions, slope, stationing, etc.) should be included in the plans. The details are shown using a plan view of the spillway with existing and proposed contours as well as a profile of the spillways along with cross-sections including any pertinent details required for sizing calculations or construction.

## 3.0 Planning and Considerations

The adjacent topography (steepness of the abutments), the existing or proposed land use, and other factors (such as a roadway over the embankment) influence the design and construction of a vegetated emergency spillway.

Vegetated emergency spillways must be built in existing ground or “cut”- they cannot be constructed out of “fill” material. Even though an emergency spillway extends the life expectancy of an impoundment and lowers the associated downstream hazard conditions, it should not be located on any portion of the embankment fill. Therefore, additional land disturbance adjacent to the embankment must be accommodated during the planning stages of a project. Sometimes, an emergency spillway may not be practical due to this or other site-specific considerations.

If site topography or other constraints preclude the use of a vegetated emergency spillway in “cut,” the principal spillway can be oversized to pass the additional flows, or an armored emergency spillway may be provided. If armoring is chosen, then riprap, concrete, articulated concrete block, or any other permanent, non-erodible surface may be used, so long as it does not lower the effectiveness of the control section controlling the flow rate. Armoring with stronger materials such as riprap should be used when the slope is steep or velocities high. A cost analysis may be helpful to aid in the selection of the spillway type.

Vegetated emergency spillways should be used only where the soils and topography will permit safe discharge of the peak flow at a point downstream from the embankment and at a velocity that will not cause appreciable erosion. Other types of channel lining may be appropriate to prevent erosion if the velocities exceed the maximum permissible velocity for vegetation. Additional flood storage in the reservoir may be provided to reduce the design flow or the frequency which the spillway is engaged.

## 4.0 Stormwater Performance Summary

In general, it is recommended that a vegetated emergency spillway be designed to operate only during flows that meet or exceed the 100-year frequency storm. A vegetated emergency spillway may also be used as a safety feature to prevent overtopping of embankment and pass high flows when the principal spillway becomes clogged.

The purpose of a vegetated emergency spillway is to convey flows that are greater than the principal spillway’s design discharge at a non-erosive velocity to an adequate receiving channel.

## 5.0 Design Criteria

Types of soil and vegetation can impact the effectiveness of the vegetated emergency spillway. The slope and cross-sectional area also contribute to the velocity at which the water moves thus influencing erosion. Each of these variations are explained in detail below.

### 5.1 Layout

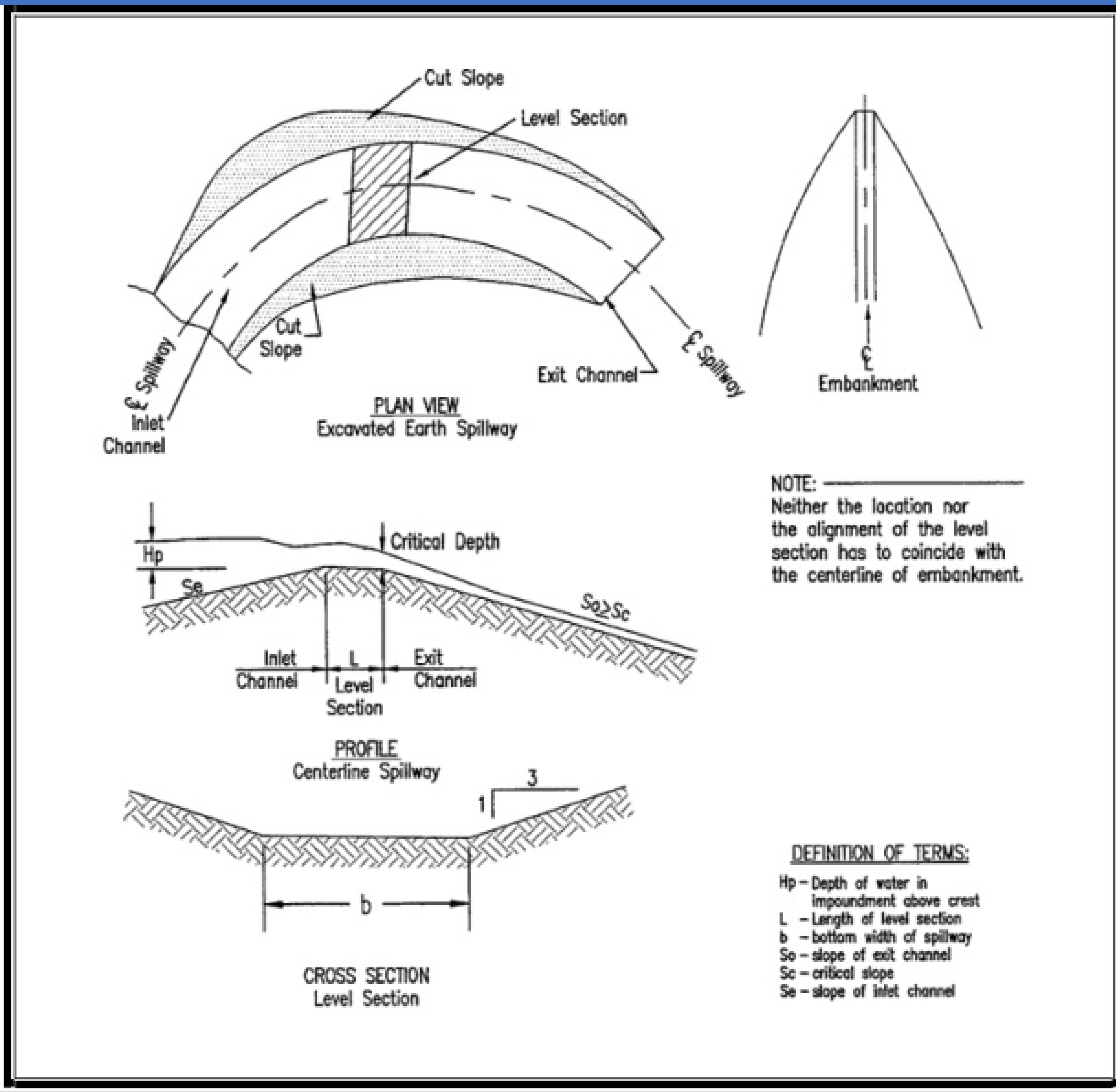
Vegetated spillways should be constructed in undisturbed earth in the abutments at one or both ends of an earthen embankment or over a topographic saddle anywhere on the periphery of the basin. The channel should be excavated into undisturbed earth or rock and the water surface, under maximum design flood discharge, should be confined within the cross section including the required freeboard. The maximum design water surface elevation through the emergency spillway should be at least 1 foot lower than the settled top of the embankment for 1 foot of freeboard.

Excavated spillways consist of three elements: (1) an inlet channel, (2) a level section, and (3) an outlet channel (see Figure P-SUP-03-1). Flow enters the spillway through the inlet channel and the depth of flow (Hp) is controlled in the level section and then discharged through the outlet channel. Flow in the inlet channel is sub-critical. Flow in the exit channel can be either critical or supercritical. The control section is, therefore, the point on the spillway where the flow passes through critical depth. It is recommended that the control section be installed close to the perpendicular intersection of the earthen embankment and the emergency spillway centerlines.

The topography must be carefully considered when constructing an emergency spillway. The alignment of the outlet channel is preferably straight and must align with a point far enough below the embankment to ensure that any flow escaping the outlet channel cannot damage the embankment. This may result in additional clearing and/or grading requirements beside the abutments, property line, and other areas to tie in the emergency spillway outlet to the receiving channel below the embankment.

Figure P-SUP-03-1 shows profiles along the centerline of a typical vegetated spillway. To reduce losses through the inlet channel, the cross sectional area of flow in the inlet channel should be large compared to the flow area at the control section. Where the depth of the channel changes to provide for the increased flow area, the bottom width should be altered gradually to avoid abrupt changes in the shape of the sloping channel banks. For vegetated emergency spillways, the recommended slope for side channel banks is 3:1 for maintenance purposes unless an alternate maintenance plan is proposed and approved The outlet channel must have an adequate slope to discharge the peak flow within the channel. However, the slope must be no greater than that which will produce maximum permissible velocities for the soil type or the planned grass cover of the spillway and receiving channel.

*Figure P-SUP-03-1 Typical Plan and Profiles Along the Centerline of an Earthen Spillway*




### 5.2 Soil Type

The type of soil and vegetative cover used in an emergency spillway can be used to establish the spillway design dimensions. Soil types are classified as erosion-resistant – soils with a K factor greater than or equal to 0.37 and easily erodible – soils with a K factor less than 0.37.

Erosion-resistant soils are those with a high clay content and high plasticity. Typical soil textures for erosion-resistant soils are silty clay, sandy clay, and clay. Easily erodible soils are those with a high content of fine sand or silt and a low plasticity or non-plastic. Typical soil textures for easily erodible soils are fine sand, silt, sandy loam, and silty loam. Table P-SUP-03-2 provides permissible velocities for a vegetated spillway based on its soil type, vegetated cover, and exit channel slope.

When a channel lining is required, the lining used should be selected based on the values provided in Table P-SUP-03-1. Note that where the velocity exceeds 10 feet per second (fps) or tractive force exceeds 10 square feet (ft2), a rigid lining will be used in place of the flexible channel linings specified below.

| Table P-SUP-03-1 Channel Lining Type Design Guidelines | |
|---|---|
| **Channel Linings using the Permissible Velocity Method** | |
| **Lining Type** | **Applicable Velocity** |
| EC-2 Type 1, 2, 3, or 4 | 0-4 fps |
| EC-3 Type 1 | 4-7 fps |
| EC-3 Type 2 | 7-10 fps |
| **Channel Linings Using the Tractive Force Method** | |
| **Lining Type** | **Applicable Force** |
| EC-2 Type 1 | 0-1.5 lb/ft2 |
| EC-2 Type 2 | 1.5-1.75 lb/ft2 |
| EC-2 Type 3 | 1.75-2.0 lb/ft2 |
| EC-2 Type 4 | 2.0-2.25 lb/ft2 |
| EC-3 Type 1 | 2.25-6.0 lb/ft2 |
| EC-3 Type 2 | 6.0-8.0 lb/ft2 |
| EC-3 Type 3 | 8.0-10.0 lb/ft2 |

| Table P-SUP-03-2 Permissible Velocities for Grass-Lined Channels | | |
|---|---|---|
| **Channel Slope** | **Lining** | **Permissible Velocity*** |
| 0 to 5% | Bermudagrass | 6 ft/second |
| | Reed canarygrass<br>Tall fescue<br>Kentucky bluegrass | 5 ft/second |
| | Grass-legume mixture | 4 ft/second |
| | Red fescue Redtop<br>Annual lespedeza<br>Small grains (temporary) | 2.5 ft/second |
| 5 – 10% | Bermudagrass | 5 ft/second |
| | Reed canarygrass<br>Tall fescue<br>Kentucky bluegrass | 4 ft/second |
| | Grass-legume mixture | 3 ft/second |

| Table P-SUP-03-2 Permissible Velocities for Grass-Lined Channels | | |
|---|---|---|
| **Channel Slope** | **Lining** | **Permissible Velocity*** |
| Greater than 10% | Bermudagrass | |
| | Reed canarygrass | 4 ft/second |
| | Tall fescue | 3 ft/second |
| | Kentucky bluegrass | |

* For highly erodible soils, permissible velocities should be decreased by 25%. An erodibility factor (K) greater than 0.35 would indicate a highly erodible soil. Erodibility factors (K factors) for many Virginia soils are listed in Chapter 6.

Source: Soil and Water Conservation Engineering, Schwab et al.

### 5.3 Vegetative Cover

The type, length, and slope of vegetative cover affects the design of a vegetated spillway. Vegetation provides a degree of retardance to the flow through the spillway by its natural roughness. Table P-SUP-03-3 gives retardance values for various heights of vegetative cover. Retardance for a given spillway will depend mostly on the height and density of the cover chosen. Generally, after the cover is selected, “retardance with a good, uncut condition” should be used to find the capacity. Because a condition offering less protection and less retardance exists during the establishment period and after mowing, a lower degree of retardance should be used when designing for stability. Refer to Appendix A Hydrology and Hydraulic Methods and Computations for further design guidance.

| Table P-SUP-03-3 Retardance Classifications for Vegetative Channel Linings | | | |
|---|---|---|---|
| **Retardance** | **Vegetative Cover** | **Stand** | **Condition** |
| B | Tall fescue | Good | Unmowed – 18” |
| | Grass-legume mixture | Good | Unmowed – 20” |
| | Small grains, mixture | Good | Uncut – 19” |
| | Bermudagrass | Good | Tall – 12” |
| | Reed canarygrass | Good | Mowed – 14” |
| C | Bermudagrass | Good | Mowed – 6” |
| | Redtop | Good | Headed – 18” |
| | Grass-legume mixture - summer | Good | Unmowed – 7” |
| | Kentucky bluegrass | Good | Headed – 9” |
| | Small grains, mixture | Poor | Uncut – 19” |
| | Tall fescue | Good | Mowed – 6” |
| D | Bermudagrass | Good | Mowed – 2.5” |
| | Red fescue | Good | Headed – 15” |
| | Grass-legume mixture – spring and fall | Good | Mowed – 2” |

## 5.4 Hydraulic Design

The hydraulic design of earthen spillways can be simplified if the effects of spillway storage are ignored. Stormwater facilities designed for site-specific compliance with state or local stormwater management regulations are typically small, and the minimal storage effects within the spillway typically do not affect the flood routing.

Two design calculation procedures are presented in Appendix A Hydrology and Hydraulic Methods and Computations. The first (Procedure 1) is a conservative design procedure that is also found in the Virginia Erosion & Sediment Control Handbook (VESCH) 1992 edition (Std., & Spec. 3.14). This procedure is typically acceptable for stormwater management basins. The second method (Procedure 2) uses the roughness (or retardance) and durability of the vegetation and soils within the vegetated spillway. This second design is appropriate for larger or regional stormwater facilities for which the construction inspection and permanent maintenance have greater implications to protect downstream properties in larger watersheds. These larger facilities typically control relatively large watersheds and are located such that the stability of the emergency spillway is essential to safeguard downstream features due to the larger flows.

If the inflow is known (from the post-developed condition hydrology) and either the desired maximum water surface elevation or the approximate width of the proposed emergency spillway (established by the embankment geometry and the adjacent topography), then the relationship between Hp, the depth of flow through the emergency spillway, and the emergency spillway bottom width (b) can be established using design Procedure 1.

If the required discharge capacity (Q) permissible velocity (V; see Table P-SUP-03-2), degree of retardance, C (see Table P-SUP-03-3), and the natural slope of the exit channel (so), are known, then the bottom width (b) of the level and exit sections and the depth of flow (Hp) may be computed using design Procedure 2.

The hydraulic design of a vegetated emergency spillway should comply with the following:

1. The maximum permissible velocity for vegetated spillways should be selected using Table C-1.
2. The slope range of the exit channel provided in Table 16-11 (Chapter 16 1999 VSM Handbook – update to 2009 version), is a minimum slope range needed to ensure supercritical flow in the exit channel.
3. Spillway side slopes should be no steeper than 3H:1V unless the spillway is excavated into rock to facilitate maintenance.
4. For a given Hp, a decrease in the outlet slope from so, as given in Table 16-11 (Chapter 16), decreases the spillway discharge, but increasing the outlet slope from so does not increase discharge.
5. The outlet channel should be aligned and graded as straight as possible and, at a minimum, the same cross section as the control section.
6. 6. The inlet channel should be aligned and graded as straight as possible to minimize erosion impacts.
7. The selected bottom width of the spillway should not exceed 35 times the design depth of flow.

   Where this ratio of bottom width to depth is exceeded, the spillway is likely to be damaged by meandering flow and accumulated debris. Whenever the required bottom width of the spillway is excessive, the use of a spillway at each abutment of the dam should be considered. The two spillways do not need to be of equal width if their total capacity meets design requirements. If the required discharge capacity exceeds the ranges shown in the referenced tables, or topographic conditions preclude the construction of the exit channel bottom using a slope that falls within the designated ranges, alternate design procedures are recommended.

8. Vegetated emergency spillways should be designed for use with the 100-year frequency storm or greater.

## 6.0 Construction Specifications

Installation of a vegetated emergency spillway consists of the following steps:

1. Excavating the proper bottom width and side slopes according to the approved plan;
2. Backfilling with topsoil in accordance with C-SSM-02 Topsoiling or as specified in the plan, whichever

   is larger;
3. Ensure materials are suitable for proposed use and meet any testing requirements specified in the

   design plans and associated documents as well as any relevant specifications such as the Surface Stabilization Measures; and
4. Stabilizing the area following the applicable Minimum Standards in 9VAC25-875-560.

   Overall, widely acceptable construction standards and specifications for a vegetated emergency spillway on an embankment, such as those developed by the U.S. Department of Agriculture (USDA)-Natural Resource Conservation Service (NRCS) or the U. S. Army Corps of Engineers should be followed. Further guidance is provided in the USDA-NRCS Engineering Field Manual and the National Engineering Handbook. Specifications for all earthwork and any other related work should conform to the methods and procedures that apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government if more stringent.

## 7.0 Operations and Maintenance Considerations

The following maintenance and inspection guidelines are recommendations. The engineer must decide if additional criteria are needed based on the size and scope of the facility. Recommended measures include:

- Vegetated emergency spillway channels should be mowed concurrent with the embankment and should not be cut to less than 6 to 8 inches high.
- The emergency spillway approach and discharge channels should be cleared of brush and other woody growth periodically.
- Any obstructions to flow, such as debris, should be removed.
- After any flow has passed through the emergency spillway, the spillway crest (control section) and exit channel should be inspected for erosion. All eroded areas should be repaired and stabilized immediately.

## 8.0 References

USDA Natural Resource Conservation Service. Engineering Field Manual.

USDA Natural Resource Conservation Service. National Engineering Handbook.

USDA Natural Resource Conservation Service. Technical Release No. 60: Earth Dams and Reservoirs.

U. S. Department of the Interior. Design of Small Dams. 1987.

Virginia Erosion and Sediment Control Handbook (VESCH), 1992.

# P-SUP-06 Pre-Treatment

The following text is adapted from Draft - Pennsylvania Post-Construction Stormwater Management (PCSM) Manual, 2023.

## 1.0 Definition

Pre-treatment is a practice in place to support operations and maintenance of stormwater assets.A pre-treatment system prolongs the lifespan of a best management practice (BMP) by removing trash and floatables, organic materials, coarse sediments, particulate matter, and associated pollutants from stormwater runoff prior to inflow to the post-construction stormwater BMP. They also slow the velocity of flow that could cause erosion prior to entering the BMP.

## 2.0 Purpose and Applicability of Best Management Practice

Pretreatment is a component of the stormwater BMP inlet. Pre-treatment typically consists of dissipaters, settling devices, or filtering devices. Pretreatment of runoff entering BMPs intended for infiltration and evapotranspiration is necessary to trap coarse sediment particles before they reach and prematurely foul the surface area of the BMP.

Pre-treatment practices are also necessary to extend the service life of quantity-only BMPs that impound water, as these areas are subject to accumulation of heavy metals, sediment, and other contaminants contained within stormwater runoff.

## 3.0 Planning and Considerations

Typically, pre-treatment includes filtration and/or the slowing of stormwater velocities to allow sediment to settle. Pre-treatment can improve the function and lifespan of a BMP and reduce maintenance costs through the capture of sediment, gross solids, heavy metals, petroleum products, and debris from inflows prior to flows entering a BMP.

Diversion of larger storm flows away from a water quality or volume-reducing BMP to a facility designed for quantity control is recommended. This diversion reduces the hydraulic loading and protects the water quality and volume reduction function of the BMP including the protection of infiltration capacity.

For infiltration BMPs, pre-treatment is critical to ensure long-term function, and diversion of larger storms to reduce hydraulic loading is often required to meet limitations on ponding depth. Pre-treatment measures must be designed to evenly spread runoff across the entire width of the infiltration area.

Several pre-treatment measures are feasible, depending on the post-construction stormwater BMP and whether it receives sheet flow, shallow concentrated flow, or deeper concentrated flows.

There may be site conditions for which certain pre-treatment practices are more preferable than others. Table P-SUP-06-1 Pre-Treatment Selection Matrix should be used as a guide for the designer in what is likely to be an iterative selection process.

**Table P-SUP-06-1 Pretreatment Selection Matrix**

| BMP | Roof Stormwater Isolation | Limit Hydraulic Loading | Treatment Train | Sediment Forebays | Grass Channels & Filter Strips | Reverse Slope Bench | Inlet Sump | Manufactured Devices | Sumped Inlet with Traps or Filters |
|---|---|---|---|---|---|---|---|---|---|
| Grass Channel | · | | | | · | | | | |
| Infiltration Practices | · | · | · | · | · | · | · | · | · |
| Bioretention | · | · | · | · | · | | · | | · |
| Dry Swales | · | · | · | · | · | | · | | · |
| Wet Swales | · | · | · | · | · | | | | |

| Table P-SUP-06-1 Pretreatment Selection Matrix | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| BMP | Roof Stormwater Isolation | Limit Hydraulic Loading | Treatment Train | Sediment Forebays | Grass Channels & Filter Strips | Reverse Slope Bench | Inlet Sump | Manufactured Devices | Sumped Inlet with Traps or Filters |
| Filtering Practices | | · | · | · | · | | · | · | · |
| Wet Ponds | | | · | · | | · | | · | |
| Extended Detention Ponds | | | · | | | · | | · | |
| Regenerative Swale Conveyance | | | · | · | | | | | |
| Constructed Wetlands | | · | · | · | | · | | · | |
| Rainwater Harvesting | · | · | | | | | | · | · |

## 4.0 Stormwater Performance Summary

Not applicable.

## 5.0 Design Criteria

### 5.1 Roof Stormwater Isolation

Stormwater from building rooftops carries minimal sediment load and generally low amounts of other pollutants such as deicing salts and heavy metals. Isolating this roof water is considered a pre-treatment practice that minimizes exposure to common pollutants before stormwater enters a BMP.

Roof drainage, while able to be directed to the BMP as sheet flow or directly connected to the BMP by roof leaders, may still require pre-treatment. Direct connection should not be used in conjunction with copper or other metal roofs, which may be susceptible to runoff of heavy metals.

| Table P-SUP-06-2 Rooftop Isolation Design Criteria | |
|---|---|
| Element | Design Criteria |
| General | Isolation of roof water is ideal pre-treatment for infiltration facilities. Leaf debris must be screened from the isolated stormwater prior to inflow of any downstream BMP. |
| Location | Roof drainage can either be directed as sheet flow over short distances of turf before entering a BMP or directly connected via roof leaders (e.g., pre-treatment may still be required in the form of screens, gutter guards). |
| Construction Methods | Roof leaders should be designed in conformance with local plumbing code. |

### 5.2 Limit Hydraulic Loading

Diversion of flow from large storm events is often needed to reduce hydraulic loading to water quality and infiltration BMPs. Larger storm events tend to be the most erosive, and erosion is a significant source of BMP failure.

The first 0.5 to 1 inch of runoff (i.e., the volume of water often referred to as the “first flush”) typically contains the highest concentrations of pollutants found in stormwater. Because most rainfall events are smaller than 1 inch, treatment of the first flush of pollutants is important to downstream water quality and BMP longevity.

Common hydraulic loading limiting techniques include:

- Limiting the drainage area to an individual BMP and providing safe, non-erosive, passage of the 100-year/24-hour storm preferably around the water quality BMP.
- Velocity entering pre-treatment facilities must be lower than 10 feet per second (fps) or energy dissipation must be provided to prevent mixing of large storm flows within the BMP.
- Backwater from a BMP may be used to limit inflow and direct flow from larger storm events to a rate-control BMP. In these cases, an additional 1 foot of head above that required for the water quality treatment volume (Tv) is allowed where necessary if there is no flow path created through the volume/water control BMP.
- An excess flow channel, often directing flows to a separate rate control facility, should be designed for all larger storms, generally all storms up to and including the 100-year/24-hour storm. The split can be accomplished using a flow splitter, submerged inlet, or other means of bypass.
- Storm drain inlet capacity can be limited to direct the desired flow to one facility, and gutter capacity can be designed to direct excess flows from large storms to another facility.
- Rate control can be provided in an upstream facility. Flow can then be metered to a water quality BMP.
- Flows can be separated from a site to minimize the need for rate control and reduce the stress on water quality BMPs. Examples include the isolation of roof water, the maximization and enhancement of natural landscape features, and treatment at the source techniques.

### 5.3 Sediment Forebays

Sediment forebays are BMP components that reduce flow velocities into a BMP, allowing sediment and debris to settle. Good engineering practice is to include forebays at all inflow locations receiving flow from both pervious and impervious drainage areas. Forebays can provide a temporary or permanent ponding area and are most typically used with surface BMPs. This ponding area is typically separated from the rest of the BMP by an earthen berm, riprap berm, concrete wall, or gabion wall. The berm or wall acts as a weir allowing water to overtop the berm from higher in the water column where water quality is typically better. Lower in the water column, the water can be filtered through the berm. The forebay bottom can be hardened to facilitate sediment removal.

| Table P-SUP-06-3 Forebay Design Considerations | |
|---|---|
| **Element** | **Design Consideration** |
| Location | Forebays should be located at major inflow locations to a BMP.<br>Major inflow locations are those receiving flow from more than 0.25 acre of impervious surface or 1.5 acres of pervious surface. |
| Storage Volume | The following forebay storage volumes are generally recommended for specific BMP types when not part of a treatment train:<br>• Constructed Wetlands: 10% to 15% of the total permanent pool volume.<br>• Wet Ponds: 10% to 15% of the total permanent pool volume.<br>• Extended Detention Basins: 10% to 15% of volume of the 2-year/24-hour storm.<br>• Infiltration Practices: 25% of the managed volume for any infiltration facility with a contributing drainage area greater than or equal to 21,780 square feet; 15% of the managed volume for any infiltration facility with a contributing drainage area less than 21,780 square feet.<br>• Other BMPs: a minimum of 0.1 inch of runoff from each impervious acre managed by the BMP. |
| Depth | The following forebay depths are generally recommended for specific BMP types:<br>• Constructed Wetlands: 4- to 5-foot-deep storage at inlet pools (at least as deep as other open water areas). Provide a minimum of 1-foot-deep storage over permanent pool in all forebays.<br>• Wet Basins: 4- to 5-foot-deep storage with a minimum flow length of 10 feet. Provide a minimum of 1-foot-deep storage over permanent pool in all forebays.<br>• Naturalized Detention Basins: As determined to meet storage volume guidance and a minimum flow length of 10 feet.<br>• All other BMPs: Minimum 18 inches deep and meet storage volume guidance and site constraints. Must fully dewater within 72 hours. |
| Length (in direction of flow) | The length to width ratio of the forebay should be 2:1 or greater. Baffles or low head berm may be used to create a longer flow path. |
| Flow Through Velocity | It is good engineering practice to provide an average velocity through the forebay of less than 2 fps during inflow from a storm event that produces the required volume. The average velocity can be determined using the continuity equation. $V=Q/A$<br>Where:<br>v = average velocity. Q = average flow rate.<br>A = average cross-sectional area perpendicular to flow assuming the forebay is 50% full of sediment. |

| Table P-SUP-06-3 Forebay Design Considerations | |
|---|---|
| **Element** | **Design Consideration** |
| Sediment Management | It is generally recommended that the accumulated sediment be removed before it occupies 50% of the forebay volume. It is good engineering practice to install a permanent vertical marker that indicates sediment depth in all forebays. It should be marked with the maximum depth of sediment storage. Virginia Department of Environmental Quality (DEQ) recommends maintenance prior to seasonal rainy periods. |
| Stabilization | Provide energy dissipators at inflow points within the forebay (see C-ECM-15 Outlet Protection). For high velocity inflows, energy dissipation may cover the entire bottom of the forebay.<br>When an earthen berm is used, stabilize the earthen berm as appropriate. |

**5.4 Grass Channels and Filter Strips as Pretreatment**

Vegetated conveyance channels and filter strips convey stormwater to a BMP. When used as pre-treatment, these systems should be lined with grass or wetland plants. Vegetated conveyance channels are designed to carry flows from the drainage area to a BMP. When designing vegetated conveyance channels, it is good engineering practice to select channel properties that reduce flows, encourage settlement of sediment, and provide vegetation to filter stormwater prior to entering a BMP.

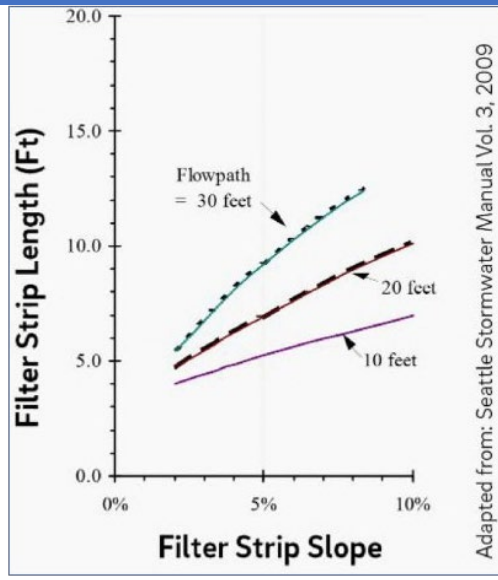
| Table P-SUP-06-4 Grass Channel as Pre-treatment Design Considerations | |
|---|---|
| **Element** | **Design Consideration** |
| Slope | Minimize slope to slow flow and allow for settlement of sediments within the channel. |
| Vegetation | When velocities permit, channels should be lined with an appropriate seed mix for the surrounding site. Vegetation should be maintained to a height of 5 to 8 inches to provide retardance to stormwater flows unless designed with wetland plants. |
| Stabilization | Dependent on flow rates in the channel. Select appropriate soil stabilization and matting in accordance with C-SSM-05 Soil Stabilization Blankets and Matting.<br>Riprap or concrete-lined channels are not acceptable for pre-treatment. |
| Construction Methods | Construction methods should be in general conformance with P-CNV-01 Grass Channels. |

A filter strip acts as a pre-treatment for sheet flow and shallow concentrated flow entering a BMP from adjacent surfaces. Like other pre-treatment components, a filter strip works by reducing runoff velocity and trapping sediment and pollutants. Filter strips may provide limited infiltration, but the infiltration volume is not considered significant unless designed with compost amendments in accordance with P-FIL-08 Soil Compost Amendments.

| Table P-SUP-06-5 Filter Strip as Pre-treatment Design Considerations | |
|---|---|
| **Element** | **Design Consideration** |
| Flow | Filter strips function best for sheet flow and can be eroded when subjected to concentrated flows.<br>Use gravel diaphragms or level spreaders in accordance with C-ECM-14 Level Spreaders |
| Vegetation | Select vegetation that is appropriate for site conditions including soil, hydrology, light, and pollution tolerances. |
| Contributing Drainage Area | Contributing drainage area (CDA) land slopes should not exceed a grade of 10% upstream of the filter strip provide Inlet the filter strip.<br>The maximum length of a CDA without an inlet energy dissipater is 100 feet parallel to flow. |
| Filter Strip | Non-erosive velocities are required for filter strips.<br>Good engineering practice is to limit filter strip slopes to 8% or less in the general direction of flow and less than 1% perpendicular to the general flow direction, unless the design includes TRM geotextile stabilization.<br>The filter strip should be installed perpendicular to flow.<br>The length of the filter strip parallel to the flow path can be selected from Figure P-SUP- 06-01 based on the slope of the filter strip for contributing flow paths less than 30 feet long. For flow paths longer than 30 feet, provide 1 foot of filter for every 2 feet of drainage path. |

**5.5 Gravel Diaphragms**

**Figure P-SUP-06-1 Filter Strip as Pretreatment Design Specifications (PWD 2020)**




A pea gravel diaphragm at the top of the slope is required for vegetated filter strips that receive sheet flow. The pea gravel diaphragm is created by excavating a 2-foot-wide and 1-foot- deep trench that runs on the same contour at the top of the filter strip and maintains a cross slope of 0%. Scarify bottom of trench and line with woven geotextile fabric against the pavement and bottom. The diaphragm serves two purposes. First, it acts as a pre- treatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip. To maintain it, periodically remove any build-up of sediments and debris and continuously monitor to prevent development of rills and gullies.

- The flow should travel over the impervious area and to the practice as sheet flow and then drop at least 2 inches onto the gravel diaphragm. The drop helps to prevent runoff from running laterally along the pavement edge, where grit and debris tend to build up (thus allowing bypass of the filter strip).
- A layer of filter fabric should be placed between the gravel and the underlying soil trench.
- If the contributing drainage area is steep (6 percent slope or greater), then larger stone (clean bank run gravel that meets Virginia Department of Transportation [VDOT] #57 grade) should be used in the diaphragm.
- If the contributing drainage area is solely turf (e.g., sports field), then the gravel diaphragm may be eliminated.

### 5.6 Reverse Slope Bench

A reverse slope bench is a pervious, usually vegetated shelf around the perimeter of a BMP that has a ponding component to pre-treat sheet flow or shallow concentrated flow. The flow is captured in the reverse slope of the bench.

| Table P-SUP-06-6 Reverse Slope Bench Design Considerations | |
|---|---|
| **Element** | **Design Consideration** |
| Location | Reverse slope benches are located around the perimeter of a BMP. Typically, they are 1 foot above the ponding elevation, soil media elevation, or infiltration surface. |
| Height | The reverse bench should slope 1 inch per foot away from the ponding area. This creates a form of forebay in which stormwater is stored in a small V-shaped depression before it overflows into the basin. |
| Width | To determine the required width of the reverse bench, divide the required pre- treatment volume by the storage provided in the reverse slope, except the minimum width of the reverse bench should be 6 feet and the maximum width is 10 feet.<br>Storage is equal to the sum of storage in topsoil on the bench and embankment and ponding below the lip of the reverse slope bench. |
| Stabilization | Plant with grasses that can be mowed to less than 6 inches tall or can be planted with native species that form a more natural buffer as illustrated above. |
| Construction Methods | Do not compact soil within 2 feet from surface.<br>Provide a minimum of 6 inches of topsoil. |

### 5.7 Inlet Sumps

Inlet sumps are areas of dead storage in storm inlets and other structures below the level of designed outflow where sediment and other gross pollutants may be captured and accumulate. The accumulated pollutants must be periodically removed to ensure the continued function of the device. Catch basins may also incorporate inverted elbows, trash screens, or other outlet controls to capture floating trash and debris. These devices provide dissipation and settling.

Unless underdrains or other devices are incorporated to drain water between storm events, these devices will retain stagnant water and may provide ideal habitat for mosquitos.

### 5.8 Manufactured Devices

Manufactured devices can treat stormwater pollutants before stormwater enters another downstream BMP. Manufactured devices may extend the life of a BMP and reduce required maintenance. Examples range from trash racks and gross solids filters (such as downspout leaf screens) to submerged orifices that screen floatables, to inlet screens and HDSs.

Generally, manufactured devices focus on preventing trash, grit, oils, and in some cases settleable solids at sizes on the order of 50 microns (μm) or greater from reaching and clogging infiltration facilities. This section includes manufactured devices that are commonly used for pre-treatment but are not likely to be used as stand-alone water quality BMPs. Types of manufactured devices included in this section are trash capture devices (includes manufactured course solids screens) and manufactured flow control devices (FCDs; includes manufactured flow splitters and passive FCDs).

MTDs are different than manufactured devices used for pre-treatment. MTDs may be used for pre-treatment or as a stand-alone BMP when authorized for such use by DEQ.

### 5.9 Trash Capture Devices

Trash capture devices (TCDs) include inlet inserts (Figure P-SUP-06-2), bar racks (Figure P-SUP-06-3), screens with high flow capacities (Figure P-SUP-06-4), or screens or netting systems (Figure P-SUP-06-5). These devices are used to capture debris, litter, and coarse sediments before a settlement tank or pond, filtration, detention, infiltration, or other BMPs.

Operation of TCDs requires periodic maintenance inspections and frequent debris removal. Timely removal of leaves, vegetation, and other organic matter can prevent the discharge of pollutants to downstream BMPs. ASTM E64 identifies pending test methods for TCDs. TCDs are important for pre-treatment and supporting BMP water quality function, but do not provide water quality credit on their own.

Welded bar trash racks are not considered a manufactured device.

***Figure P-SUP-06-2 Trash Capture Device Example – Inlet Inserts Fabco Industries***

***Figure P-SUP-06-3 Trash Capture Device- Bar Racks – Rain Harvest Systems***

*Figure P-SUP-06-4 Trash Capture Device Example – High-Flow Screens - Bio Clean*

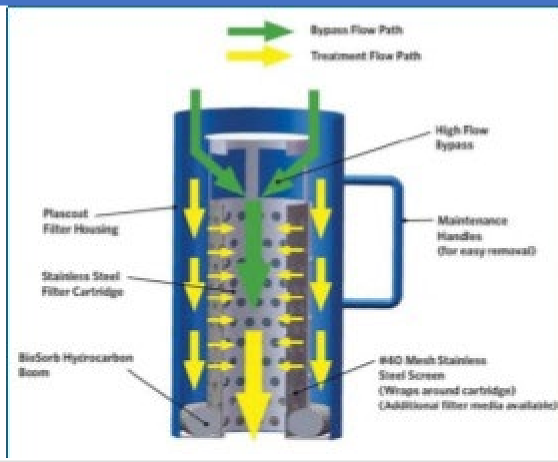



**Table P-SUP-06-7 Trash Capture Device Design Specifications**

| Parameter | Specifications |
|---|---|
| Material | Material should be durable and resistant to photo-degradation, weathering, oxidation, or other corrosive conditions.<br>Epoxy-coated rebar should be used. |
| Opening Size | The size of the openings is typically between 0.25 and 4.5 inches. The size of the device openings should be less than the opening size of the downstream component. |

### 5.10 Manufactured Coarse Solid Screens

Manufactured coarse solid screens are a type of TED; however, they are specifically geared to the capture of coarse solids and are generally adhered to the exterior of pre-cast structures. Like TCDs, these devices do not provide WQM credit, only pre-treatment function.

Coarse solid screens and TCDs may extend the life of a BMP and reduce maintenance requirements. Examples include inlet screens and gross solids filters. All BMPs should have a means for managing trash and coarse solids.

*Figure P-SUP-06-5 Manufactured Coarse Solids Screen*

| Table P-SUP-06-8 Specifications for Manufactured Coarse Solids Screens | |
|---|---|
| **Parameter** | **Specification** |
| Material | Material should be durable and resistant to photo-degradation, weathering, oxidation, or other corrosive conditions. |
| Opening Size | The size of the opening is typically 0.25 inch in diameter. The size of the device opening should be less than the opening of the downstream orifice. |

### 5.11 Manufactured Flow Control Devices

Types of manufactured flow-control devices (FCDs) include passive, active, or adaptable. Pre-treatment FCDs are typically passive but can be active. Passive FCDs often include weirs, orifices, and constant head devices.

Passive FCDs can include manufactured FCDs, such as vortex regulators, which act as an orifice but have a larger effective opening size to allow for the passage of trash and limits clogging. Redirection of higher flows can also be a passive management method to prevent scouring flows from passing through a filter or BMP if there are no moving parts included in the device.

Manufactured flow splitters redirect portions of runoff from larger storm events to protect infiltrating BMPs or other vegetated surfaces from scour. Flow splitters may be passive or active FCDs. Flow splitters as pre-treatment are generally passive, but they may be active if they are used in conjunction with a valve.

### 5.12 Sumped Inlet with Traps or Filters

An inlet and grate can be modified for pre-treatment to incorporate a sump and trap. A sump is provided within an inlet box and is designed such that the bottom of the inlet box is below the outlet pipe invert. This sump area provides storage volume for sediment and debris to settle out of the collected runoff. A trap or hood may be attached over the outflow pipe to prevent floatable or other debris from traveling downstream through the system or clogging the outflow pipe. Inlets installed with a trap or hood and sump maximize pre-treatment efficiencies.

| Table P-SUP-06-9 Sumped Inlet with Traps or Filter | |
|---|---|
| **Element** | **Design Consideration** |
| Location | Sumps, traps, and filters can be provided for inlets upstream of a BMP to pre- treat all stormwater volumes that pass through an inlet box. |
| Sump Depth | Generally, a minimum 24 inches of sump is recommended below the invert of the outlet pipe (see trap manufacturer recommendations). |
| Trap Placement | Trap should be installed over outlet pipe opening within inlet per the manufacturer's instructions.<br>When a sump and hood are included in an inlet design, DEQ recommends that a minimum 18 inches be provided between the bottom of the hood and the top of the sump.<br>A skirt or wall can be used to trap floatable trash and hydrocarbons, similar in design to a grease trap. |
| Inlet Screens/Filters | Should be installed in inlet according to manufacturer's specifications. |
| Connection | Generally designed to provide pre-treatment for inflow pipes to BMPs |
| Maintenance | Inlets should be emptied when debris and sediment fill half of the storage in the area. |

## 6.0 Construction Specifications

Specifications will vary based on the element selected for pre-treatment.

## 7.0 Operations and Maintenance Considerations

Specifications will vary based on the element selected for pre-treatment.

## 8.0 Reference

Pennsylvania Department of Environmental Protection. 2023. Pennsylvania Post-Construction Stormwater Management (PCSM) Manual. Draft ed. 374

# P-SUP-07 Quantity Only Approach to BMPs

## 1.0 Definition

### 1.1 Detention Basin

Detention basins are earthen structures constructed by creating an impoundment either within a natural depression or through excavation of existing soil and installation of an embankment. Detention basins attenuate stormwater runoff by increasing runoff flow lengths, attenuating peak events, and storing stormwater. It is generally intended that the main ponding area completely drains down to dry conditions between storms; however, a normal pool below the detention storage can be provided. These best management practices (BMPs) are designed to manage peak rates and control the quantity of discharge volume to satisfy channel and flood protection requirements. There are variations, such as those discussed in P-BAS-03 Extended Detention Pond or P-BAS-02 Wet Pond, that can support additional water quality management for site compliance with pollutant removal requirements, which can be referenced in other water quantity BMP specifications. This specification focuses on the design details for a basin that provides no stormwater quality treatment with the only function of controlling rate and volume of stormwater runoff.

### 1.2 Underground Detention Basin

Underground detention basins are excavated, usually under pavement, playing fields, and open space/common areas to attenuate stormwater runoff by temporarily storing runoff and draining down to dry conditions between storms.

Stormwater is typically stored in stone and pipe but can be held in vaults or other manufactured materials. These systems primarily attenuate peak rates and manage runoff volume for channel and flood protection requirements in areas where land value is high (e.g., in developed urban settings). These BMPs are also important for thermal mitigation because they cool stormwater underground before releasing it downstream.

## 2.0 Purpose and Applicability of Best Management Practice

The primary application for water quantity control is to attenuate peak flows, limit downstream flooding, and provide channel and flood protection volumes to meet stormwater quantity requirements. The primary application of this BMP is for use on sites that meet their water quality objectives through other means, although their use is not limited to such.

### 2.1 Detention Basin Feasibility/Limitations

The following feasibility criteria should be evaluated when considering detention basins as the final practice to provide channel and flood protection detention volumes with upstream treatment trains or other runoff-reducing or treatment BMPs provided onsite to achieve the stormwater quality treatment required.

| Table P-SUP-07-1 Feasibility Criteria | |
|---|---|
| **Parameter** | **Details** |
| Depth to Water Table and Bedrock | The bottom of the detention facility should not intersect the seasonally high groundwater table. If the basin has a permanent pool below the detention areas, the pool can intersect the groundwater table elevation. Refer to P-BAS-02 Wet Pond for design guidelines for this situation. Where shallow groundwater is encountered, the design and installation of an impermeable liner on the bottom of the basin can be explored. |
| Soils | The permeability of soils is seldom a design constraint for detention basins. Infiltration through the bottom of the pond is encouraged unless it impairs the integrity of the embankment. Soil explorations should be conducted at the proposed basin embankment to estimate infiltration rates and properly design the embankment cut-off trench.<br><br>An initial soil exploration and investigation should be conducted to rule out infiltration as a preferred practice and to rule out the presence of karst topography. |
| Tailwater Conditions | The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the basin. Design tailwater condition elevation will be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a high tide elevation evaluation will accompany the tailwater condition evaluation. |
| Tidal Impacts | The outlet elevation of a basin should be located above the tidal mean high water elevation to limit tidal backflow into the pond. No detention storage used for runoff routing will be accounted for below the mean high water tidal elevation. |
| Perennial Streams | Locating detention basins in perennial streams is typically not allowed and will require Section 401 and Section 404 permits from the appropriate state or federal regulatory agency. |

| Table P-SUP-07-2 Detention Basin Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and other such structures | 25 feet horizontal | Closer offsets may be considered on a case-by-case basis where impermeable liners are specified by the designer. |
| Property lines | 10 feet horizontal | |
| Septic system drain fields | 50 feet horizontal | |
| Private water wells | 50 feet horizontal | |
| Underground utility | 5 feet horizontal | Refer to utility owner standards |

**Note:**

* Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the toe of the embankment on the downstream side and the design high water on the upstream side.

**2.2 Underground Detention Basin Feasibility/Limitations**

The primary application for water quantity control is to attenuate peak flows, limit downstream flooding, and provide channel and flood protection volumes to meet stormwater quantity requirements. This BMP is suitable where owners can perform the required maintenance and there is limited space for a detention basin. This BMP is important for redevelopment, especially in densely populated and developed areas, and allows owners to free up space for other activities, such as recreation and green space.

**Table P-SUP-07-3 Underground Detention Basin Feasibility Criteria**

| Parameter | Details |
|---|---|
| Depth to Water Table and Bedrock | The seasonally high water table can intersect the bottom of a sealed underground detention such as vaults and tanks; however, underground detention vaults and tanks require an anti-flotation analysis to check for buoyancy problems in high water table areas where the bottom of the practice will be within the seasonally high groundwater table and must be designed and installed to manufacturers specifications. For open-bottom underground detention, such as plastic arch systems, the base of the detention facility should not intersect the seasonally high groundwater table. The installation of impervious liners can be explored where the groundwater will intersect and should be designed and installed per manufacturer recommends and specifications. |
| Soils | The permeability of soils is seldom a design constraint for underground detention basins. Infiltration through the bottom of the practice is encouraged unless the site is located within a hot spot. Structural load-bearing capacity of subsurface soils must be adequate to support the detention device and stormwater runoff. An initial soil exploration and investigation should be conducted to rule out infiltration as a preferred practice and to rule out the presence of karst topography. |
| Tailwater Conditions | The flow depth in the receiving channel should be considered when determining outlet elevations and discharge rates from the underground detention basin.<br><br>Design tailwater condition elevation will be supported by a reasonable resource and/or analysis. For direct discharges to tidal waters, a high tide elevation evaluation will accompany the tailwater condition evaluation. |
| Tidal Impacts | The outlet elevation of an underground detention basin should be located above the tidal mean high water elevation to limit tidal backflow into the basin. No detention storage used for runoff routing will be accounted for below the mean high water tidal elevation. |

Check with manufacturer recommendations for additional site design constraints.

| Table P-SUP-07-4 Underground Detention Basin Offset Guidance | | |
|---|---|---|
| **Feature** | **Offset*** | **Notes** |
| Existing buildings, bridge supports, and other such structures | 25 feet horizontal | Closer offsets may be considered on a case-by- case basis where impermeable liners are specified by the designer. |
| Property lines | 10 feet horizontal | |
| Underground utility | 5 feet horizontal | Refer to utility owner standards |
| Septic system drain fields | 35 feet horizontal | |
| Private water wells | 50 feet horizontal | |

**Notes:**

* Local subdivision and zoning ordinances and design criteria should be consulted to determine minimum setbacks. Offsets are measured from the toe of the embankment on the downstream side and the design high water on the upstream side.

## 3.0 Planning and Considerations

| Table P-SUP-07-5 Detention Basin Community and Environmental Concerns | |
|---|---|
| **Concern** | **Details** |
| Aesthetics | Detention basins tend to accumulate sediment and trash, which residents are likely to perceive as unsightly and creating nuisance conditions. Fluctuating water levels in basins also create a difficult landscaping environment. In general, designers should avoid designs that rely solely on detention basins for stormwater quantity requirements. |
| Existing Wetlands | Detention basins should never be constructed within existing natural wetlands, nor should they inundate or otherwise change the hydroperiods of existing wetlands. |
| Existing Forests | Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during pond design and construction.<br>Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Wright et al. 2007). |
| Coastal Plain | Consider the use of bubbler aeration and proper fish stocking to maintain nutrient cycling and healthy oxygen levels in permanent pools that influence groundwater in these areas. |
| Hotspots | If used on a site with an underlying water supply aquifer or when treating a hot spot, a separation distance of 2 feet is recommended between the bottom of the detention basins. Install a liner to prevent pollutants from reaching underlying groundwater aquifers. |

| Table P-SUP-07-5 Detention Basin Community and Environmental Concerns | |
|---|---|
| **Concern** | **Details** |
| Stream Warming Risk | Dry detention basins carry less risk of stream warming than other pond options, but they can warm streams if they are un-shaded or contain significant surface area in shallow pools. If a detention basin discharges to temperature-sensitive waters, it should be forested, contain the minimum pools to prevent clogging, and have a drawdown time of no longer than 24 hours. If a longer drawdown time is necessary, the additional detention time may be allowed if sufficient landscaping with an emphasis on shade is provided. |
| Trout Streams | Pond practices tend to raise the water temperatures in receiving streams. Therefore, the use of detention basins, particularly with a permanent pool, in watersheds containing trout streams is restricted to situations in which upland runoff reduction practices cannot meet the full channel and flood protection volume requirements. In these cases, basins should:<br>• Be designed with a maximum 24-hour detention time (to avoid excessive warming of runoff);<br>• Have a minimum outlet micro-pool volume sufficient to prevent clogging;<br>• Be planted with trees so it becomes fully shaded; and<br>• Be located outside of any required stream buffers. |
| Safety Risk | Dry detention basins are generally considered safer than other wet pond options because they have few deep pools. Side slopes and unfenced headwalls, however, can still impose some safety risks. Gentle side slopes and safety benches graded near the water line of any water feature and high-water elevation should be provided to avoid potentially dangerous drop-offs, especially where basins are located near residential areas. Refer to P-BAS-02 Wet Ponds for safety requirements for basins with a permanent wet pool. |
| Mosquito Risk | The fluctuating water levels within detention basins have potential to create conditions that lead to mosquito breeding. Mosquitoes tend to be more prevalent in irregularly flooded ponds than in ponds with a permanent pool (Santana et al. 1994). Designers can minimize the risk by implementing a stormwater wet pond or wetland. |

| Table P-SUP-07-6 Underground Detention Basin Community and Environmental Concerns | |
|---|---|
| **Concern** | **Details** |
| Coastal Plain | The use of impermeable polyvinyl chloride (PVC) liners may be considered where separation distances to structures are minimal. |
| Damage to existing structures and facilities | Underground detention should not be used where their operation may create a risk for basement flooding, interfere with subsurface sewage disposal systems, or affect other underground structures.<br>Underground detention should be designed so that overflow drains away from buildings to prevent damage to building foundations.<br>The use of impermeable polyvinyl chloride (PVC) liners may be considered where separation distances to structures are minimal. |

## 4.0 Stormwater Performance Summary

### 4.1 Dry Detention Basin

Dry detention facilities are intended to control peak flows, limit downstream flooding, and provide channel and flood protection volumes. Routing calculations must be used to demonstrate that the storage volume is adequate.

No water quality treatment is provided by this practice. A control structure is used to control peak flows for channel and flood protection and to limit downstream flooding ensuring an adequate conveyance at the outfall.Dry detention basins are designed to completely empty out, typically in less than 24 hours, resulting in limited settling of particulate matter and the potential for re-suspension of sediment by subsequent runoff events.

### 4.2 Underground Detention

Underground detention facilities are intended to control peak flows, limit downstream flooding, and provide channel and flood protection. Although limited stormwater treatment may be provided by this practice, it is not the intent of this BMP to address water quality.

No water quality treatment is provided by this practice, although some underground detention systems can incorporate proprietary water quality treatment, which may achieve stormwater treatment in accordance with manufactured treatment device specifications.

## 5.0 Design Criteria

| Table P-SUP-07-7 Detention Basin Design Geometry | |
|---|---|
| **Parameter** | **Details** |
| Side Slopes | Side slopes leading to the extended detention pond should generally have a gradient no steeper than 3H:1V for earthen slopes. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. Steeper grades can be achieved with other structural elements. |
| Safety Features | Several design features of impounding structures are intended to provide elements of safety but are not required for design:<br>• A safety bench is a flat bench located just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. Except when the stormwater pond side slopes are 5H:1V or flatter, provide a safety bench that is a minimum 10-foot-wide bench with a maximum cross slope of (2%), located immediately above the detention design high water when routed detention high water elevations exceed 4 feet in depth; earthen slopes above the safety bench should be no steeper than 3:1.<br>• Fencing of basins is not generally desirable; however, it may be required by local review authority depending on site location and basin configuration.<br>• Safety benches should be landscaped with vegetation that hinders or prevents access to the pool.<br>• The principal spillway opening must be designed and constructed to prevent access by small children.<br>• End walls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a safety hazard. Consult local building codes to determine if fencing is required for lesser drop-offs near a walkway, path, residential yard, public common area, parking lot, or driveway.<br>• An emergency spillway and associated freeboard must be provided in accordance with applicable local or state dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges and provide a safe and stable discharge of runoff from the detention basin in the event of spillway overflow. Safe and stable discharge minimizes the possibility of erosion and flooding of downstream areas. |
| Ponding Depths | The depth of the basin will be determined by the required detention storage volume and detention area of the basin. It is recommended that the depth at high water level not exceed 10 feet to minimize negative vegetation impacts. |

### 5.1 Required Geotechnical Testing

Soil explorations should be conducted within the footprint of the proposed embankment, in the vicinity of the proposed outlet, and in at least two locations within the proposed detention basin area or surrounding area. Soil boring data are needed to: (1) identify the physical characteristics of the excavated material to determine its adequacy as structural fill or for other uses, (2) determine the need for and appropriate design depth of the embankment cut-off trench, (3) support structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine the depth to groundwater and bedrock, and (5) evaluate potential infiltration losses (and the potential need for a liner).

Additional guidance on geotechnical criteria for impoundment facilities is provided in P-SUP-01 Earthen Embankments. Guidance on soil explorations in general is provided in Appendix C. Geotechnical investigation for dry ponds with karst terrain should comply with the survey methods outlined in Appendix E Site Assessment and Design Guidelines for Stormwater Management in Karst, Virginia.

| Table P-SUP-07-8 Conveyance and Overflow | |
|---|---|
| **Parameter** | **Details** |
| Internal Slope | To keep the detention basin dry after a storm event, the basin should be sloped along the basin floor leading to the outlet structure. Promoting positive drainage within the basin may result in drier soils between rain events.<br>Turf grass can also be used in dry bottom basins. Basins with turf grass will need minimum bottom slopes of 0.5% to 1% toward the outlet structure to ensure adequate drainage between events. Basins with a permanent wet pool can be flat with no slope through the practice. Areas above the normal high water elevations of the detention facility should be sloped toward the basin to allow drainage.<br>Careful finish grading is required to avoid creation of upland surface depressions that may retain runoff. The bottom area of storage facilities should be graded toward the outlet to prevent standing water conditions. |
| Principal Spillway | The principal spillway will be designed with acceptable anti-flotation, anti-vortex, anti-seep collar, and trash rack devices. Trash racks must be installed at the intake of the outlet structure and designed to avoid acting as the hydraulic control for the outlet system. The spillway must generally be accessible from dry land. Refer to P- SUP-02 Principal Spillways for design criteria. |
| Emergency Spillway | Detention basins must be constructed with overflow capacity to safely pass the 100-year design storm event without overtopping the embankment and causing structural damage to the facility through either the primary spillway (with 2 feet of freeboard to the settled top of embankment) or a vegetated or armored emergency spillway (with at least 1 foot of freeboard to the settled top of embankment). Refer to P-SUP-03 Vegetated Emergency Spillways for design criteria. REQUEST GRAPHIC FROM SAG |

| Table P-SUP-07-8 Conveyance and Overflow | |
|---|---|
| **Parameter** | **Details** |
| Non-Clogging Low-Flow Orifice | Detention basins with drainage areas of 10 acres or less, where small-diameter outlet pipes and orifices are typical, are prone to chronic clogging by organic debris and sediment. Vertical perforated risers wrapped in gravel are the preferred orifice. Horizontal perforated extensions wrapped in gravel help to maintain a dry basin bottom. Conventional trash racks need to have spacing that is half the diameter of the orifice. This is not practical for orifices with diameters 3 inch or less; consequently, orifices less than 3 inches in diameter should be avoided. Refer to P-SUP-02 Principal Spillways for design criteria and information regarding low-flow orifice design. |
| Adequate Outfall Protection | The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged during the emergency spillway design event, whichever is greater). The channel immediately below the pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance with care taken to minimize tree clearing along the downstream channel. Outlet protection or energy dissipation should be provided consistent with C-ECM-15 Outlet Protection. |
| Inlet Protection | Inlet areas should be stabilized to ensure non-erosive conditions during storm events up to the overbank flood event (i.e., the 10-year storm event). Outlet protection or energy dissipation should be provided consistent with C-ECM-15 Outlet Protection. Inlet pipe inverts should generally be located at or slightly below the forebay pool elevation. Inlet pipes should not be fully submerged at normal pool elevations. Where the inlet pipe needs to be submerged, pipe velocities must support minimum velocities for sediment flushing per Virginia Department of Transportation (VDOT) Drainage Manual requirements.<br><br>A hydraulic grade line analysis considering the tailwater effects of the normal pool elevation will be completed that shows the adequacy of the upstream storm system during the 10-year storm. |
| Dam Safety Permits | Detention basins with high embankments or large drainage areas and impoundments may be regulated under the Virginia Dam Safety Act (§ 10.1-606.1 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20 et seq.). Refer to P-SUP-01 Earthen Embankments for additional information. |

### 5.2 Maintenance Features

Good maintenance access is needed so crews can remove sediments from the basin, alleviate clogging, and repair risers. The following basin maintenance considerations can be addressed during design in order to make ongoing maintenance easier:

- Adequate maintenance access must extend to the basin bottom. Any safety benches, riser, and outlet structure can occur and must have sufficient area to allow vehicles to turn around.

- The riser or outfall device should be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.
- Access roads must: (1) be constructed of materials that can withstand the expected frequency of use, (2) have a minimum width of 8 feet, and (3) have a profile grade that does not exceed 15 percent. Steeper grades are allowable if appropriate stabilization techniques are used such as gravel or other material.
- A maintenance right-of-way or easement must extend to the basin from a public or private road.
- Use manholes, access points, or other similar structures for maintenance access to all chambers and pipes. Provide cleanouts at ends of all underdrain and distribution pipes.
- Locate access where cars and traffic will not interfere with maintenance and inspection to the greatest extent possible.
- Access to underground vaults and tanks may require confined space entry. Ladder steps should be provided for access to systems with a depth of 4 feet or greater.

The designer should check to see whether sediments can be spoiled (deposited) onsite or must be hauled away.

**Table P-SUP-07-9 Underground Detention Basin Design Geometry**

| Parameter | Details |
|---|---|
| Structural Design | Underground detention basins, vaults, and tanks must meet structural requirements for overburden support and traffic loading if appropriate. |
| Maximum Depth | The maximum depth from finished grade to the basin invert should be 20 feet. |

### 5.3 Pre-Treatment

Pre-treatment is an integral design feature used to maintain the longevity of an underground detention basin. Pre-treatment practices must be located at each major inlet to trap sediment and debris and preserve the capacity of the basin. Gutter guards or leaf filters should be used on all roof gutters as pre-treatment.

Designers should select the appropriate pre-treatment practice based on site conditions. Surface flows must pass through pre-treatment designed to remove sediment, grit, oil, grease, and trash. Flows from vegetated areas require pre-treatment to remove sediment via settlement or filtration. Flows from treatment trains are generally considered pre-treated. Refer to P-SUP-06 Pre-Treatment for design criteria and specifications.

### 5.4 Required Geotechnical Testing

Soil explorations should be conducted within the footprint of the proposed underground detention. Soil boring data are needed to: (1) determine the physical characteristics of the excavated material to determine its adequacy as structural fill or other use, (2) determine the need and appropriate design depth of the detention basin, (3) provide data for structural designs of the basin (e.g., bearing capacity and buoyancy), (4) determine the depth to groundwater and bedrock, and (5) evaluate potential infiltration losses (and the potential need for a liner).

Guidance on soil explorations in general is provided in Appendix C**.** Geotechnical investigation for basins with karst terrain should comply with the survey methods outlined in Appendix E.

| Table P-SUP-07-10 Conveyance and Overflow | |
|---|---|
| **Parameter** | **Details** |
| Non-Clogging Low Flow Orifice | Underground detention basins with small contributing drainage areas, where small- diameter outlet pipes and orifices are typical, are prone to chronic clogging by organic debris and sediment. Conventional trash racks need to have spacing that is half the diameter of the orifice. This is not practical for orifices with diameters 3 inch or less; consequently, orifices less than 3 inches in diameter should be avoided. Refer to P-SUP-02 Principal Spillways for design criteria and information regarding low-flow orifice design. Access to the outlet structure must be provided for inspection and cleaning. |
| Overflow Capacity | Underground detention basins must be constructed with overflow capacity to safely pass the 100-year design storm event without causing structural damage to the facility or damage or flooding of adjacent and downstream infrastructure and properties. |
| Design Detention Storage | Where an underground storage practice is located underneath a designed pavement section, the design storage elevation should not be closer than 1 foot below the design pavement section to prevent frequent inundation of the pavement section. |
| Adequate Outfall Protection | The design must specify an outfall that will be stable for the maximum (pipe-full) design discharge (the 10-year design storm event or the maximum flow when surcharged, whichever is greater). The channel immediately below the basin outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance with care taken to minimize tree clearing along the downstream channel. Outlet protection or energy dissipation should be provided consistent with C-ECM-15 Outlet Protection. |
| Inflow Components | Directly connect roof drainage to detention or detention distribution pipes when possible. A distribution pipe can be used to connect all inflow components and should be located above the underdrain when possible. For directly connected roof drainage into an underground detention system, no additional pre-treatment is required other than gutter guards or leaf filters on gutter downspouts. |
| Underdrain | Underdrains should generally be provided for open bottom basins with minimal infiltration. Storage above the lowest outlet invert can be modeled and routed as available for detention and channel and flood protection control. |
| Embankments and Excavation | Slope sides of underground detention basins outward from the bottom gradually at approximately 0.1:1 to protect compaction of adjacent soils. Refer to manufacturer’s recommendations and specifications for installation. |

| Table P-SUP-07-11 Underground Basin Design Variations | | |
|---|---|---|
| **Variations** | **Description** | **Recommendations** |
| Storage component variations | Underground pipes and chambers | High-density polyethylene (HDPE), corrugated metal pipe (CMP), concrete, or PVC pipe materials are recommended to be placed within the stone storage.<br>Pipe should be installed observing manufacturer's pipe spacing, minimum cover, and maximum cover recommendations.<br>A minimum of 4 inches of stone bedding under pipe or chamber structure should be provided.<br>Multiple pipe sizes can be used to maximize storage. Provide access to pipes larger than 36 inches in diameter.<br>Proprietary chambers should be installed in accordance with manufacturer's recommendations. |
| | Underground vaults | Provide human access to vaults.<br>Proprietary vaults should be installed in accordance with manufacturer's recommendations. |
| | Underground plastic grid storage | Various structure types can be stacked and interlocked.<br>Grid systems are commonly known for their ability to provide a high void space efficiently for storage of stormwater.<br>Proprietary products should be installed in accordance with manufacturer's recommendations. |
| Active/Adaptive Systems | Uses rainfall forecasting and system storage to improve performance | Incorporation of active and adaptive flow control devices can improve volume and/or peak rate performance. |

## 6.0 Construction Specifications

### 6.1 Construction Sequence for Detention Basins

The following is a typical construction sequence that can be followed to properly install a detention basin. The steps may be modified to reflect different detention basin designs; site conditions; and the size, complexity, and configuration of the proposed facility.

***Step 1: Use of detention basins as an erosion and sediment (E&S) control.*** A detention basin may serve as a sediment basin during project construction. If so, the volume should be based on the more stringent sizing rule (erosion and sediment control requirement vs. water quantity detention volume). Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction detention basin in mind. The bottom elevation of the detention basin should be lower than the bottom elevation of the temporary sediment basin.

The construction notes should clearly indicate that the facility will be dewatered, dredged, re-graded, and stabilized to design dimensions after the original site construction is complete. Appropriate procedures should be implemented to prevent discharge of turbid waters when the basin is being converted into a detention basin.

***Step 2: Stabilize the drainage area.*** Final grading and construction of detention basin components should only be initiated after the contributing drainage area (CDA) to the pond is stabilized.

***Step 3: Assemble construction materials*** onsite, make sure they meet design specifications, and prepare any staging areas.

***Step 4: Install E&S controls*** prior to construction including temporary dewatering devices and stormwater diversion practices. All areas surrounding the basin that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

***Step 5: Clear and strip*** the project area to the desired sub-grade.

***Step 6: Excavate the core trench and install the spillway pipe.***

***Step 7: Install the riser or outflow structure*** and ensure the top invert of the overflow weir is constructed level at the design elevation.

***Step 8: Construct the embankment and any internal berms*** in 8- to 12-inch lifts, or as directed by geotechnical recommendations, and compact as required with appropriate equipment.

***Step 9: Excavate/Grade*** until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the basin.

***Step 10: Construct the emergency spillway*** in cut or structurally stabilized soils.

***Step 11: Install outlet protection*** including emergency and primary outlet apron protection.

***Step 12: Stabilize exposed soils*** with temporary seed mixtures appropriate for the basin buffer. All areas above the normal pool elevation should be permanently stabilized by hydroseeding or seeding over straw.

***Step 13: Plant the pond buffer area*** following the pondscaping plan.

### 6.2 Construction Inspection

Multiple inspections are critical to ensure that stormwater ponds are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting;
- Initial site preparation (including installation of E&S controls);
- Excavation/Grading (interim and final elevations);
- Installation of the embankment, the riser/primary spillway, and the outlet structure;
- Implementation of the pondscaping plan and vegetative stabilization; and
- Final inspection (develop a punch list for facility acceptance).

A construction phase inspection checklist for detention basins is provided at the end of this specification.

In order to facilitate maintenance, the contractor should measure the actual constructed pond depth at three areas within the basin or other feature and mark and georeference them on an as-built drawing. This simple dataset will enable maintenance inspectors to determine pond sediment deposition rates in order to schedule sediment cleanouts.

Upon final inspection and acceptance, the global positioning system (GPS) coordinates for all detention basins should be logged for entry into the Virginia Stormwater Management Program (VSMP) Authority's maintenance tracking database.

### 6.3 Sample Construction Inspection Checklist for Detention Basins

The following checklist provides a basic outline of the anticipated items for the construction inspection of a detention basin. Inspectors should review the plans carefully and adjust these items and the timing of inspection verification as needed to ensure that the intent of the design and the inspection is met. Finally, users of this information may incorporate these items into a VSMP Authority Construction Checklist format consistent with the format used for E&S control and BMP construction inspections.

### 6.4 Pre-Construction Meeting

- Pre-construction meeting with the contractor designated to install the basin has been conducted.
- Identify the tentative schedule for construction and verify the requirements and schedule for interim inspections and sign-off.
- Subsurface investigation and soils report supports the placement of a basin in the proposed location.

### 6.5 Construction of Detention Basin Embankment and

### Principal Spillway

- Stormwater has been diverted around or through the area of the basin embankment to a stabilized conveyance and perimeter erosion control measures to protect the facility during construction have been installed.
- Materials for construction of the embankment and principal spillway are available and meet the specifications of the approved plans.
- Key trench, principal spillway (including the riser and barrel), anti-seepage controls, outlet protection, and other features are built in accordance with approved plans.
- Geotechnical analysis and approval of the core (if required) and embankment material have been provided, and the material has been placed in lifts and compacted in accordance with the approved plans.
- **Certification of Embankment and Principal Spillway Inspection**: Inspector certifies that each element of the embankment and principal spillway has been constructed in accordance with the approved plans.

### 6.6 Excavation of Detention Basin

- Excavation of the basin geometry (including bottom shape, depth, side slopes) achieves the elevations in accordance with approved plans.
- Excavation of internal micro-topographic features: micro-pool outlet, forebays, and other features is in accordance with approved plans.
- Impermeable liner, when required, meets project specifications and is placed in accordance with manufacturer's specifications.

- **Certification of Excavation Inspection**: Inspector certifies that the excavation has achieved all the appropriate grades, grade transitions, and basin geometry as shown on the approved plans.

### 6.7 Landscaping Plan and Stabilization

- Exposed soils on pond bottom, side slopes, and buffer areas are stabilized with specified seed mixtures, stabilization matting, mulch, and other practices in accordance with approved plans.
- Appropriate number and spacing of plants are installed and protected on the aquatic bench and pond buffer in accordance with the approved plans.
- All E&S control practices have been removed.
- Follow-up inspection and as-built survey/certification has been scheduled.
- GPS coordinates have been documented for the basin installation.

### 6.8 Detention Basin Material Specifications

The basic material specifications for detention basins are outlined in Table P-SUP-07-12.

**Table P-SUP-07-12 Detention Basin Materials Specifications**

| Component | Specification |
|---|---|
| Grass and Landscaping | C-SSM-10 Permanent Seeding<br>Appendix G Plant Selection |
| Outlet Orifices and Spillway | P-SUP-02 Principal Spillways |
| Inlet and Outlet Protection | C-ECM-15 Outlet Protection<br>C-ECM-13 Riprap |
| Erosion Control Blankets | C-SSM-05 Soil Stabilization Blankets and Matting<br>Detention basins should be protected by a biodegradable erosion control blanket to provide immediate stabilization of the banks. |
| Embankments | P-SUP-01 Earthen Embankment |
| Emergency Spillways | P-SUP-03 Vegetated Emergency Spillway |

### 6.9 Underground Detention Basin

Eskin et al. 2021 state that "The underground storage technique utilizes many of the same construction techniques and materials as the other green infrastructure techniques, but it does not inherently include plantings.

Please note that the underground storage technique can be paired with various surface treatments, including any of the other green infrastructure techniques. The design engineer should customize the specifications included in the construction documents to reflect all the items included in the design. Refer to the manufacturers recommended Installation specifications for manufactured underground detention systems."

Design guidance on pre-treatment is provided in P-SUP-06 Pre-Treatment.

Inspection during critical stages of construction is required. The critical stages for this BMP are as follow:

- Excavation to elevation;
- Construction of inlets and outlets;
- Installation of pipe and stone backfill, geotextiles, and impermeable liner as applicable;

- Construction of underdrain systems and observation wells as applicable;
- Pipe placement and stone backfill; and
- Repaving or grading.

## 7.0 Operations and Maintenance Considerations

### 7.1 Maintenance Agreements

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875-535) includes requirements for long-term maintenance of stormwater management facilities. To ensure successful implementation of basins, long-term maintenance and operation should consider the following, to include inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

- Restrictive covenants or other mechanisms enforceable by the VESMP Authority should be in place to help ensure that basins are maintained as well as to pass the knowledge along to any subsequent property owners.
- Access to basins should be covered by a drainage easement to allow access by the VESMP Authority to conduct inspections and perform maintenance when necessary.
- All basins should include a long-term Maintenance Agreement consistent with the provisions of the Virginia Erosion and Stormwater Management Regulation and should include the recommended maintenance tasks and a copy of an annual inspection checklist.
- The Maintenance Agreement should also include contact information for owners to obtain local or state assistance to solve common nuisance problems such as mosquito control, geese, invasive plants, vegetative management, and beaver removal.

### 7.2 Maintenance Inspections Detention Basins

Maintenance of detention basins is driven by annual inspections that evaluate the condition and performance of the pond including the following:

- Measure sediment accumulation levels in the basin.
- Monitor the growth of wetlands, trees, and shrubs planted. Record the species and their approximate coverage and note the presence of any invasive plant species.
- Inspect the condition of stormwater inlets to the pond for material damage, erosion, undercutting, and subsidence/sinkhole formation.
- Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, gully erosion, or subsidence/sinkhole formation that may undermine embankment integrity.
- Inspect basin outfall channel for erosion, undercutting, riprap displacement, woody growth, subsidence/sinkhole formation, and other issues.
- Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, subsidence/sinkhole formation, and other issues.
- Inspect condition of all trash racks, reverse sloped pipes or flashboard risers for evidence of clogging, leakage, debris accumulation, and other issues.
- Inspect maintenance access to ensure it is free of woody vegetation, and check to see whether valves, manholes, and locks can be opened and operated.
- Inspect internal and external side slopes of the basin for evidence of sparse vegetative cover, erosion, slumping, or subsidence/sinkhole formation, and make needed repairs immediately.

Inspection results will trigger specific maintenance tasks. Example maintenance inspection checklists for basins are provided in Appendix H.

For detention basins constructed in karst areas, inspections should include examination for subsidence features anywhere within the basin, at inlets leading to the basin, and at the basin outfall. Any subsidence/sinkhole discovered is considered a mode of failure and should be repaired using the appropriate sinkhole repair/mitigation.

### 7.3 Common Ongoing Maintenance Tasks Detention Basins

Detention basins are prone to clogging at the low-flow orifice. This component of the pond's plumbing should be inspected at least twice a year. The constantly changing water levels in basins make it difficult to mow or manage vegetative growth. The bottoms of dry detention basins often become soggy, and water-loving trees such as willows may take over. The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing only periodically to sustain healthy growth) or forest.

The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables that tend to accumulate in any micro-pools and on the bottom of the basin.

Frequent sediment removal from the basin is essential to maintain the function and performance of a basin. For planning purposes, maintenance plans should anticipate cleanouts every 5 to 7 years, or when inspections indicate that detention storage is being impacted by accumulated sediments (absent an upstream eroding channel or other source of sediment, the frequency of sediment removal should decrease as the drainage area stabilizes). As noted above, the designer should also check to see whether removed sediments can be spoiled (deposited) onsite or must be hauled away. Sediments excavated from detention basins are typically not considered toxic or hazardous and can be safely disposed by either land application or landfilling.

## 8.0 Underground Detention Basin

### 8.1 Construction Sequence

The following is a typical construction sequence that can be followed to properly install underground basin practices. The sequence may need to be modified to reflect the scale of basin, site conditions, and whether an underdrain needs to be installed.

Underground basin practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. Second, heavy construction equipment loading can result in compaction of the soil atop the practice, which can then damage the underground basin. For this reason, a careful construction sequence and manufacturer's installation recommendations must be followed.

During site construction, the following steps are critical:

- Avoid excessive compaction by delineating the area of the proposed practice and preventing construction equipment and vehicles from traveling over the proposed location.
- Keep the practice "off-line" until construction is complete. Prevent sediment from entering the infiltration site using super silt fence, diversion berms, or other means. In the E&S control plan, indicate the earliest time at which stormwater runoff may be directed to a conventional infiltration basin The E&S control plan must also indicate the specific methods to be used to temporarily keep runoff out of the BMP.
- Infiltration practice sites should never serve as the sites for temporary sediment control devices (e.g., sediment traps) during construction.

- Upland drainage areas need to be completely stabilized with a thick layer of vegetation prior to commencing excavation for underground basins, as verified by the local E&S control inspector/program.

### 8.2 Installation

The actual installation of an underground basin practice should be performed to the manufacturer's recommendations.

### 8.3 Construction Inspection

Inspections are needed during and immediately after construction to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists to include signoffs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions. An example construction phase inspection checklist for infiltration practices is provided at the end of this specification. Inspection at the following key points during construction will help ensure successful performance:

- Check elevations of the facility and outlet invert.
- Ensure that the facility has not been damaged by construction equipment driving overtop of the practice.
- Check the underdrain and distribution pipes for clogging.
- Stabilize the CDA prior to bringing the facility into service.

Upon final inspection and acceptance, the GPS coordinates should be logged for all underground detention facilities and submitted for entry into the local BMP maintenance tracking database.

The underground storage system must include inspection ports used to observe the amount of accumulated sediment within the system and to ventilate the system prior to confined space entry. Once the accumulation has reached a level indicated by the manufacturer, the system must be cleaned using a high-pressure water technique, which sprays water on the inside of the chambers, loosens the sediment, and vacuums it out of the system.

The system is accessed for maintenance using a manhole structure and distribution pipe manifold. The inspection port should be inspected semi-annually or per manufacturer guidelines.

### 8.4 Ongoing Maintenance

Effective long-term operation of underground detention basin practices requires a dedicated and routine maintenance inspection schedule with clear guidelines and schedules, as shown in Table P-SUP-07-13. Where possible, facility maintenance should be integrated into routine maintenance tasks.

| Table P-SUP-07-13 Typical Maintenance Activities for Underground Detention Basins | |
|---|---|
| **Maintenance Activity** | **Frequency** |
| Ensure that the CDA, inlets, and facility surface are clear of debris. Ensure that the CDA is stabilized.<br>Remove sediment, trash, and oil/grease from pre-treatment devices as well as from overflow structures.<br>Repair undercut and eroded areas at inflow and outflow structures. | Quarterly |
| Check observation wells or access ports after a storm event more than 0.5 inch in depth. Standing water observed in the well after 3 days is a clear indication of clogging.<br>Inspect pre-treatment devices, diversion structures, and outlets for sediment buildup and structural damage. | Semi- annually |
| Clean out accumulated sediments from the pre-treatment BMP and basin. | Annually |

## 9.0 References


Southern Lowcountry Design Manual

GA Stormwater Manual, NJ Stormwater Manual, MD Stormwater Manual,

Eskin, J., Price, T., Cooper, J, and W. Schleizer. 2021. “A Design Guide for Green Stormwater Infrastructure Best Management Practices.” Environmental Consulting & Technology, Inc. 119 pp.

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# P-SUP-08 Permanent Level Spreader

## 1.0 Definition

A permanent level spreader is a flow control measure that receives concentrated, potentially erosive inflow, and converts to a sheet flow condition by discharging across a horizontal level weir onto areas of undisturbed soil that is stabilized by existing vegetation or into another structural BMP.

## 2.0 Purpose and Applicability of Best Management Practice

A level spreader is used to intercept concentrated sediment-free runoff from stabilized areas and convert it to sheet flow where it can be released to down-gradient areas in a non-erosive manner.

Use a level spreader where there is a need diffuse stormwater flows by evenly distributing flows over a stabilized vegetative surface or in conjunction with other BMPs such as filter strip, grass channel, rooftop disconnection, infiltration system, etc.

Use a rigid spreader lip as discussed below for a permanent installation of a level spreader. If a level spreader is proposed for use in Virginia Department of Transportation (VDOT) rights-of-way, refer to the appropriate VDOT standards and specifications for specific regulations.

## 3.0 Planning and Considerations

Filter Strip (BMP P-FIL-07), Grass Channel (BMP P-CNV-01), Rooftop Disconnection (BMP P-FIL-01), etc. each call for a stable outlet for concentrated stormwater flows. The level spreader is a relatively low-cost structure to convert smaller volumes of concentrated flow to sheet flow for release without causing erosion downstream where conditions are suitable (see Figure P-SUP-08-1).

Select a level spreader site/location prior to site prep in previously undisturbed soil where the outlet area below the level lip is uniform with a maximum slope of 10% and is stabilized by existing vegetation.

Ensure that the outlet lip is constructed to be completely level in a stable, undisturbed soil. Any depressions in the lip will concentrate the flow, resulting in erosion.

Use a rigid outlet lip design to create the desired sheet flow conditions. Treat runoff water containing high sediment loads in a sediment-trapping device before releasing the runoff to a level spreader.

## 4.0 Stormwater Performance Summary

**MS-8: CONCENTRATED RUNOFF**– Concentrated runoff shall not flow down cut or fill slopes unless contained within an adequate temporary or permanent channel, flume or slope drain structure.

**MS-11: OUTLET PROTECTION**– Before newly constructed stormwater conveyance channels or pipes are made operational, adequate outlet protection and any required temporary or permanent channel lining shall be installed in both the conveyance channel and receiving channel.

9VAC25-875-560

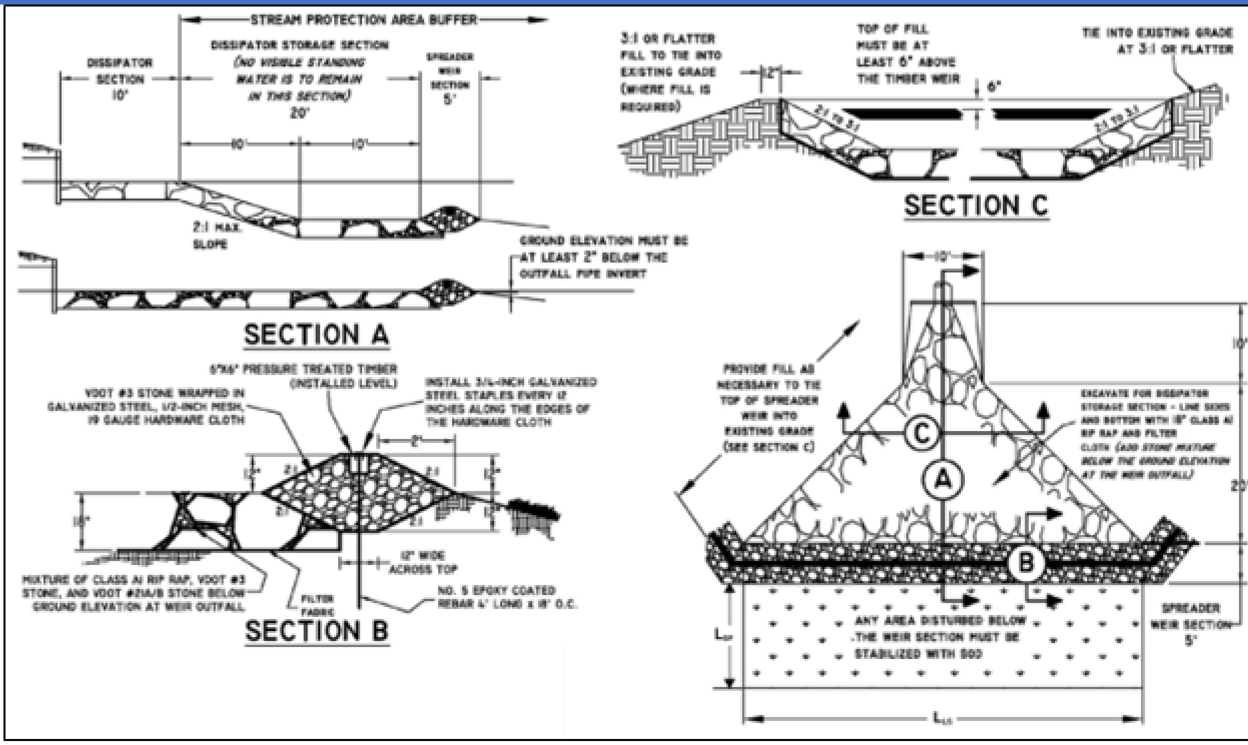
**Erosion Control Efficiency: Moderate**

**Sediment Removal Efficiency: Low**

## 5.0 Design Criteria

Construct a level spreader where a minimum clearing and grading is required downstream of the spreader lip to allow free overflow of stormwater over the weir. If clearing/grading is required, the disturbed area should be planted with sod as per the specifications for Sodding (BMP C-SSM-06). The area below level lip should be uniform with a slope of 10% or less and is stabilized by natural vegetation (Virginia Department of Environmental Quality [VDEQ] 1992).

**_Figure P-SUP-08-1 Outlet Flowing into Level Spreader_**




Source: Adapted from Henrico Department of Public Works 2022

| Table P-SUP-08-1 Level Spreaders as a Permanent Best Management Practice Design Criteria | |
|---|---|
| **Permanent Level Spreaders** | |
| **Topic** | **Requirement** |
| Sheet Flow Discharge | Convert piped or channelized stormwater runoff to sheet flow prior to discharge. Provide documentation/computations demonstrating that discharges of sheet flow from level spreaders: (a) will not adversely impact any downgradient property (i.e., cause erosion and/or cause or worsen localized flooding); and (b) will not adversely impact any downgradient environmental features.<br><br>Specify the remediation of any active erosion, sedimentation, or flooding in the sheet flow path on the plans.<br><br>Locate the area of sheet flow outside the limits of clearing and grading and protect by erosion and sediment controls or restore the area according to Soil Compost Amendment specification (BMP P-FIL-08) immediately prior to establishing permanent stabilization.<br><br>Sheet Flow Depth: Design the 10-year 24-hour post-development sheet flow depth to be less than or equal to 0.1 foot for the entire length of the flow path to the downgradient stormwater conveyance system.<br><br>Sheet Flow Length: Compute maximum design length of sheet flow path to the downgradient stormwater conveyance system:<br><br>$$L_{SF} = \frac{100\sqrt{S}}{n}$$<br>where:<br><br>$L_{SF}$ = maximum length of sheet flow (feet)<br><br>S = slope (feet/foot)<br><br>n = Manning's roughness coefficient (U.S. Department of Agriculture, Natural ResourceConservation Service [USDA-NRCS] National Engineering Handbook, Table 15-1 [2008])<br><br>Sheet Flow Velocity: Compute the 10-year, 24-hour post-development sheet flow velocities downgradient of the level spreader using the following equation for velocity:<br><br>$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$<br>where:<br><br>V = Velocity (feet per second)<br><br>n = Manning's roughness coefficient (USDA-NRCS National Engineering Handbook, Table 15-1 [2008])<br><br>R = Hydraulic radius (feet) = A / P<br><br>S = Land slope (feet/foot)<br><br>A = Flow area (square feet) = Length of Level Spreader x 0.1 foot<br><br>P = Wetted perimeter (feet) = Length of Level Spreader + 0.1 foot + 0.1 foot<br><br>Spreader Velocity: The design 10-year 24-hour post-development sheet flow velocity should be less than or equal to the values shown in Table C-ECM-09-2, Permissible Velocities for Grass-Lined Channels, within Stormwater Conveyance Channel (BMP C-ECM-09) to ensure that reconcentration does not prematurely occur. |

| Table P-SUP-08-1 Level Spreaders as a Permanent Best Management Practice Design Criteria | |
|---|---|
| **Permanent Level Spreaders** | |
| **Topic** | **Requirement** |
| Spreader Design | Provide detailed level spreader designs on the plans; include construction details, dimensions, materials, layout, and site-specific details to ensure the level spreader ties into adjacent slopes and stormwater runoff does not short circuit and flow around the level spreader.<br>Orient level spreaders to be parallel to downgradient contours.<br><br>Design level spreaders (top or lip elevation) to be no higher than 3 to 4 inches above the downgradient land surface. Provide a smooth transition between the level spreader and downgradient land surface.<br><br>Construct level spreaders of concrete or other non-erodible material (e.g., rock).<br>Provide a maintenance plan on the plans.<br><br>Spreader Length: Compute the level spreader length using the following equation (minimum level spreader length is 10 feet; maximum level spreader length is 200 feet):<br><br>$L_{LS} = \frac{Q}{C_W \times H^{3/2}}$ where:<br><br>LLS = Length of level spreader (feet)<br><br>Q = 10-year 24-hour post-development peak flow rate (cfs)<br><br>CW = Weir coefficient (assume 3.3 for rectangular weir)<br><br>H = Depth of water immediately upslope of level spreader (assume 0.1 foot) |
| Grade | The side slopes of the spreader should be 2H:1V or flatter and should be tied into higher ground to prevent flow around the spreader. |
| Spreader Lip | Use a rigid lip of non-erodible material, such as pressure-treated timbers or concrete curbing, for a permanent installation.<br><br>*Rigid spreader lips should have a maximum design flow of 30 cfs.* |
| Outlet Area | Runoff from the level spreader should be released on a generally smooth area to preserve sheet flow and prevent concentration. This area should be well-vegetated with a maximum slope of 10%. |
| Pipe Outlet Level Spreader | Install a pipe outlet level spreader to introduce storm flows into a vegetated buffer area at a slower rate and spread the flow over a larger area than would normally occur with an outfall pipe. |
| Vegetation | Seed and mulch all disturbed areas immediately after construction. |
| Easements | Offsite discharges of sheet flow from a level spreader, with the exception of those discharges meeting the requirements of Safe Harbor, or there is no increase in the 1-year 24-hour and 10-year 24-hour storm post-development runoff volumes and velocities as compared to the pre-development volumes and velocities, should be encompassed with a drainage easement. The minimum width of the easement should be the length of the level spreader plus 5 feet on each side. The minimum length of the easement should be the distance of the sheet flow path to the down-gradient stormwater conveyance system. |

## 6.0 Construction Specifications

1. Construct level spreaders on undisturbed soil (not fill material).
2. Level spreaders are a permanent part of a site's stormwater management system. Therefore, the uphill development should be stabilized before directing runoff to this system.
3. Construct dissipation and plunge pool sections.
4. Construct the spreader lip at 0% grade to ensure uniform spreading of stormwater runoff.
5. Construct the spreader lip on undisturbed soil to uniform height and 0% grade over the length of the spreader. Protect the lip of an earthen level spreader with an erosion-resistant material, such as a reinforced erosion control blanket or turf reinforcement mat, to prevent erosion and enable establishment of vegetation.

   *Rigid Lip Only* – Provide a smooth transition between the level spreader and the native ground downslope. Entrench the rigid level lip at least 2 inches below existing ground and securely anchor to prevent displacement. Install an apron of VDOT #1, #2, or #3 coarse aggregate to the top of the level lip and extended downslope at least 3 feet. Place filter fabric under stone and use galvanized wire mesh to hold stone securely in place (see Figure P-SUP-08-2).
6. Discharge the released runoff onto undisturbed stabilized areas with slope not exceeding 10%. Construct the slope to be sufficiently smooth to preserve sheet flow and prevent flow from concentrating.
7. For piped outlet, line the sides and bottom of the plunge pool excavation with filter fabric underlining and Class AI riprap in accordance with BMP C-ECM-13.

   Construct the spreader weir section by excavating a trench to the depth and configuration shown on Figure P-SUP-08-1, laying down hardware cloth and backfilling with VDOT No. 3 aggregate. Use hardware cloth that is galvanized steel, ½ inch mesh, 19 gauge. Wrap the hardware cloth around the aggregate and timber as shown on Figure P-SUP-08-1 and staple the edges to the top of the timber every 12 inches with ¾-inch galvanized steel staples.

   Install the level 6-inch by 6-inch pressure treated timber.
8. Immediately after construction, appropriately seed and mulch the entire disturbed area of the spreader.
9. Ensure that the end of the level spreader is constructed high enough to prevent water conveyance at this location and fulfill the proper intent of the best management practice.

## 7.0 Operations and Maintenance Considerations

Inspect the level spreader at least once a year and after every measurable rainfall event (i.e., 0.5 inch per 24 hours) and make repairs immediately as needed.

Maintain the level spreader lip at zero grade to allow proper function of the measure. Avoid the placement of any material on the level spreader and prevent construction traffic across the structure.

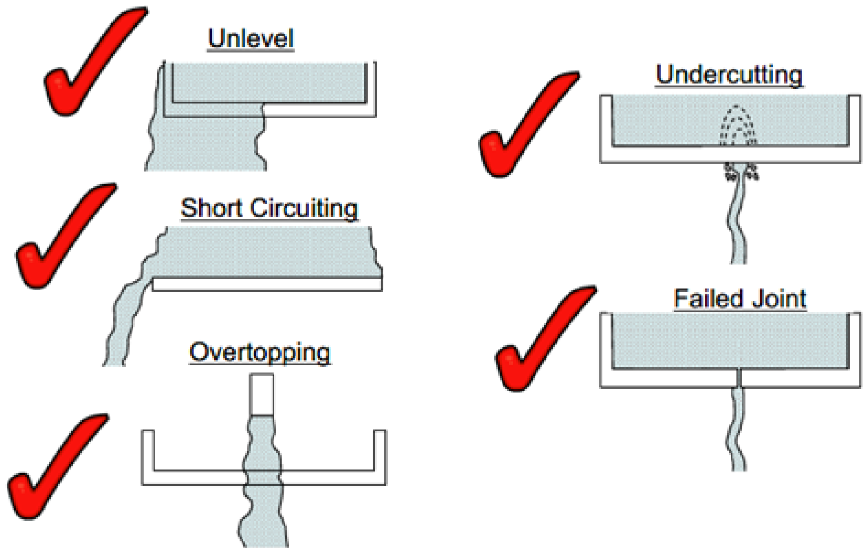
Immediately repair any damage to the level spreader. Inspect the level spreader in the same conditions for subsidence along the perimeter of the measure.

Inspect for low points, sags, cracks, breaks, etc. in the level spreader that would result in concentrated flow discharging over the spreader. Any identified alterations to the grade of the level spreader must be repaired immediately.

Debris buildup within the channel should be removed when it has accumulated to 20% of channel capacity.

### 7.1 Common Level Spreader Failures

Figure P-SUP-08-2 Common Level Spreader Failures




Source: Rocco 2007

Inspect the downstream area of the level spreader for any development of water channelization or subsidence.

Inspect the upstream diversion channel after every rainfall. If any changes in soil morphology are observed within the undisturbed soil and are seen to be forming a sinkhole or soil intrusion, carefully monitor that location. If an existing sinkhole is discovered where runoff is found to be diverting, that sinkhole may be transitioned and classified into a United States Environmental Protection Agency (USEPA) Class V injection well. More information on Class V injection wells is provided at the following USEPA website: https://www.epa.gov/uic/basic-information-about-class-v-injection-wells#:~:text=A%20Class%20V%20well%20is%20used%20to%20inject,simple%20shallow%20wells%20to%20complex%20experimental%20injection%20technologies

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# CHAPTER 9 BMP CONSTRUCTION

**Contents:**

Once land development and associated construction and post-construction best management practices (BMPs) are designed and approved, a development project may move into the construction phase. During construction, coordination among the contractor, designer (or reviewing engineer), and owner/operator is critical to ensuring that erosion, sedimentation, and other adverse impacts are minimized and that post-construction BMPs are properly installed. This chapter focuses on proper construction methods and sequencing of construction and post-construction stormwater BMPs.

## 9.1 Introduction

The process to design, build, operate, and maintain construction and post-construction stormwater BMPs is challenging for all parties involved. Site considerations unforeseen or overlooked during the design phase can have major impacts during the construction phase if not addressed.

## 9.2 Pre-Construction Meeting

Pre-construction meetings should be held at least 7 days prior to any land-disturbing activity commencing (including clearing, grubbing, and installing site access or trackout controls). Local Virginia Erosion and Stormwater Management Program (VESMP) authorities may have an alternative schedule for pre-construction meetings; therefore, each operator should verify with the VESMP authority in which the construction is located.

The owner/operator should invite all contractors, property owners, design engineers, and regulators to an on-site pre-construction meeting.

## 9.3 Pre-Construction Submittals and Shop Drawings

Pre-construction submittals and shop drawings are intended to confirm all project participants' interpretation of the design drawings and their intent. The contractor should use the submittals and shop drawing process to demonstrate exactly how the work is to proceed prior to purchasing and fabricating structures.

## 9.4 Sequence of Construction

One component of the approved soil erosion and stormwater management plan or erosion and sediment control plan is a proper and detailed construction sequence. During construction, this sequence must be followed faithfully by the contractor keeping in mind that the sequence may need to be adjusted, in communication with the engineer and reviewing agencies, to account for unforeseen conditions. The goal is to limit disturbance, erosion, and sedimentation and to ensure appropriate conditions for installation of post-construction BMPs.

Section 9.4.1 details sequencing considerations for typical construction activities. Where a construction BMP will be converted to a post-construction stormwater BMP, a more detailed sequence for this conversion may be required.

### 9.4.1 Typical Sequence

Table 9-1 outlines the typical sequence of construction for each activity anticipated.

**Table 9-1 Typical Construction Sequence**

| Construction Activity | Sequence |
|---|---|
| Identify and field mark protection areas (e.g., natural resource areas, buffer zones, filter strips, trees). | Site delineation should be completed before construction begins. |
| *Construction access*. Construction entrance, construction routes, equipment parking areas and cutting of vegetation (necessary perimeter controls). | First land-disturbing activity - Establish protected areas and designated resources for protection. Stabilize bare areas immediately with gravel and temporary vegetation as construction takes place. |
| *Sediment traps and barriers*. Basin traps, sediment fences, and outlet protection (necessary perimeter controls). | Install principal basins after construction site is accessed. Install additional traps and barriers as needed during grading. |

| Table 9-1 Typical Construction Sequence | |
|---|---|
| **Construction Activity** | **Sequence** |
| *Runoff control.* Diversions, silt fence, compost filter sock, and outlet protection. | Install key practices after principal sediment traps and before land clearing and grading. Install additional runoff control measures during grading. |
| *Runoff conveyance system.* Stabilize stream banks, storm drains, channels, inlet and outlet protection, and slope drains. | Where necessary, stabilize stream banks as early as possible. Install principal runoff conveyance system with runoff control measures. Install remainder of system after grading. |
| *Grubbing and grading.* Site preparation: cutting, filling, and grading; sediment traps, barriers, diversions, drains; surface roughening. | Begin major grubbing and grading after principal sediment and key runoff control measures are installed. Clear borrow and disposal areas only as needed. Install additional control measures as grading progresses. |
| *Surface stabilization.* Temporary and permanent seeding, mulching, sodding, and installing riprap. | Apply temporary or permanent stabilization measures immediately on all disturbed areas where work is delayed or complete. |
| *Building construction.* Buildings, utilities, paving. | Install necessary erosion and sedimentation control practices as work takes place. |
| *Landscaping and final stabilization*. Topsoiling, planting trees and shrubs, permanent seeding, mulching, sodding, installing riprap. | Last construction phase - Stabilize all open areas including borrow and spoil areas. Remove and stabilize all temporary control measures. |
| *Maintenance.* | Perform maintenance inspections weekly and make maintenance repairs immediately after periods of rainfall. |

Source: Adapted from Minnesota Stormwater Manual

## 9.4.2 Phases of Construction

It is critical that earth-disturbing activities follow a planned sequence that minimizes the risk of erosion and sediment transport during the construction phase.

### 9.4.2.1 Interim and Temporary Grading Conditions

During construction, drainage patterns may temporarily deviate from the existing and proposed conditions. These “interim” drainage patterns must be accounted for by the designer when developing the erosion and sediment control plans to ensure that runoff does not leave the site uncontrolled. During construction, it is imperative that the contractor and engineer work collaboratively to minimize erosion and sedimentation during interim conditions.

This is an often-overlooked part of the construction process that can result in significant impairments to downstream waterways, not to mention erosion and sedimentation on site that can impede the performance of post-construction BMPs.

### 9.4.2.2 Sequencing BMPs

A BMP sequence is a specified work schedule that coordinates the timing of earth-moving activities and subsequent stabilization with the installation and removal of construction BMPs or the conversion of those construction BMPs to post-construction stormwater BMPs. A construction BMP sequence should be developed for every earth-moving project requiring a written erosion and sediment control plan. The BMP installation sequence should be complete (i.e., it should address all aspects of the proposed earth-moving as it applies to erosion and sediment control). The sequence should be a step-by-step outline of the proposed project detailing which BMPs will be installed prior to each stage of construction.

The purpose of the sequence is to reduce the potential for accelerated erosion and the resultant sediment pollution to surface waters by ensuring that the construction BMPs are in place and functioning when they are needed. The following are suggested best practices for maximizing the efficacy of the construction sequence during construction:

- **Working with the Contractor.** Where the earth-moving contractor is known at the time of the application, the contractor should be involved in the development of the sequence to minimize potential conflicts of the proposed sequence with efficient construction practices. Any earth-moving contractor who finds the sequence to be non-feasible, in whole or in part, will need to obtain written approval from the approving agency prior to altering the sequence.
- **Customize the Sequence.** Because each project differs from all others in some way, the BMP installation sequence must be site-specific. It should identify the specific BMPs that will be employed during each stage of construction. Generalized statements such as, "Install all proposed control facilities within XYZ watershed" are not acceptable.
- **Use Project Phasing.** Whenever possible, larger projects should be phased so that only part of the site is disturbed at any one time, thus minimizing sediment transport from dormant parts of the project. Cuts and fills should be coordinated to minimize the need for temporary storage of materials. Ideally, the sequence should be set according to watershed areas with disturbances limited to one watershed at a time. Where it is not possible to limit disturbance to one watershed at a time, the sequence should clearly identify the BMPs that should be in place and functioning before work progresses into an adjacent watershed. In this way, the contractor may work within the various watersheds or drainage areas in the order most efficient or even simultaneously, so long as the sequence is followed for each watershed or drainage area.
- **Keep it Simple.** Sequences that require complicated or restrictive construction practices should be avoided wherever possible. Apparent savings in construction of BMPs can be lost by unrealistic restrictions placed upon the contractor. The simpler the staging requirements, the more likely it is that the contractor will be able to complete the project without stepping outside of the approved sequence. A system of channels and traps or sediment basins usually provides adequate sediment pollution protection while allowing freedom to the contractor to perform the earth-moving in a cost-effective manner.

**Suggested Outline for Construction BMP Sequencing**

- Field-mark limits of disturbance and environmentally sensitive areas (including steep slopes, riparian buffers, wetlands, springs, and floodways).
- Establish rock construction entrances or other trackout control measures.
- Establish site access and access to critical first stage construction BMPs.
- Build access roads and the construction BMPs that they manage.
- Install environmentally sensitive area BMPs (e.g., temporary/permanent stream crossings, wetlands disturbance).
- Install roadway drainage structures (e.g., catch basins, junctions)
- Install surface water diversions.
- Install perimeter controls.
- Install erosion control, sediment control, and surface stabilization measures.
- Perform site earthwork.
- Install permanent stabilization measures.
- Remove/Convert construction BMPs.

- **Manage Close to the Source.** Concentrating site runoff into a few large impoundments is not always the best solution to sediment pollution or stormwater management. Designers should consider whether several smaller structures could operate more efficiently, at a lower cost, and with less impact on receiving waters than one large one. Managing site runoff close to its source is therefore encouraged.
- **Do Not Neglect Access.** If it is necessary to construct access roads in order to install proposed BMPs, the sequence should address how these access roads will be stabilized. If the access road is to remain in place following completion of any BMP, runoff from the roadway should be directed into an appropriate BMP by means of a waterbar, culvert, broad-based dip, or other drainage control device. The locations of temporary access roads should be shown on the plan maps. Further, the sequence should indicate that stabilized construction entrances will be installed wherever it is known that construction vehicles will be exiting onto a roadway (public or private). It should also indicate the necessity of constructing a stabilized construction entrance wherever needed, although not specifically identified by the plan.
- **Get Control Early.** Appropriate controls should be installed and functioning prior to clearing and rubbing. General site clearing and grubbing should be performed only where suitable BMPs have been installed and are functioning. Progressive clearing and grubbing, beginning in the location of BMPs and support areas, may be used if the installation of BMPs keeps pace with the clearing and grubbing. Additionally, the sequence should specify the completion of the proposed construction BMPs (e.g., basins, traps, channels), including any required outlet protection or conveyance channels, prior to any general earth-moving within a specific work area.
- **Keep Controls in Place Until the Site is Stable.** The BMP installation sequence should specify the removal of temporary construction BMPs upon completion and stabilization of the disturbed area tributary to each BMP, as approved by the VESMP or VESCP inspector. Conditions of stabilization should be specified. Vegetated areas must achieve a uniform, mature, erosion-inhibiting vegetative cover over the entire disturbed area. 9VAC25-875-560. Roadways and parking areas should at least have a clean subbase in place
- Emphasize Immediate Stabilization. The sequence must require immediate stabilization upon temporary cessation of work (14 days or more), or as soon as any graded area reaches final grade.

(See 9VAC25-875-500 F 8.) Waiting for an entire phase to reach final grade before seeding and mulching is not acceptable.

- Separate Maintenance Guidance. Maintenance information should not be included in the BMP sequence. All maintenance information should be contained in the maintenance section of the plan drawings or adjacent to the construction detail(s) for the specific BMP. In addition, maintenance information should be included in the operation and maintenance plan for the project.

In addition, the following best practices should be employed when developing sequencing for specific types of construction BMPs:

- **Stream Crossings.** Temporary stream crossings must be provided wherever clearing vehicles will be crossing existing stream channels (perennial or intermittent). (See MS 12 and MS 13 at 9VAC25-875-560.) Initial clearing should be limited to that which is necessary to install the proposed perimeter BMPs. Wherever it is necessary for construction vehicles to cross a proposed channel, the sequence should include the installation of a temporary crossing as described in Chapter 8 of this Handbook.
- **Sewer Discharges.** Wherever BMPs will be discharging to proposed storm sewers, the storm sewers should be installed and functioning prior to construction of the BMPs in question and protected so that sediment-laden water cannot enter the system without first being filtered or otherwise treated to remove sediment. However, care should be taken to avoid conflicts with any proposed cuts or fills in the areas of the proposed storm sewer location.
- **Streams and swales.** The sequence should describe how flow/runoff in existing streams or swales will be handled during any proposed culvert (pipe or box) installation. It is recommended that a critical sequence be included along with the installation detail on a detail sheet. The main sequence of construction may refer to the critical sequence without repeating the specifics. The plan should also specify how water pumped from work areas during culvert construction will be handled in accordance with the Construction General Permit (9VAC25-880).
- **Basins and traps.** Sequences should specify the controls to be used during construction of any proposed basins or traps. If stream flow needs to be diverted around the work area, the sequence should provide instructions for how this will be accomplished. Note: bypass pipes should be constructed around, not through, basins or traps. The sequence should also describe the proper method of embankment construction and stabilization or refer to the specifications provided elsewhere on the plan drawings.
- **Constructed fills.** Runoff should be directed away from cut slopes and constructed fills wherever possible. Designers should refer to C-ECM-05 for specifications for diversions that may be placed at the tops of fill slopes to direct runoff to temporary slope drains or ditches, which discharge into sediment traps, sediment basins, or conveyance channels that in turn discharge to basins or traps located below the fill.
- **Cut/fill interfaces.** Anticipated runoff at the cut/fill interfaces should be addressed by the sequence. Because erosion gullies tend to form at these locations, some means of conveying the water downslope should be provided (e.g., catch basins or suitably lined groin ditches).
- **Storm and Sanitary-Sewer Lines.** The sequence should provide specifics about the installation of any proposed storm and sanitary sewer lines or utility lines. If storm inlets (existing or proposed) need protection, the sequence should indicate when the protection should be installed. Utility lines that cross traps and basins should be constructed prior to the embankment construction.
- **Construction to Post-Construction BMP Conversion.** Any construction BMPs that are to remain as post-construction stormwater BMPs must be modified where necessary to meet the requirements of the permanent facility. If any sediment basins or traps are to be converted to detention ponds, conversion should be restricted to the growing season, and the sequence should describe the procedure to be used. This should include, at a minimum, the following:

- Flushing accumulated sediment from the contributing storm sewer system;
- The method of dewatering the impoundment;
- Removal and proper disposal of accumulated sediment;
- Removal of all other temporary facilities such as baffles, cleanout stakes, and dewatering facilities;
- Sediment protection of permanent orifice or weir until interior of permanent facility is stabilized;
- Removal of the temporary riser/orifice and the installation/opening of the permanent riser/orifice; and
- Stabilization of the interior of the impoundment as well as steps necessary to provide any proposed infiltration capacity.

Installation of post-construction stormwater BMPs not used as temporary construction BMPs should be scheduled after their contributing drainage areas have been stabilized. Wherever this is not possible, the post-construction stormwater BMPs should be protected from sediment-laden runoff. Failure to adequately protect post-construction stormwater BMPs from sediment deposition will require rehabilitation to restore them to proper functioning.

### 9.4.2.3 Stormwater BMP Function and Failure Points

The following section has been adapted from the Water Environment Federation Manual of Practice No. 39: Urban Stormwater Controls Operation and Maintenance.

The primary objective or "function" of a BMP is the common characteristic that groups various BMPs together. During the design stage, it is critical to identify potential failure points in the BMP where the primary function of the practice would be compromised. Potential failure points are often readily identified through the specific site-design characteristics of the BMP. These include:

- **Retaining Water.** A site designed to retain water likely manages a larger contributing area, which presents its own challenges when considering fail points. A designer must consider how water is conveyed to the BMP, as well as the components that provide for the permanent pool to function. For constructed wetlands, special consideration should be afforded to the nuances of establishing the vegetation in the permanent pool, as it is critical to the water feature's function. The volume of stormwater and what is carried in that runoff (e.g., sediment and fine aggregate) are critical management points for the designer to manage during construction through both temporary and permanent design measures.
- **Infiltration or Filtration.** The primary function of BMPs that either infiltrate or filtrate is that water must "move through" the practice. A designer must consider how this "movement" could be affected during construction, most typically by the quality of the material installed, which is governed by the material specification. The secondary consideration affecting that primary function during construction is protecting that "movement" by considering what is carried in the stormwater runoff (sediment and fines) conveyed to the BMP.
- **Establish Thriving Vegetation.** For BMPs with vegetation, the establishment of the vegetation and maintenance of these features are critical to the function of the facility. The designer must consider how to effectively plan for and manage the planting windows and plant species-specific establishment to provide maximum functional performance. The vegetation plays an integral role in deep infiltration through matured root systems and uptake through evapotranspiration, working with the soil, aggregate, and piping systems. Therefore, designing to promote growth of these root systems is essential. For root systems to establish maturity, it is important to control invasive species whose shallow roots can inhibit this growth and "choke out" the preferred plant.
- **Reusing Water.** Water collected by rainwater harvesting BMPs (BMP P-BAS-04) may present the opportunity to reuse for irrigation of other vegetated features on the site or other non-potable uses

where allowed by local building code. The designer should consider the volume of stormwater in these applications and how this range and fluctuation can be managed by the facility. The schedule for installation of these facilities may be a key consideration during construction, as coordination between a building contractor and a site contractor is necessary to optimize function.

- **Manufactured Treatment Devices.** Manufactured treatment devices (MTDs) can provide specialized treatment and removal of sediment and/or fines, as well as other constituents that may be unique to a given site. For some of these MTDs, the volume of runoff is directly related to the performance of the practice; for others, regular maintenance is critical to retain the screening and filtering function of these facilities. A designer must consider when the primary function of these MTDs must be online related to other functions of the site and consider temporary measures that may be needed to preserve that function.

Designing for these potential fail points requires the primary function of the BMP to be the continued focus. Designers should approach this by evaluating function at the site and through the watershed in two ways: (1) Anticipate these fail points and incorporate preferred methods of addressing them in a phased approach in construction documents; and (2) Anticipate the temporary and long-term maintenance needs during construction to retain the function of these critical features. Design, specification, and communication of adequate stormwater control and protection are essential to preserving the primary function of stormwater control measures during construction.

## 9.5 Key Construction Topics

This section details key topics and lessons learned for the construction of stormwater BMPs that are particularly critical for minimizing environmental impacts. These lessons learned should be applied not only to the design process but should be followed and implemented during construction through collaboration between the designer and contractor. Being responsive to field conditions is key to implementing a construction process that minimizes impacts to both land and water.

### 9.5.1 Minimize Limits of Disturbance

Minimize adverse impacts of the development on water quality and the hydrologic site conditions by minimizing overall site disturbance. This typically begins at the design phase. The designer should minimize cuts and fills to the greatest extent practical, with finished floor elevations of buildings set at elevations that work with the natural topography. Careful delineation of access points and corridors can also help to limit overall disturbance.

Environmentally sensitive areas, such as steep slopes, wooded areas, wetlands and stream channels, and riparian corridors, should be clearly delineated during the design phase. Prior to clearing and grubbing, these environmentally sensitive areas should be clearly delineated in the field, and contractors and subcontractors should be educated on avoidance of disturbance in these areas.

### 9.5.2 Perimeter Controls

Perimeter controls are typically used as a sediment barrier for small, disturbed areas and as initial protection against sediment pollution during the early phases of construction before establishing other construction BMPs, such as sediment traps and basins.

Perimeter controls, such as compost filter socks, should be installed as early as feasible in the sequence once access has been established.

### 9.5.3 Construction Haul Roads

Construction haul roads are often critical for projects in more remote areas but may be used where required on any type of project. Construction haul roads should be cut in once construction entrances and perimeter construction BMPs are established and functioning.

For roads that will be used for extended periods of time, the designer should consider soil types and the potential for rutting of the road by construction vehicles. Where soils are more susceptible to piping, sliding, or pumping, the designer should consider timber matting for road stabilization. Where feasible, use existing roads, driveways, and other routes to minimize impacts.

## 9.5.4 Steep Slopes

Generally, disturbance of steep slopes (typically those greater than 25 percent in grade) should be avoided whenever possible. If disturbance of steep slopes is proposed, it is critical to implement effective measures to minimize surface erosion and prevent caving or piping. Following proper procedures and standards of practice can help to minimize adverse impacts:

- **Site Assessment:** Conduct a thorough assessment of the site's topography, soil conditions, and hydrology. Understand the slope gradient, soil composition, and surface drainage patterns to determine potential erosion risks. Slope failure can impact any construction project, and such failures can have significant impacts on property and the safety and welfare of the public. The contractor must be familiar with the soils present and their susceptibility for slope failure. The contractor must take all steps necessary to minimize or prevent slope failure, especially where this would endanger the public or result in significant property damage.
- **Retaining Walls:** Consider installing retaining walls to stabilize the slope and prevent soil movement. Retaining walls can help control surface flow and minimize erosion by creating terraces or steps.
- **Diversions:** Implement proper diversions in accordance with Diversion (BMP C-ECM-05) and Temporary Right-of-Way Diversion (BMP C-ECM-07) to redirect water away from the slope and into natural or engineered channels or swales.
- **Soil Stabilization Blankets:** Use soil stabilization blankets, in accordance with Soil Stabilization Blankets and Matting (BMP C-SSM-05), to provide immediate erosion protection and assistance with retaining moisture within the soil and promoting vegetation growth.
- **Hydroseeding or Mulching:** Hydroseeding involves spraying a mixture of seeds, water, fertilizer, and mulch onto the slope. Mulching alone can also be used. This helps establish vegetation quickly, stabilizing the soil and preventing erosion. See C-SSM-09 or C-SSM-10, as applicable, for further specifications.
- **Vegetation Selection:** Choose appropriate plant species that are well-suited for steep slopes and erosion control. Select deep-rooted plants that can anchor the soil and prevent erosion effectively. Consult with local experts to identify suitable native species.
- **Terracing:** If feasible, consider constructing terraces or benching the slope to create flatter areas. Logs, fascines, or fiber rolls may also be used to construct terracing. This can help reduce the overall slope angle, decreasing the potential for erosion.
- **Surface Roughening:** Where steep slopes are disturbed, surface roughening practices, in accordance with Surface Roughening (BMP C-SSM-03), should be employed.
- **Construction Phasing:** Plan construction in stages to minimize the exposed soil area at any given time. Complete erosion control measures on each phase before moving to the next, ensuring that the soil remains protected.
- **Monitoring and Maintenance:** Regularly inspect erosion control measures and maintain them as needed. Replace or repair damaged erosion control blankets and reseed bare areas and monitor

the growth and health of vegetation. Promptly address any erosion issues to prevent further damage.

### 9.5.5 Anti-Compaction Protocols

Soil compaction slows or prevents precipitation from infiltrating and increases runoff, which reduces the amount of water available for evapotranspiration and plant growth. Compaction also interferes with the aeration of the soil, which lowers oxygen levels and raises carbon dioxide levels around tree roots.

There is an increasing reliance on infiltration BMPs for Virginia Stormwater Management Program (VSMP)/VESMP compliance. Infiltration BMPs must be properly designed, constructed, and maintained to perform as intended. Some BMPs, such as permeable pavement, require compaction to provide strength and stability. However, soils are often unintentionally compacted during construction.

Soils at construction sites are generally compacted because of excavation, mixing, stockpiling, equipment storage, and equipment traffic. In addition, exposed subsoil is susceptible to compaction. Clay soils and wet soils are more susceptible to compaction. Infiltration, permeability and root penetration become limited when dry soil bulk density exceeds 1.85 g/cm$^3$ in sandy soils, 1.60 in loamy soils and 1.50 g/cm$^3$ in clays. Compacted soils should be loosened with a shank ripper or other appropriate tillage implement to or below minimum soil depths for infiltration/permeability criteria as set forward in applicable BMPs.

## 9.6 Witness and Hold Points

Witness and hold points are critical points within the construction process where all work stops for further inspection by the engineer or their delegate. It is at this stage that the inspecting engineer or their delegate will ensure that all critical stages, elevations, components, and specifications pertaining to the BMP in question have been installed in accordance with the plan.

Critical stages of the BMP construction process, where the engineer or their delegate should be present on site to inspect the work may include, but are not limited to:

- Confirmation of excavated infiltration depths;
- Underdrain construction;
- Outlet structure placement and construction;
- Stone or media placement that may not otherwise be visible upon completion of construction; and
- Any other components or stages that may be deemed critical by the VSMP Authority.

## 9.7 Construction Site Housekeeping and Materials Management

Pollution prevention includes a suite of good housekeeping practices designed to prevent contamination of stormwater from a range of materials and wastes occurring at a construction site. Even though sediments are typically the pollutant of concern in stormwater discharges from construction sites, other potential pollutants might be discharged from the site during construction. These pollutants include material solid waste, wash water, and spills of fuels and other hazardous chemicals. The section will help operators at the construction site maintain building materials and limit the discharge of pollutants.

9VAC25-875-500, stormwater pollution prevention plan, sets out the requirements for the plan, one of which is a pollution prevention plan for regulated land-disturbing activities. The pollution prevention plan (PPP) includes details for the installation, implementation, and maintenance of effective pollution prevention measures to minimize the discharge of pollutants. Per 9VAC25-875-520, the PPP shall detail, at a minimum, such measures designed, installed, implemented, and maintained to:

- **Material Storage, Handling, and Disposal.** Minimize the exposure of building materials and products, construction waste, trash, landscape materials, fertilizer, pesticides, herbicides, detergents, sanitary waste, and other materials present on the site to precipitation and to stormwater runoff.
- **Wash Water Containment.** Minimize the discharge of pollutants from equipment and vehicle washing, wheel wash water, and other wash waters. Wash water must be treated in a sediment basin or alternative control that provides equivalent or better treatment prior to discharge.
- **Spill Prevention, Control and Countermeasures.** Minimize the discharge of pollutants from spills and leaks and implement chemical spill and leak prevention and response procedures.

## 9.7.1 Materials and Waste Management

The principals described below are designed to help identify the construction practices that should be documented in the PPP and implemented at the site.

- Provide for waste management and disposal.
- Describe all solid and/or liquid waste that will be generated on site. Construction and domestic waste will have designated waste containers (e.g., dumpster or trash receptacles) of sufficient size and number to contain all solid waste.
- Separate hazardous or toxic waste from construction and domestic waste and dispose in accordance with state and federal regulations.
- Treat and/or dispose of sanitary and septic waste in accordance with state or local regulations.
- Establish proper material handling and staging areas.
- Designate storage areas and handling procedures for building products, pesticides, herbicides, fertilizer, and landscape materials.
- Provide either a cover to prevent contact with rainwater or similarly effective means designed to prevent discharge of pollutants from these areas.
- Designate storage areas and handling procedures for storage of fuels, oils, hydraulic fluid, other petroleum products, and other chemicals. Store in water-tight containers and provide either cover to prevent contact with rainwater or similarly effective controls designed to prevent discharge of pollutants (e.g., spill kits).
- Designate storage areas and handling procedures for hazardous or toxic materials. Store all outside containers within appropriately sized secondary containment (e.g., spill berms, decks, containment pallets) to prevent spills from being discharged or provide similarly effective means designed to prevent the discharge of pollutants (e.g., covered storage area or spill kit available onsite).
- Clean up spills immediately using dry cleanup methods where possible and dispose of used material properly as defined in Section 8.4.1. Do not clean surfaces or spills by hosing. Eliminate sources of spill to prevent discharge or the continuation of an ongoing discharge.
- Designate responsible party with appropriate training certifications for handling each type of stored materials. Provide all necessary emergency contact information.
- Designate paint and concrete washout areas.

- Provide an effective means of eliminating the discharge of water from the washout and cleanout of stucco, paint, concrete, form release oils, curing compounds, and other construction materials.
- Direct all wash water into a leak-proof container or leak-proof pit. The container or pit must be designed so that no overflows can occur due to inadequate sizing or precipitation. Handle washout or cleanout wastes as follows:
  - Do not dump liquid wastes into storm sewers.
  - Dispose of liquid wastes in accordance with applicable sanitary requirements.
  - Remove and dispose of hardened concrete waste consistent with handling of solid construction waste.
- Locate washout or cleanout activities as far away as possible from surface waters and stormwater inlets or conveyances. To the extent practicable, designate areas to be used for these activities and conduct such activities only in these areas.
- Establish proper equipment/vehicle fueling and maintenance practices.
- Describe equipment and vehicle fueling and/or maintenance occurring on site. Provide an effective means of eliminating the discharge of spilled or leaked chemicals, including fuels, from the area in which these activities occur.
- Control equipment/vehicle washing and allowable non-stormwater discharges.
- Describe equipment and vehicle washing occurring on the site. Establish practices that will be implemented to minimize the discharge of pollutants from equipment and vehicle washing, wheel washing, and other types of washing. Examples of effective control include, but are not limited to:
  - Locate activities away from surface waters and stormwater inlets or conveyances.
  - Direct wash waters to a sediment basin or sediment trap using filtration devices, such as filter bags or sand filters, or other similarly effective controls.
- Describe how discharges of soaps, detergents, and solvents are prevented. Provide cover (e.g., plastic sheeting or temporary roofs) to prevent contact with rainwater or a similarly effective means designed to prevent the discharge of pollutants from these areas.
- Develop a spill prevention and response plan.
- Describe procedures used to prevent and respond to leaks, spills, and other releases. These procedures will demonstrate the expeditious stopping, containing, and cleaning up spills, leaks, and other releases. Identify the name or title of the individual responsible for detection and response.
- Include procedures for notification of appropriate emergency response agencies and regulatory agencies where a leak, spill, or other release containing a hazardous substance or oil in an amount equal to or more than a reportable quantity occurs during a 24-hour period. Contact information must be posted in locations that are readily accessible and available.

Some projects and sites may be required to develop a Spill Prevention Control and Countermeasure (SPCC) plan under a separate regulatory program (40 Code of Federal Regulations 112). If an SPCC plan is developed or already exists, include references to the relevant requirements from the plan.

Construction materials comprise a significant portion of the Commonwealth's waste stream, and ensuring the proper transport and disposal of such materials from the job site is critical to protecting the environment and Virginia's surface waters.

## 9.7.2 Concrete Washout

Part II B 4, pollution prevention plan, of the Construction General Permit, 9VAC25-880-70, contains requirements for concrete wash water at a construction site. In summary, for any project on which concrete will be poured or otherwise formed onsite, subsection 4.e.(5) requires provision of a suitable washout facility for the cleaning of chutes, mixers, and hoppers of the delivery vehicles unless such a facility will be used at the source of the concrete. Under no circumstances may wash water from these vehicles be allowed to enter any surface waters, be disposed of through infiltration, or otherwise disposed of on the ground. From a practical perspective, the operator at the site should ensure that proper signage is provided to drivers so that they are aware of the presence of washout facilities.

***Figure 9-1 Washout Example***

*Source: Alexis Sidari, PE, Arcadis*

Washout facilities should not be placed within 50 feet of storm drains, open ditches, surface waters, or sinkholes. They should be sited in a convenient location for the trucks, preferably near the place in which the concrete is being poured, but far enough from other vehicular traffic to minimize the potential for accidental damage or spills.

Wherever possible, they should be located on slopes not exceeding a 2 percent grade.

## 9.7.3 End-of-Workday Procedures

End-of-workday procedures are critical for ensuring that construction materials are secured and disturbed areas are properly stabilized. Some good end-of-workday procedures for land-disturbing activities may include:

- **Clear the work area:** Remove any tools, equipment, debris, or materials from the work area and return them to their proper storage locations. This helps prevent accidents, damage, or theft.
- **Secure the site:** Make sure that all construction barriers, fences, or signage are in place and properly secured. This prevents unauthorized access to the site during non-working hours.
- **Safely store hazardous materials:** If there are any hazardous materials on the site, ensure they are properly stored in approved containers and stored in a designated area. This helps prevent leaks or spills that could harm the environment.
- **Cover exposed areas:** If there are any open trenches or excavations, cover them securely to prevent accidents or injury to workers or pedestrians. Any disturbance that will remain for longer than 14 days must be stabilized in accordance with Chapter 8.
- **Clean the site access:** Any loose sediment, debris, mud, or other materials that may have been tracked onto the surrounding road network must be cleaned at the end of each workday. All sediment is to be swept or otherwise directed back to the site.
- **Dust control measures:** Implement dust control measures, such as watering down loose soils or applying dust suppressants, to minimize the spread of dust and protect air quality.
- **Clean up spills and debris:** If there are any spills or debris left behind from the day's activities, clean them up promptly and dispose of them properly. This helps prevent pollution and maintains a clean work environment.
- **Inspect all construction BMPs:** Inspect construction BMPs, such as perimeter controls, basins, and/or erosion control blankets, to ensure they are functioning effectively. Repair or replace them as needed in accordance with Chapter 8. Inspections should include checking for subsidence/sinkhole formation and for failure of water-tight BMPs that incorporate basins to hold water (e.g., sediment sumps), which can be an indication of karst failure.

- **Secure equipment and vehicles:** Park and secure all equipment and vehicles in a designated area, ensuring they are turned off and safely parked. This helps prevent theft or damage to the equipment.
- **Document work progress:** Keep accurate records of the work performed during the day including photographs and written reports. Any failures or compromise in construction BMPs should be documented. This documentation can be useful for project management, compliance, and future reference.
- **Communicate with the team:** Before leaving the site, have a brief meeting or discussion with the team to review the day's progress, address any issues or concerns, and plan for the next day's activities. This helps ensure everyone is on the same page and promotes a collaborative working environment.

## 9.8 Inspection Protocols during Construction

During construction, successful implementation of the soil erosion and stormwater management plan requires maintenance and effective operating conditions for all BMPs, consistent with good engineering practices and (where applicable) manufacturer specification. When site inspections identify control measures that are not operating effectively, maintenance should be performed as soon as practicable. Site inspections should identify existing control measures that need to be modified. If additional control measures are necessary for any reason, implement them as soon as practicable.

Identify routine maintenance and provide a maintenance schedule. Keep a written record of site inspections and follow-up maintenance that is required and performed.

The following are inspection requirements for the Construction General Permit:

**Responsibilities (9VAC25-880-70 Part II, Subsection G.1.)**

Required inspections shall be conducted by the qualified personnel identified in the SWPPP. The operator is responsible for ensuring that the qualified personnel conduct inspections at the frequency specified in the General Construction Permit.

**Inspection Schedule (9VAC25-880-70 Part II, Subsection G.2.)**

The inspection schedule for construction activities depends on the condition of the water body receiving the discharge (i.e., no specified condition, impaired, approved Total Maximum Daily Load, exceptional), weather conditions (i.e., frozen ground conditions), and whether the construction involves linear construction activities. At a minimum, inspections shall be conducted at least once every five business days or at least once every 10 business days and no later than 24 hours following a measurable storm event. Consult the Construction General Permit for more specific details.

In areas that are temporarily stabilized or in which runoff is unlikely due to winter conditions (e.g., the site is covered with snow or ice or the ground is continuously frozen), the inspection frequency may be reduced to once per month. If weather conditions, such as above freezing temperatures or rain events, make discharges likely, the operator shall resume regular inspection frequency.

**Inspection Requirements (9VAC25-880-70 Part II, Subsection G.3.)**

As a part of each inspection, the qualified personnel shall, at a minimum:

1. Record the date and time of the inspection and the amount of cumulative rainfall since the last inspection.
2. Record the information and a description of any discharges occurring at the time of inspection.
3. Record any land-disturbing activities that have occurred outside of the approved erosion and sediment control plan.

4. Inspect the following in accordance with the approved erosion and sediment control plan, identify the maintenance needs, and evaluate the effectiveness of minimizing sediment discharge including whether the control measure has been appropriately used.
   a. All perimeter erosion and sediment controls;
   b. Soil stockpiles and borrow areas for stabilization or sediment trapping measures;
   c. Completed earthen structures such as dams, dikes, ditches, and diversions for stabilization;
   d. Cut and fill slopes for appropriate stabilization;
   e. Sediment basins and traps, sediment barriers, and other control measures installed to control sediment discharge from concentrated stormwater;
   f. Temporary and permanent channel, flume, or other slope drain structures installed to convey concentrated runoff flowing down cut and fill slopes;
   g. Storm inlets and outlets that have been made operational to ensure that sediment-laden stormwater does not enter without being filtered or prevent scouring at the outlets; and
   h. Construction vehicle access routes that intersect or access paved roads.
5. Inspect areas that have reached final grade or that will remain dormant for more than 14 days for initiation of stabilization.
6. Inspect areas that have reached final grade or that will remain dormant for more than 14 days for completion of stabilization within 7 days of reaching grade or stopping work.
7. Inspect for evidence that the erosion and sediment control plan has not been implemented properly. Evidence may include the following:
   a. Concentrated stormwater flows, such as rills, riverlets, or channels, that cause erosion when such flows are not filtered, settled, or similarly treated prior to discharge;
   b. Sediment-laden or turbid flows of stormwater that are not filtered or settled to remove sediments prior to discharge;
   c. Deposits of sediment in areas that drain to unprotected stormwater inlets or to catch basins that discharge to surface waters. Failing sediment controls due to improper installation, lack of maintenance, or inadequate design are considered unprotected;
   d. Deposits of sediment from the construction on any property outside of the construction covered by the Construction General Permit;
   e. Portions of the site on which required stabilizations has not been initiated or completed;
   f. Sediment basins without a dewatering device allowing discharge from below the designed wet pool elevation;
   g. Sediment traps without adequate wet and dry storage and without restricted discharge from the drawdown of the dry storage portion of the trap; and
   h. Land disturbance outside the delineated area to be disturbed.
8. Inspect pollutant-generating activities documented in the SWPPP for proper implementation, maintenance, and effectiveness.
9. Identify any pollutant-generating activities not identified in the SWPPP.
10. Identify and document the presence of any evidence of a discharge of pollutants prohibited by the Construction General Permit including, but not limited to, the following:
    a. Wastewater from washout of concrete unless managed by an appropriate control;
    b. Wastewater from washout and cleanout of stucco, paint, form release oils, curing compounds, and other construction materials;
    c. Fuels, oils, or other pollutants used in vehicle and equipment operation and maintenance;
    d. Oils, toxic substances, or hazardous substances from spills or other releases; and
    e. Soaps and solvents used in equipment and vehicle washing.

**Inspection Report (9VAC25-880-70 Part II, Subsection G.4.)**

A record of each inspection and of any corrective action must be retained by the operator as part of the SWPPP for at least 3 years from the date on which permit coverage expires or is terminated. The inspection reports will identify any incidents of non-compliance. Where a report does not identify any incidents of non-compliance, the report will contain a certification that the facility is in compliance with the SWPPP. The report will be signed by Qualified Personnel.

Inspection Reports and major observations should include:

- Date and time;
- Inspector name, qualifications, and certification statement;
- Summary of findings;
- An estimate of the amount of rainfall at the construction site (in inches) from the runoff-producing storm event requiring the inspection, or if inspecting on a 7-day schedule, the amount of rainfall (in inches) since the previous inspection;
- A description of any discharges occurring at the time of inspection;
- The location(s) of discharges of sediment or other pollutants from the site;
- Location(s) of control measures that need to be maintained;
- Location(s) of control measures that failed to operate as designed or proved inadequate for a particular location;
- Location(s) at which additional control measures are needed that did not exist at the time of inspection;
- List of corrective actions required including any changes to the SWPPP that are necessary to implement as a result of the inspection and in order to maintain permit compliance; and
- Documentation of any corrective actions required from prior inspections.

**Corrective Actions (9VAC25-880-70 Part II, Subsection H.)**

The operator shall implement corrective action(s) identified because of an inspection as soon as practicable but no later than five (5) business days after discovery or a longer period as approved by the VESMP authority.

## 9.8.1 Construction Inspection Process

Close attention to detail must be given during the construction inspection process, particularly in the construction of post-construction stormwater management BMPs. Because many of the critical components of a BMP will be below grade after construction, it is important to verify proper construction while the components are still visible for inspection.

Inspectors should verify that the BMPs are being constructed according to the approved plans and specifications. This includes checking the placement and alignment of components, such as inlet and outlet pipes, grates, and control measures, as well as checking that the BMP is constructed at the correct depth, width, and orientation.

Ensure that the size of the stormwater BMP is appropriate for the tributary drainage area and the expected flow. This includes checking the capacities of detention basins, infiltration trenches, or other storage components to ensure that the design volume is being provided. Inspectors should pay close attention to media mixes and stone used in BMP construction to ensure that the design specifications are being met.

- **Verify that the site is properly graded to promote adequate drainage.** Inspectors should verify that the site is graded in so that the proposed post-construction stormwater BMPs receive stormwater runoff for management. Verify that no portions of the drainage area bypass the BMP other than those identified in the design plans.
- **Ensure that stormwater BMPs have proper access points for future inspection and maintenance.** This can include checking the locations and accessibility of inspection ports, cleanouts, and maintenance access roads.
- **Verify adherence to the construction sequence.** Inspectors should check to make sure the construction sequence is being followed correctly, especially for BMPs with multiple components. This ensures that each component is installed at the appropriate time and in the correct order.
- **Check documentation thoroughly.** Verify that all necessary documentation, such as construction records, inspection reports, and as-built drawings, are being properly maintained and updated throughout construction.

By monitoring these aspects during construction, inspectors can help ensure that stormwater BMPs are built correctly and function effectively at preventing water pollution and environmental damage.

# 9.9 Common BMP Construction Issues

If post-construction stormwater BMPs are not built in accordance with the design plans and specifications, the BMP may be susceptible to reduced performance or even failure.

## 9.9.1 Construction BMP Common Construction Mistakes

When installing construction BMPs, there are several common mistakes that designers and contractors often make. The following mistakes can undermine the effectiveness of the BMPs and lead to increased erosion and sedimentation:

- **Failing to properly assess site conditions and potential sources of erosion can result in the installation of inadequate or inappropriate BMPs.** It is crucial to thoroughly evaluate the site to determine the appropriate BMPs needed during the land-disturbing activity. Choosing the incorrect BMPs for the specific site conditions can render them inadequate or ineffective. When selecting the appropriate BMP for your project, the designer should consider such factors as soil type, grade, and the maximum anticipated drainage area and/or runoff volume.
- **Improper installation of BMPs can lead to their failure.** Common failure points occur at perimeter controls, typically because of unanticipated concentrated flows or larger than expected drainage areas. The designer should try to anticipate and visualize the sequence of construction; the correct construction BMP for later phases of the project may not necessarily be the most appropriate during an interim phase.
- **Lack of familiarity with the plans and the specified construction BMPs.** Contractors should be familiar with the installation and maintenance of the proposed BMPs. Common installation errors occur typically due to improper or ineffective training of the contractor.
- **Failure to account for changes in site conditions.** It is important to assess and adapt the construction BMPs that have been deployed on site. While the plan should not be changed without prior approval from the engineer, the contractor should recommend improvements if it is observed that a certain BMP is no longer useful or serving its intended purpose. For instance, street sweeping and dust control operations on asphalt pavements should not necessarily be conducted during periods of precipitation or cool overcast skies.

## 9.9.2 Post-Construction Stormwater BMP Common Construction Mistakes

As with construction BMPs, common mistakes can undermine BMP performance and, as such, learning from these mistakes is critical for ensuring proper performance of installed BMPs. Some common post-construction stormwater BMP construction mistakes include:

- **Improper installation:** This can include incorrectly placing or connecting BMP components, leading to reduced effectiveness or even failure of the system.
- **Inadequate sizing:** Post-construction stormwater BMPs must be properly sized to handle the expected volume and flow of stormwater runoff. If the BMP is undersized, it may not effectively capture and treat the runoff, leading to increased pollution and erosion.
- **Poor maintenance access:** All BMPs require regular inspection and maintenance. If the access points are not properly designed and located, it can be difficult or unsafe for maintenance personnel to reach the BMP for necessary upkeep.
- **Lack of erosion and sediment control:** During construction, proper erosion and sediment control measures must be implemented to prevent sediment from entering the stormwater system. Failure to do so can result in clogged infrastructure and decreased water quality.
- **Inadequate outlet protection:** The outlet of post-construction stormwater BMPs should be designed to prevent erosion and promote proper discharge in accordance with Chapter 8. Without adequate protection, erosion can occur, deteriorating the integrity of the outlet structure and potentially causing downstream issues.
- **Incorrect vegetation selection:** Vegetation plays a crucial role in post-construction stormwater BMPs by stabilizing soil, promoting infiltration, and filtering pollutants. Selecting inappropriate plant species or failing to follow planting guidelines can hinder the overall performance of the BMP.
- **Lack of training and education:** Proper training and education of contractors, construction workers, and maintenance personnel is essential for ensuring that stormwater BMPs are constructed and maintained correctly. Without adequate knowledge, mistakes are more likely to occur.

By being aware of these common mistakes and taking proactive measures to avoid them, construction projects can ensure that stormwater BMPs function effectively, protecting water quality and minimizing environmental impacts.

# 9.10 References

Minnesota Pollution Control Agency. 2006. Minnesota Stormwater Manual. St. Paul, MN. Available online at: https://www.pca.state.mn.us/business-with-us/minnesota-stormwater-manual. Accessed September 8, 2023.

Water Environment Federation. 2023. Manual of Practice No. 39: Urban Stormwater Controls Operation and Maintenance. February 10.

# CHAPTER 10 BMP INSPECTION AND MAINTENANCE

**Contents:**

## 10.1 Introduction

Once constructed, best management practices (BMPs) are crucial for managing water quantity and/or water quality. Failure to provide effective maintenance can reduce the hydraulic capacity and pollutant removal efficiency of BMPs and conveyance systems and result in additional downstream erosion and pollution (Figures 10-1 and 10-2).

While stormwater BMP maintenance is typically the responsibility of the developer during construction, long-term maintenance usually falls to the property owner, a neighborhood association, or a municipality. As required by the state regulations, the Virginia Erosion and Stormwater Management Program (VESMP) authority or Virginia Stormwater Management Program (VSMP) authority often require a formal maintenance agreement for permanent post-construction BMPs, which specifies a required maintenance schedule and gives the local government and/or VSMP authority the right to enter the private property and conduct inspections and maintenance.

**The Evolution of Stormwater Maintenance Needs**

With the introduction of smaller water quality-focused BMPs, stormwater management maintenance needs have evolved over time.

During the 1970s and 1980s, stormwater management consisted only of “peak shaving” facilities where peak flow under post-development conditions was reduced to that under pre-development conditions. These facilities did not require as frequent sediment removal maintenance as current quality BMPs because the residence time of stormwater within a peak shaving facility would likely only be several hours.

The introduction of stormwater control measures for water quality has changed operation and maintenance (O&M) needs in two important ways.

- Because many pollutants (such as bacteria and nutrients) bind to sediment, the treatment mechanism for many BMPs is based on filtering or settling sediment. This results in the need to regularly remove accumulated sediment.
- Stormwater management systems have diversified and have become, in many cases, smaller in scale. These changes create additional challenges for maintenance in terms of the diversity of maintenance tasks and the number of facilities that need to be maintained.

***Figure 10-1 An Unmaintained Stormwater Conveyance Channel Generating Sediment to the Receiving Channel***

*Source: CWP 2009*

***Figure 10-2 Common Issues with Installation of Post-Construction BMPs (Example: Bioretention)***

Site runoff bypasses bioretention swale.

Bioretention area does not drain properly.

*Source: Center for Watershed Protection (CWP) 2009*

This chapter provides an overview of the following topics:

1. Inspection and maintenance requirements including responsibilities for monitoring, reporting, and enforcement;

2. Legal instruments for codifying maintenance requirements and responsibilities including Maintenance Plans and Agreements; and
3. Inspection and maintenance best practices including common pitfalls and an overview of common tasks associated with maintaining BMPs.

In addition to the material provided in this chapter, designers and developers should be aware that **each of the BMP design specifications contains specific inspection and maintenance activities required to ensure the proper functioning of the BMP.** Each BMP specification also includes examples of inspection-maintenance checklists for each non-proprietary BMP.

# 10.2 Inspection and Maintenance Requirements

Local Stormwater Management (SWM) programs in Virginia have a legal mandate in the Virginia Erosion and Stormwater Management Act and Virginia Erosion and Stormwater Management Regulation (Regulation) to require inspection and maintenance of BMPs (§ 62.1-44.15:27 E 2, Code of Virginia, and §§ 9VAC25-875-130 and 9VAC25-875-535 of the Regulation), including:

1. Assigning maintenance responsibility through legally binding agreements;
2. Providing adequate access to BMPs; and
3. Enforcing compliance with maintenance requirements.

For individual development projects, in most cases, the property owner or a neighborhood association will assume responsibility for long-term maintenance of post-construction BMPs under the oversight of the applicable VESMP, or in rare cases, the Virginia Erosion and Sediment Control Program (VESCP). However, in some cases, VESMP/VESCP authorities assume partial or complete responsibility for BMP maintenance. Developers should ensure that they coordinate with the local VESMP/VESCP authority and the long-term property owner (if known) to determine the maintenance responsibilities early in the design process.

Note: for the purposes of this chapter of the Handbook, the term "Virginia Erosion and Stormwater Management Program" or "VESMP" means a program established by a VESMP authority but may also be used interchangeably to refer to Virginia Department of Environmental Quality (VDEQ) when administering a VSMP on behalf of a locality that has chosen not to adopt and administer a VESMP.

In some cases (but not often), the property owner and property developer are the same entity (e.g., universities, hospitals). Where the developer is not the long-term owner operator, the developer still plays an important role in ensuring the BMPs are properly sited and designed to minimize maintenance, maintenance during construction is rigorously implemented, and that accurate and comprehensive as-built information is provided to the long-term owner.

## 10.2.1 Maintenance Agreements

Maintenance responsibilities are codified within a maintenance agreement, typically between the property owner and the VESMP authority (or VDEQ when acting as a VSMP authority). A maintenance agreement is the compliance mechanism to ensure that maintenance is performed regularly. All stormwater BMPs must have “an instrument recorded in the local land records prior to permit termination or earlier as required by the authority” (9VAC25-875-535, note that this requirement would not apply to legacy BMPs that were installed prior to the establishment of construction stormwater permit requirements in the early 1990's). The instrument is the maintenance agreement. Developers should check with the VESMP authority to understand the timing of the maintenance agreement in relation to the permitting process.

Per 9VAC25-875-535, the maintenance agreement shall, at a minimum:

- Be submitted to the authority for review and approval prior to the approval of the SWM Plan;

- Be stated to run with the land;
- Provide for all necessary access to the property for purposes of maintenance and regulatory inspections;
- Provide for inspections, maintenance, and the submission of inspection and maintenance reports to the VESCP, VESMP, or VSMP authority; and
- Be enforceable by all appropriate governmental parties.

The Virginia Erosion and Stormwater Management Regulation (Regulation) provides a potential exemption from the requirement to record the maintenance agreement where the development project consists of a single residential lot.

VESMP authorities may require stormwater facility/BMP owners to sign locality-specific Maintenance Agreements. These agreements establish the owner's responsibilities for maintaining the BMP and may define scenarios in which the locality will enter the property to conduct periodic maintenance of the BMPs and the timeframe in which the owner of the facility must complete the requested repairs.

In addition to the basic requirements listed above, common aspects of maintenance agreements include:

- Identification of the legally and financially responsible entity for maintenance, repairs, and inspections;
- Requirements for record keeping and notifications; and
- Indemnification language.

For example, a maintenance agreement could specify that the local government accepts responsibility for inspecting and maintaining the stormwater system's structural components including the periodic removal of debris and accumulated sediments, but that vegetative and aesthetic maintenance would still rest with the property owner.

VDEQ has approved the model stormwater management facility maintenance agreement in Section 10.2.1.1 for use on projects where it is the permitting authority.

### 10.2.1.1 Model Stormwater Management Facility Maintenance Agreement

THIS AGREEMENT is made this _____ day of _______________ 20______, by and between ________________________________________ (the Owner), and the Virginia Department of Environmental Quality (the Department).

WITNESSETH:

WHEREAS, the Owner is the owner of certain real property in _______________ County, Virginia, Tax Map Parcel Number(s) __________, as recorded by deed in the land records of _______________ County, Virginia at Deed Book ________, Page ________ (the Property);

WHEREAS, the Department currently is the Virginia Stormwater Management Program (VSMP) Authority for __________________ County;

WHEREAS, the Property is being developed into a project known and designated as ______________________________________, as shown and described on the stormwater management plan for the Property dated ____________________, 20______, and revised through ____________________, 20______ (the Plan), a copy of which is retained by the Department and incorporated herein by reference;

WHEREAS, the Plan includes one or more permanent stormwater management facilities (the Facility) to control post-development stormwater runoff from the Property; and

WHEREAS, to comply with § 62.1-44.15:28 of the Code of Virginia and the attendant regulations pertaining to this project, the Owner agrees to maintain the Facility in accordance with the Maintenance Plan dated ____________________, 20______, and revised through ____________________, 20______ (the Maintenance Plan), a copy of which is attached hereto as Exhibit A.

NOW, THEREFORE, in consideration of the foregoing premises and the mutual covenants contained herein, the receipt and sufficiency of which are acknowledged hereby, and in accordance with the following terms and conditions, the parties agree as follows:

1. The Department and its agents may enter the Property to perform periodic inspections to ensure the proper maintenance and functioning of the Facility. These inspections will be conducted at reasonable times. Whenever possible, the Department will notify the Owner prior to entering the Property. If the Department finds that repairs must be undertaken to return the Facility to the original design, as shown and described in the Plan, the Owner shall complete any such repairs within thirty (30) calendar days of the inspection or a longer period as approved by the Department.

2. The Owner, at the Owner's sole expense, shall construct the Facility in accordance with the Plan, and shall provide to the Department a construction record drawing for the Facility prior to termination of coverage under the General VPDES Permit for Discharges of Stormwater from Construction Activities, also known as the "Construction General Permit".

3. The Owner, at the Owner's sole expense, shall maintain and repair the Facility in perpetuity and in a manner which will enable the Facility to remain in compliance with the Virginia Erosion and Stormwater Management Regulations and the Facility's original standards, as shown and described in the Plan and Maintenance Plan. The Owner shall keep written maintenance and repair records and provide copies to the Department upon request.

4. The Owner, at the Owner's sole expense, shall inspect the Facility according to the schedule set forth in the Maintenance Plan. These inspections shall be conducted by a person who is licensed as a professional engineer, architect, landscape architect, or land surveyor pursuant to Article 1 (§ 54.1-400 et seq.) of Chapter 4 of Title 54.1 of the Code of Virginia; a person who works under the direction and oversight of a licensed professional engineer, architect, landscape architect, or land surveyor; or a person who holds an appropriate certificate of competence from the Department. If the inspector finds during an inspection that repairs must be undertaken to return the Facility to the original design as shown and described on the Plan, the Owner shall complete any such repairs within thirty (30) calendar days of the inspection or a longer period as approved by the Department. The Owner shall keep written inspection records and provide copies to the Department upon request.

5. The Owner shall provide a right of ingress and egress for the Department and its agents to perform the periodic inspections referenced above and to undertake or have undertaken maintenance and repair of the Facility, if such maintenance is deemed necessary by the Department and not adequately completed by the Owner. It is expressly understood and agreed that the Department is under no obligation to maintain or repair the Facility. The Owner shall reimburse the Department for all maintenance and repair costs within thirty (30) calendar days after receiving a demand for reimbursement. The Owner acknowledges that the Department may take any other enforcement actions as may be available at law.

6. The Owner shall save, hold harmless, and indemnify the Department and its agents against all liability, claims, demands, costs and expenses arising from, or out of, the Owner's failure to comply with the terms and conditions set forth herein, or arising from acts of the Owner related to the construction, operation, maintenance or repair of the Facility.

7. This Agreement shall constitute a covenant running with the land and shall inure to the benefit of and shall be binding upon the parties hereto, their respective heirs, successors and assigns, including, without limitation, any subsequent Virginia Erosion and Stormwater Management Program Authority for _______________ County and all subsequent owners of the Property, as well as any property owner's association or similar organization responsible for maintenance of the Facility. This Agreement shall be described in full or incorporated by reference into each deed of conveyance out of the Property. The Owner shall notify the Department in writing within 30 days of conveying any interest in the Property affecting the ownership or responsibility for maintenance of the Facility.

8. Upon execution of this Agreement, it shall be immediately recorded in the Clerk's Office of the Circuit Court of _______________ County, Virginia, at the Owner's sole expense. A copy of the recorded agreement shall be provided to the Department within 30 days of recordation. The Owner also stipulates, by this Agreement, that final plats for any land on which the Facility and/or a portion of the Facility is situated will include a reference to this Agreement and to its location in the land records of _______________ County, Virginia.

IN WITNESS WHEREOF, the Owner and the Department have caused this Agreement to be signed in their names by their duly authorized representatives as of the date first set forth above.

[Signatures appear below]

_____________________________, Owner

By: ______________________________

Name: ______________________________

Title: ______________________________

Date: ______________________________

COMMONWEALTH OF VIRGINIA

COUNTY OF _______________, to-wit:

The foregoing instrument was acknowledged before me this _____ day of _______________, 20___, by ____________________ in [his/her] capacity as ____________________ for _________________________, the Owner.

________________________________ [SEAL]

Notary Public

My Commission Expires: _________________________

Notary Registration Number: _____________________

Virginia Department of Environmental Quality

By: ______________________________

Name: ______________________________

Title: ______________________________

Date: ______________________________

COMMONWEALTH OF VIRGINIA

COUNTY OF _______________, to-wit:

The foregoing instrument was acknowledged before me this _____ day of _______________, 20___, by ____________________ in [his/her] capacity as ____________________ for the Virginia Department of Environmental Quality.

________________________________ [SEAL]

Notary Public

My Commission Expires: _________________________

Notary Registration Number: _____________________

## 10.2.2 Maintenance Plans

Prior to the approval of a BMP design, an O&M plan should be prepared consistent with the O&M requirements in each BMP specification. The content of the Maintenance Plan varies based on the requirements of the VESMP authority with respect to administrative items like reporting and documentation.

The Maintenance Plan provides details on how each BMP will be maintained including specific tasks and frequencies. The Maintenance Plan is incorporated by reference into the Maintenance Agreement. The Maintenance Plan also provides the basis for the development of an Owner's Manual, which is discussed in Section 10.3.4.

## 10.2.3 Transfer of Authority

During Transfer of Authority, responsibility for post-construction BMP maintenance is transferred from the development team to the long-term owner/operator at the end of construction. The local VESMP authority may lay out a specific process for transitioning O&M responsibility from construction to post-construction that differs from VDEQ. The authorized representative during construction should ensure that the authority is delegated per the VESMP authority requirements and that, during design, the design professional should indicate that process on the site plans.

Transition of a BMP from the development team, who leads design and construction, to the long-term owner team is a vital and often overlooked part of the process. Several sections of the Handbook address elements of this transition.

- Chapter 4 contains the regulatory framework and requirements for the transition of facility ownership.
- Chapter 9 contains the construction phase requirements for stormwater facility maintenance programs.

In addition to items discussed in these sections, at minimum, transition of facility ownership should include a discussion of the following items.

- **Facility-specific features** – Based on the design, infrastructure requires certain maintenance and inspection practices that may deviate from typical maintenance as documented in the relevant BMP specification.
- **Access during maintenance** – Determine the access location to the entire facility for the ultimate owner including how to maintain the access to the SWM facility. The design drawings should contain setbacks as required by the municipality and a labeled access path. See also Section 10.2.4.
- **Reporting Responsibility** – The facility owner should review the reporting requirements for the BMP.

- **O&M issues** – The facility owner should have access to the design files that contain information about to how the BMP should be functioning. The facility owner should review and clarify any questions regarding the operation of the facility including how maintenance issues should be addressed.
- **Design issues** – The owner should be given action items to complete if there is a noted issue with a facility that is maintained correctly but not functioning properly.
- **Non-standard or proprietary features** – Some facilities use manufactured treatment devices (MTDs), underground storage, or other methods of quality or quantity control. The owner should have information regarding maintenance of the features, as well as related manufacturer contact information if problems or questions arise.

These items are typically codified in the Maintenance Plan, maintenance agreement, and Owner's Manual.

## 10.2.4 Access and Maintenance

BMPs must have an instrument recorded in the local land records that provides for all necessary access to the property where a BMP is located to provide inspections and maintenance of the BMP. 9VAC25-875-535. Typically, this is done through an easement. As a best practice, when using an easement or other instrument, the owner or developer should establish the locations and configurations of the nstrument during the design phase and show it clearly on the design drawings. Specific setbacks for BMPs are included in the BMP specifications.

Configure access and maintenance instruments or easements to allow for the maintenance tasks that may be needed. If heavy equipment will be necessary to perform maintenance tasks (such as removing sediment from a forebay), typically, a roadway with a minimum width of 12 feet should be provided to the BMP. Easements may be owned and maintained by the owner of the BMP facility, whether an individual, a corporation, or a unit of government. Easements or other instruments for BMPs that are not publicly maintained should include provisions to permit public inspection and maintenance if the owner is not properly maintaining the BMP. Each BMP specification includes provisions for access and maintenance.

Easements may be necessary to ensure that important components of the ESM Plan remain in place over time. This is especially true for site planning techniques that provide runoff reduction benefits (e.g., conserving open space, restoring forest cover) and practices that may not be obvious BMPs to property owners (e.g., bioretention facilities that often appear to be merely discretionary landscaping). Securing easements after a project is built and after properties are occupied is time-consuming and uncertain. Therefore, developers are strongly encouraged to secure easements during the review of stormwater plans. This requires the stormwater reviewer to coordinate with the department or staff person that reviews property plats for the locality. To have the force of law, the easement must be recorded consistent with state law.

The following are some considerations for securing stormwater easements:

- Easements should cover:
    - The BMPs;
    - Enough land around the BMPs for construction equipment to enter and maneuver. This includes access
    - to dams, risers, safety benches, forebays, and outlets, as appropriate;
    - For ponds, a setback (e.g., 25 feet) from the flood (100-year) pool area;
    - Access routes for maintenance; and
    - According to program policies, conveyances and structures associated with the BMPs.

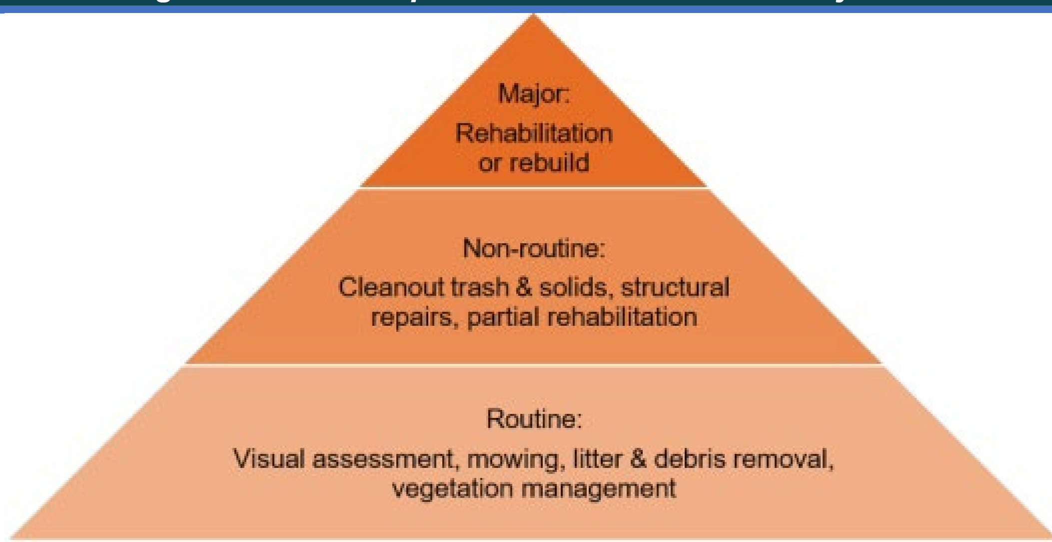
- For drainage easements, the easement width should increase as the top width of the channel or depth of the pipe increases. For example, the easement width should be progressively increased in increments of 5 feet for pipes at depths of 10, 15, and 20 feet.
- Ensure that access routes are of adequate width (minimum of 12 feet) and an acceptable longitudinal slope (no steeper than 15 percent). Surfacing should be based on the anticipated frequency of use and types of equipment involved. Although gravel may be a suitable surface, consider pervious surfaces (e.g., reinforced turf or paver blocks) that do not increase the site's impervious cover.
- Record easements with the Clerk of Court in the jurisdiction where the property is located,
- An easement agreement or deed of easement will help specify the rights and responsibilities of both the easement holder and the owner. For instance, the deed or agreement can spell out that the owner is responsible for mowing and routine maintenance and that fences and other obstructions are not permitted.

Securing agreements to access and maintain previously installed BMPs may also be necessary. Many existing BMPs require costly repairs to restore effective function. It is not uncommon for the local program to assume responsibility for the BMPs only after the private party: (1) maintains the BMP to a minimum specified performance level and (2) provides legal access and easement documents.

## 10.2.5 Maintenance Implementation

Once responsibilities have been transferred, maintenance agreements are in place, and construction is completed, the responsible party will implement ongoing maintenance for applicable BMPs (see also Section 10.2). Typically, maintenance elements include short-term (routine or more frequent), long-term (non-routine or less frequent), and major (rare) actions, as depicted on Figure 10-3.

***Figure 10-3 BMP Operation and Maintenance Pyramid***




*Source: Stormwater Magazine (Buranen 2008)*

Broadly, individual maintenance tasks break down into two categories: non-routine and routine (also called corrective maintenance). Non-routine maintenance consists of repairing plumbing, components, and infrastructure; it is typically costly and requires an enhanced level of expertise. Routine maintenance principally involves removing accumulated trash and debris and managing vegetative growth (see Table 10-1).

| Table 10-1 Examples of Non-Routine and Routine Maintenance | |
|---|---|
| **Structural Maintenance Items (Non-routine)** | **Routine Maintenance Items** |
| • Clogged or broken pipes<br>• Missing or broken parts (e.g., valves, seals, manhole)<br>• Cracked concrete<br>• Dam repairs<br>• Erosion at outfall or on banks<br>• Sinkhole formation or subsidence within the BMP footprint<br>• Regrading or dredging<br>• Mechanical equipment repairs<br>• Landscaping needs complete refurbishment | • Mowing<br>• Removal of small amounts of sediment<br>• Removal of vegetative overgrowth and woody plants<br>• Removal of trash and yard debris<br>• Replacing dead or diseased landscaping<br>• Control of invasive plants<br>• Vegetation and media maintenance<br>• Nuisance control (e.g., animals, undesirable plan communities, etc.)<br>• Minor cleaning of pretreatment devices, inlets, outlet structures, chambers, etc. |

Sources: CWP 2008; Water Environment Federation et al. 2022

The approach to implementing maintenance will depend on the size of the site and number and type of BMPs under maintenance, as well as the capabilities of the long-term owner/operator. Table 10-2 summarizes the inspection and maintenance repair crew and equipment that may be needed for maintaining and inspecting a typical site.

**Table 10-2 BMP Inspection, Maintenance, and Repair Crew and Equipment Summary**

| Task | Description | Basic Equipment |
|---|---|---|
| Inspection | Aboveground inspection crew or confined space crew | PPE, van, pickup truck, tablet, manhole lift device, shovels, pick, camera, whiteboard, confined space equipment |
| Routine Maintenance | Aboveground routine maintenance crew<br>Underground routine maintenance crew<br>Regeneration/full vacuum street sweeper | PPE, van, pickup truck, tablet, 7k trailer, mowers, vac truck, sediment dewatering, street sweeper, seeding, mulchers, mowers, disposal equipment |
| Non-Routine Maintenance | Aboveground structural non-routine maintenance crew | Single axle dump truck, trailer, mini-excavator, excavator, track loaders, hand tools |

PPE = personal protective equipment

## 10.2.6 Enforcement

Once inspection and maintenance agreements are in place, the responsible party will implement the O&M program for applicable BMPs for the life of the BMPs. The applicable regulating entity (usually a VESMP authority) will maintain an oversight, inspection, and enforcement role, which mainly includes requiring periodic reporting, conducting inspections, and implementing enforcement actions when needed, unless reporting and inspections are conducted by the BMP owner. These may initially consist of a Notice of Violation but may proceed to civil and even criminal penalties for more serious cases of intentional negligence. In most maintenance agreements, the VESMP authority is also permitted to enter the property to make necessary repairs and assign applicable costs to the owner in the event of non-compliance.

## 10.3 Best Practices for Developers and Designers

Once a BMP is constructed and turned over to a long-term owner/operator, it should be managed in the context of a program that provides for documentation, tracking, and inspection, as well as routine and corrective maintenance. The size, extent, and sophistication of the program will vary substantially according to the number, location, and variety of BMPs under management. Local governments, large institutions or big retailers may have a robust and sophisticated maintenance program; a small apartment building or independent business may need something much simpler.

While developers are not typically involved in this phase of maintenance, developers are expected to be aware of the process and to implement BMPs during the design and construction phase to ensure that maintenance will be successful in the long term. This starts with early coordination by the development team with the eventual facility owners prior to construction.

### 10.3.1 Engage Facility Owners During Design and Construction

Engaging the long-term owner/operator early in the BMP design process is perhaps the most critical best practice to ensure long-term success of O&M programs. The operator during design and construction is likely not the same entity or individual responsible for the long-term maintenance of the stormwater facility. This means that the decision during design and construction will impact someone who may not be involved in the selection, design, and construction of the BMP.

As a designer, developer or applicant, engaging the ultimate owner of the facility early in the design and during construction will facilitate the delegation of responsibility when the general permit is terminated after construction because the long-term owner will have information regarding BMP performance, maintenance access, and the BMP-specific requirements for maintenance as detailed in the BMP specifications.

When development is proposed for a new site, the developer should identify the long-term owner/operator if possible and engage with this entity to gain a sense of available maintenance resources and level of knowledge. These initial conversations will help to inform the selection and design of BMPs (see also Chapter 6), helping to ensure that the owner is well prepared to take on maintenance for the proposed BMPs. This engagement should continue throughout the development of the Maintenance Plan and agreement and negotiation of easements (see Section 10.1).

At the pre-construction meeting, the parties should review the Maintenance Plan, maintenance responsibilities, and schedules. For MTDs, a representative from the manufacturer may be included to help define long-term inspection and maintenance efforts.

### 10.3.2 Develop a BMP Database During Design

Whether the owner/operator is responsible for one or hundreds of BMPs, inventory, tracking, and inspection of BMPs are essential best practices that will be implemented during the long-term inspection and maintenance program. From a designer/developer standpoint, the creation of a database of designed/constructed assets that can be handed off to the long-term owner/operator helps to ensure that all assets are inventoried and accounted for prior to the beginning of long-term maintenance. For simpler projects, a spreadsheet may suffice, whereas for larger projects with numerous BMPs, the use of a spatial database with mapping function (i.e., geographic information system) is suggested. Ultimately, this information should be incorporated and referenced as appropriate in the Owner's Manual.

Tips for developing an asset "database" during design and construction include:

- Developing a system of unique BMP IDs that can be retained through design, construction, and maintenance;
- Creating a reference map showing each BMP and unique ID that can be used to reference tabular information;
- Creating a tabular database or spreadsheet that contains critical information pertaining to each BMP including the type, size, location of the asset, date built, and any maintenance-related information – access restrictions;
- Updating the database or spreadsheet based on as-built data; and
- Incorporating any significant maintenance-related issues encountered during construction (e.g., any issues with plant establishment, sediment buildup).

## 10.3.3 Design BMPs with Maintenance in Mind

Beyond coordinating with the long-term owner on issues such as easements and maintenance responsibilities, developers need to ensure BMPs are designed and constructed to be easily and safely maintained in the long term. Chapter 6 provides additional information on maintenance considerations for BMP design.

### 10.3.3.1 Safety Considerations

The means for accessing a BMP should ensure that the safety of the inspector is always considered. Health and safety plans should be considered during the BMP design to ensure safe implementation of the inspection program. The safety plan should identify the following:

1. All PPE needed to perform the job;
2. Types of tools needed to perform the job;
3. Checklist for crews when preparing for the inspection work;
4. Access/parking plan when arriving at site – where to park and the safest route from the vehicle to the BMPs;
5. Weather considerations; and
6. Logistics.

### 10.3.3.2 Inspection and Monitoring Considerations

Design of a BMP/stormwater management facility should consider ease of access and feasibility of maintaining the BMP. This may entail widening the maintenance access to account for larger vehicles or providing additional stabilization at a point along a BMP slope that will be used as the entrance point for the maintenance or inspection equipment. Landscaping plans should consider the types of plantings around the BMP to allow for easier visual inspections. For example, planting large coniferous trees adjacent to a maintenance access road may hinder visual inspections. For larger stormwater management facilities, safety benches and pitch of slope banks ensure that maintenance can be conducted in a safe manner and in a way that reduces the time spent inspecting each BMP (increased program efficiency).

### 10.3.3.3 Additional Design Considerations

BMP selection and design should consider the ease of maintenance and match the capabilities of the long-term owner/operator. Specific considerations include the following:

- Consider bioretention systems and other surface systems for which long-term owners will need to provide on-site landscape maintenance. Maintenance for these systems can typically be incorporated into landscape maintenance, while maintenance for porous pavement and subsurface systems typically requires specialty services/contracts.
- Limit the drainage area to BMP area ratio, particularly for high sediment loading systems.
- Avoid the use of underground systems or porous pavement if sediment and debris loading is high, as these systems are difficult to access and clean.
- Consider aesthetic expectations for surface vegetated BMPs that will double as landscape features, particularly for systems that are close to residences or are in heavily trafficked areas.
- Make the planting palette maintenance-friendly. Pick a few hardy species that are easily recognized and distinguished from weeds.
- Consider how the system will function if maintenance is not perfect. Despite best intentions, maintenance is not perfect, and designers should focus on designing systems that will continue to function even under less than ideal conditions.
- Watch for erosion potential in steeply sloping environments. Effective energy dissipation is key to reducing inflow velocities. Also, consider flow splitters/diversions so that high flows are routed around BMPs that can be vulnerable to erosion.

## 10.3.4 Develop an Owner’s Manual

The development of a comprehensive Owner’s Manual to guide O&M is another important best practice that can begin prior to transfer of the responsibilities to the long-term owner. Incorporating elements of the Owner’s Manual, such as inspection and maintenance checklists and maintenance schedules, into a Maintenance Plan (submitted as a prerequisite for design and construction approvals), can make the transition to long-term O&M easier and more efficient. Additionally, links to the BMP database or spreadsheet (see Section 10.3.2) along with an explanation of each data field (i.e., metadata, as well as a map depicting BMP and easement locations) should be included in the Owner’s Manual. Similarly, an Owner’s Manual should include accurate as-built drawings, performance criteria tied to design criteria, and manufacturer/contractor warranties and maintenance instructions.

### 10.3.4.1 Inspection and Maintenance Checklists

The Owner’s Manual typically includes inspection and maintenance checklists to structure the performance of these activities and facilitate documentation. Sample checklists are provided by BMP in Appendix H.

### 10.3.4.2 Maintenance Schedules

Table 10-3 provides recommendations for the frequency of maintenance inspections depending on the type of BMP involved. Ideally, at least during the first 2 years of operation, devices that include vegetation and/or permanent pools of water in a highly engineered system require inspection monthly and after large storm events in order to identify any problems with flow conveyance or vegetative health before they become serious. All other BMPs should be inspected quarterly and after large storm events. Following that initial period, assuming facilities continue to operate without problems and depending on the type of facility, inspections may be conducted annually or, at the absolute minimum, once every 5 years.

**Table 10-3 Recommended Inspection Frequency for BMPs**

| Inspection Frequency | BMPs |
|---|---|
| Monthly and within 24 hours after every water quality storm (greater than 1 inch of rainfall) | Constructed Stormwater Wetlands<br>Wet Ponds<br>Wet Extended Detention Basins<br>Bioretention Cells |
| Quarterly and within 24 hours after every water quality storm (greater than 1 inch of rainfall) | Level Spreaders<br>Infiltration Devices<br>Filter Practices<br>Dry Extended Detention Basins<br>Permeable Pavement<br>Rain Tanks and Cisterns<br>Vegetated Roofs<br>Filter Strips*<br>Wet and Dry Swales*<br>Grass Channels* |

Note: *Although these devices require quarterly inspection, mowing will usually be conducted at more frequent intervals during the growing season.

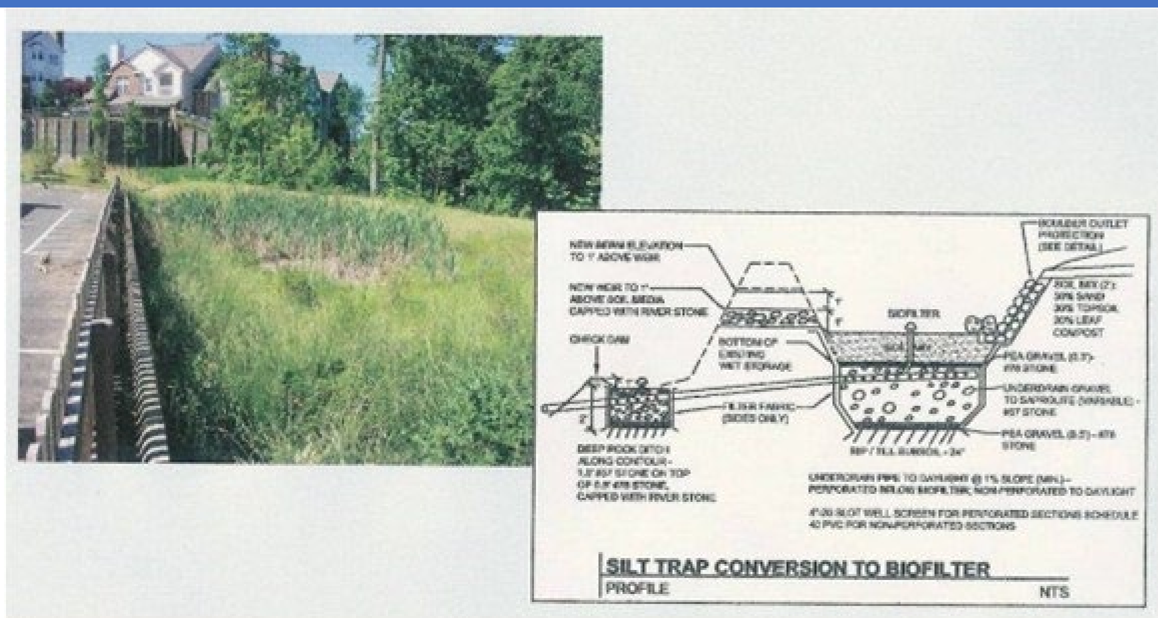
*Source: North Carolina Department of Environment and Natural Resources 2007*

### 10.3.4.3 As-Builts

After construction is completed, qualified engineers and surveyors will prepare as-built drawings of BMPs for a permanent record of the structures. The as-built plans are a critical element of future inspections. Although the acceptance of as-built plans is primarily a plan reviewer function, construction inspectors can play a key role in confirming the accuracy of as-built plans. They can also add documentation to the file that might be extremely useful for the maintenance inspection staff, who will ultimately inherit inspection responsibilities, unless inspections are conducted by the BMP owner.

As-built plans should be prepared by qualified engineers and surveyors to verify that post-construction BMPs have been installed according to plans and specifications. Inspection staff should confirm these as-built plans and take photographs of as-built conditions. Doing so will provide useful documentation and help answer questions when future maintenance issues are identified (Figure 10-4). This is particularly important for control practices that may change their function during transition from construction to post-construction. Examples are sediment basins that become permanent ponds or sediment traps converted to biofilters. For additional details on the requirements for as-builts, see Section 4.4.3.1.

**Figure 10-4 Construction Inspectors Should Be Involved in Confirming As-Built Plans**




*Source: CWP 2008*

### 10.3.4.4 Performance Criteria

Performance criteria from the BMP specifications should be incorporated into the Owner's Manual as a reference point for inspections. Performance criteria are tied to regulatory criteria for which a particular BMP was designed.

### 10.3.4.5 Warranties

Another component of a comprehensive Owner's Manual is a stormwater warranty. Stormwater facility warranties are typically recorded for MTDs, although warranties can also apply to other BMP features.

## 10.4 Summary of BMP Operation and Maintenance Tasks and Activities

All maintenance will be performed in accordance with standard maintenance practices as identified in the approved Maintenance Plan and the applicable BMP specifications. Common maintenance activities to be performed include routine activities, such as weeding and trash removal, and non-routine activities, such as major structural repairs. The following sections provide an overview of the most common types of maintenance activities.

## 10.4.1 Plantings

Native upland and flood fringe plantings are generally stable and should not need much maintenance or re-establishment. Shoreline fringe areas are subject to harsher conditions as a result of the frequent wetting and drying associated with this zone. Aquatic plantings are the most difficult to establish initially. Typically, vegetation in the aquatic and shoreline fringe zones will require some replanting or enhancement during the first 2 years of SWM facility operation. Preliminary results of studies of stormwater plantings indicate that a healthy vegetative community will establish if proper conditions are created (although the final set of species may not be those that were originally planted).

Planting methods can be separated into the following three main categories (from terrestrial to aquatic) based on the moisture level and types of vegetation that will grow in these conditions:

- **Upland/Flood Fringe.** The two types of plantings used are herbaceous (ground covers and grasses) and woody vegetation (shrubs and trees). Planting should occur in the spring after groundwater levels have normalized. Ground cover can be installed either by hydroseeding or using a custom seed mix in a nutrient-rich medium impregnated in a biodegradable mesh like blanket. Individual shrubs and trees can be planted manually, with openings made in the mesh blanket for each individual plant if necessary.
- **Shoreline Fringe (Wet Riparian).** Shoreline fringe vegetation should be planted in mid-May to early June but after water levels have subsided to a stable level. Some form of protection of the seed mixture and soil nutrient medium (if required) should be provided in this dynamic zone of water level fluctuation. In order to establish ground cover in this zone, the biodegradable mesh-like blanket suggested for the upland zone is also highly recommended for this zone. Shrubs and trees can be planted through openings created in the mesh blanket.
- **Aquatic Fringe/Shallow Water.** The establishment of plantings in this zone will require greater material handling and growth monitoring, both in the short term and over the long term. Emergent vegetation is easily planted by hand if the substrate is suitable (e.g., ideally, a firm substrate with at least 10 percent organics by volume). Young shoots (rather than rhizomes or corms) are preferable for planting because these plants are already growing with an established root structure (for early stability). The plants should be at least 4 inches tall, and planting should occur from late May to early June. Sprigs or plugs are preferable for planting emergent plants because the root material is already contained in a suitable growth medium.

Mature growth should be planted to establish submerged rooted plants (including pondweeds) if planted in late spring to early summer when the mature plants can take advantage of warmer water and sunlight penetration. Plantings in early spring or fall should take the form of vegetative propagules, such as turions or rhizome plugs, which can germinate in the spring or over the winter and begin growing in the subsequent growing season.

## 10.4.2 Vegetation Maintenance

Vegetation maintenance is an important component of any stormwater maintenance program. As such, a site-specific vegetation maintenance plan should be developed, implemented, and adjusted over time. It is also important to note that there are specific requirements related to certain management practices that must be followed such as those performed within buffers. The grasses and plants in all BMPs require regular attention, but particularly in vegetative BMPs, such as filter strips, dry and wet swales, grass channels, bioretention facilities, and constructed stormwater wetlands. The development of distressed vegetation, bare spots, and rills indicates that a BMP is not functioning properly. Problems can have many sources such as the following:

- Excessive sediment accumulation, which can clog the soil pores and produce anaerobic conditions;
- Nutrient deficiencies or imbalances including pH and potassium;

- Water-logged conditions caused by reduced soil drainage or a high seasonal water table; and
- Invasive weeds and nuisance plants.

Maintenance of vegetation will naturally change as the vegetation matures; therefore, the soil in vegetated areas should be tested every other year and adjusted to sustain vigorous plant growth with deep, well-developed root systems. Soil aeration is recommended for filter strips and grassed swales in which sediment accumulation rates are high. Ideally, vegetative cover should be mown infrequently, providing for the development of thick stands of tall grass and other vegetation. Also, trampling of vegetation by pedestrian traffic should be prevented.

Areas immediately upstream and downstream of some BMP plantings often experience increased erosion. Although properly designed, located, and transitioned installations experience this effect to only a minor degree, all erosion should be repaired immediately to prevent worsening. Live stakes, live fascines, and other soil bioengineering techniques, possibly in combination with 3-D geotextiles, can be applied to erosion in natural drainage ways with minor grading (see also Section 10.4.5).

Table 10-4 describes some of the vegetation-specific maintenance at various types of BMPs. It is important to note that there are specific requirements related to certain management practices that must be followed such as those performed within buffers. In addition, vegetation should be removed if it poses threats to human safety, buildings, fences, and other important structures. Finally, vegetation maintenance naturally changes as the vegetation matures after construction.

### 10.4.2.1 Grass Cutting

Generally, grass cutting should be limited around SWM facilities. Allowing grass to grow tends to enhance water quality and provide other benefits for wet facilities. Short grass around a wet stormwater facility provides an ideal habitat for nuisance animal species such as geese. Allowing the grass to grow is an effective means of discouraging geese. Grass cutting is one maintenance activity undertaken solely to enhance the perceived aesthetics of the facility. The frequency of grass cutting depends on surrounding land uses, local municipal or homeowner's association bylaws, and public or peer pressure. In view of the various influences, grass should be cut as infrequently as possible but with sensitivity to the aesthetic concerns of nearby residents.

Grass around wet facilities should not be cut to the edge of the permanent pool. Allowing grass to grow tall enhances water quality and provides other benefits for wet facilities such as deterrence of nuisance wildlife. As a safety precaution, grass should be cut parallel to the shoreline with grass clippings ejected upland in order to avoid adding organic matter to the pond.

**Table 10-4 Vegetation Maintenance for BMPs**

| Activity | Instruction |
| --- | --- |
| Replacement of Dead Plants | All dead plants should be removed and disposed of. Before vegetation that has failed on a large scale is replaced, the cause of the failure should be investigated. If the cause can be determined, it should be eliminated before vegetation is replaced. |
| Plant Selection | When possible, use native plants to increase probability of survival. Refer to Appendix G for more information on selecting the optimal plants to use. |

| Table 10-4 Vegetation Maintenance for BMPs | |
|---|---|
| **Activity** | **Instruction** |
| Fertilization | The objective of fertilizing at a BMP is to secure optimum vegetative growth rather than yield (often the objective with other activities such as farming). Soil should be tested every 3 years, then the soil can be amended with lime and fertilizer as needed to sustain vigorous plant growth. Infertile soils should be amended before installation and then fertilized periodically thereafter. Fertilizer can be composed of minerals, organic matter (manure), compost, green crops, or other materials. |
| Irrigation/ Watering | Watering vegetation is usually necessary during the germination period, as well as occasionally thereafter to preserve the vegetation through drought conditions. This can typically be accomplished by installing a permanent irrigation system or frost-proof hose bib or using potable water trucks. |
| Mulching | Mulch should be used to maintain soil temperature and moisture, as well as to improve site aesthetics. A 0.5-inch layer is typically adequate. Ideally, mulch should be removed before winter to prevent an infestation of rodents. |
| Weeding | Weeding is often necessary in the first growing season, particularly if herbaceous grasses are outcompeting the young woody vegetation. The need for weeding may be largely eliminated by minimizing the amount of seed used for temporary erosion control. Weeding may also be required if, over time, invasive or undesirable species are entering the site and outcompeting plants that are specifically desired for the treatment of the stormwater. |
| Cultivating/ Hoeing | Hoeing is often required to loosen overly compacted soil and eliminate weeds that compete with the desirable vegetation. |
| Pruning | Pruning is used to trim plants to a desired shape and remove dead wood. Pruning can force single-shoot shrubs and trees to assume a bushier configuration. |
| Thinning | Thinning dense brush may be necessary for particular species to thrive, to increase the vigor of individual specimens, to reduce flow obstructions, and to increase the ability of maintenance staff to access the entire BMP. Tall maturing trees typically have no place in a BMP (except for buffers) and should be removed as soon as possible. |
| Aeration | Soil aeration is recommended for filter strips and grassed channels in which sediment accumulation rates are high. |
| Staking | Saplings of tall trees planted in or near the BMP may require staking. Care should be taken not to damage the tree’s roots or trunk with stakes or ties. Stakes should be kept in place for 6 to 18 months, and the condition of the stakes and ties should be checked periodically. |
| Wound Dressing | Broken or damaged branches and other wounds on trees should be dressed in accordance with recommendations from a trained arborist. |

| Table 10-4 Vegetation Maintenance for BMPs | |
|---|---|
| **Activity** | **Instruction** |
| Disease Control | Based on monitoring observations, either insecticides or (preferably) organic means of pest and fungal control should be used. |
| Mowing | Mowing of perennial herbaceous grasses and wildflowers, especially once seed heads have set, promotes redistribution of seed for this self-sustaining system. However, mowing should be carefully controlled, especially when performed for aesthetics. As adjacent property owners and citizens in general learn more about BMPs, their vision of what is aesthetically pleasing can change. Grasses associated with BMPs, in healthy herbaceous stands, should never be mown more than once each year. |

### 10.4.2.2 Weed Control

Weeds are generally defined as any kind of vegetation that is unwanted in a particular area. In terms of BMPs, weeds are generally invasive species that cannot provide the intended function of the planting strategy or other non-native species such as purple loosestrife, the spread of which is undesirable. Local weed control rules should be consulted for local requirements. Weed control should be completed annually or bi-annually.

Ideally, weeding should be performed by hand to prevent the destruction of surrounding vegetation. The use of herbicides and insecticides, which cause water quality problems, should be prohibited near BMPs. However, if their use is required, it should be performed by a licensed certified applicator or following manufacturer directions. The use of fertilizer should also be limited to minimize nutrient loading to the downstream receiving waters.

## 10.4.3 Maintenance of the Aquatic Environment

An important yet often overlooked aspect of non-routine maintenance of BMPs that have a permanent pool of water is the need to regularly monitor and maintain conditions that promote a healthy aquatic environment. An indicator of excess nutrients (a common problem) is excessive algae growth in the permanent pool of water. In most cases, such problems can be addressed by encouraging the growth of more desirable aquatic and semi-aquatic vegetation in and around the permanent pool. The plants selected should be tolerant of varying water levels and have a high capacity to incorporate the specific nutrients associated with the problem. Other options include the use of mechanical aerators, filters, or chemical flocculates. If algae proliferation is not addressed, algae-laden water will be washed downstream and may contribute to nuisance odors and pollution stresses in downstream aquatic habitat.

## 10.4.4 Debris and Litter Removal

Trash removal is an integral part of BMP maintenance. Generally, a “spring cleanup” is needed to remove trash from all surface BMPs. Subsequently, trash removal is performed as required based on observations during regular inspections. Special attention should be given to removing floating debris, which can clog the outlet device or riser. Regularly removing debris and litter is well worth the effort and can be expected to help in the following ways:

- Reduces the chance of clogging in outlet structures, trash racks, and other facility components;
- Prevents damage to vegetated areas;
- Reduces mosquito breeding habitats;

- Maintains facility aesthetics;
- Reduces conditions for excessive surface algae; and
- Reduces the likelihood of stagnant pool formation.

## 10.4.5 Stability and Erosion Control

The best way to promote soil stability and erosion control is to maintain a healthy ground cover in and around the BMPs, which is why it is important to establish and follow a vegetation management plan. When vegetation is not managed, areas of bare soil quickly erode, potentially clogging the facility with sediment. Therefore, bare areas need to be stabilized as quickly as possible. Newly seeded areas should be protected with mulch and/or an erosion control mat that is securely staked.

Erosion is quite common at inlets and outlets of BMP facilities and should be repaired as soon as possible. Erosion control efforts should also extend to areas immediately downstream of the BMP.

The roots of woody vegetation (e.g., young trees and shrubs) can cause embankments to be unstable. Consistent mowing of the embankment controls stray seedlings that take root. Growth of trees and shrubs further away from the embankment should not pose a threat to the stability of the embankment and can provide important runoff filtering benefits. Trees and shrubs should not be planted within maintenance and access areas.

Finally, subsidence and sloughing can result in sinkholes on embankments or basin and channel bottoms. Subsidence and sloughing are not solely related to karst areas. The presence of these issues or sinkholes anywhere within the BMP perimeter or along the treatment train can short-circuit the stormwater management system, and it should always be considered a criterion of BMP failure that must be addressed and corrected.

## 10.4.6 Sediment Removal and Disposal

Sediment gradually accumulates in BMPs and must eventually be removed for continued successful operation of the BMP. However, removal intervals vary among facilities. The required frequency of sediment removal depends on many factors including the following:

- The type of BMP;
- The design storage volume (e.g., if the active and permanent pool storage is oversized for sediment storage);
- The characteristics of the upstream catchment area (e.g., land use, level of imperviousness, upstream construction activities and effectiveness of sediment and erosion control activities); and
- Municipal practices (e.g., winter weather roadway sanding and salting) in the contributing drainage area.

Wet sediment is more difficult and expensive to remove than dry sediment. The entire facility should be able to drain completely and allowed to dry sufficiently so that heavy equipment can operate on the bottom. Refer to the BMP specifications for the specific maintenance guidance for these BMPs.

Underground or proprietary BMPs – such as vaults, chambers, and other structures that require accumulated material to be pumped out – require special consideration. For such facilities, inspection and maintenance staff may be required to have confined-space training to satisfy Occupational Safety and Health Administration safety requirements. Also, some types of proprietary devices require more frequent maintenance in order to perform as designed. Maintenance contracts are essential when such BMPs are specified on plans.

At sites in which sediment loads are expected to be high, designers should designate a dewatering and storage area on the site. This area should be located outside of the floodplain.

Sediment removed from a BMP requires proper disposal. Generally, there are three sediment disposal options:

- **On-Site Disposal.** On-site disposal allows the sediment to be disposed of on any land area that is not regulated (e.g., land other than floodplain). During site planning, when determining land requirements for stormwater control measures, land can be set aside for on-site disposal of sediment removed from the BMPs during maintenance. The areas used for sediment disposal should be landscaped after each sediment removal operation to stabilize the soil and provide a natural appearance.
- **Off-Site Disposal.** Offsite disposal does not reduce the developable area, landscaping/grading does not have to be performed, and there are no perceived liability/health concerns with respect to the surrounding landowners. Offsite disposal can mean disposal at a sanitary landfill or disposal at another area undergoing filling. The selection of a deposition site depends on the quality of the sediments and the availability of and distance to the alternative fill areas.

  Temporary disposal areas are recommended for surface end-of-pipe stormwater management facilities – particularly those that do not have a maintenance bypass – because this provides a location for the sediment to dry before transporting it offsite. Where temporary sediment disposal areas (i.e., drying areas) are not feasible due to limited availability of land or high cost, the means of dealing with the un-dewatered sediment should be detailed in the SWM plan and maintenance agreement, which must be approved by the VESMP authority.
- **Hazardous Waste Disposal.** Although sediment removed from BMPs is expected to contain contaminants (metals, bacteria, nutrients), the levels of pollutants involved are typically not sufficient for it to be classified as hazardous waste. Hazardous waste must be deposited at a hazardous waste facility. Transportation costs and disposal fees are high for hazardous waste because licensed haulers must transport the material, and accessible hazardous waste receiving facilities may be limited in number or distance. Laboratory testing may be required to determine if material is hazardous. Typically, testing is conducted to meet the requirements of the disposal facility, which in turn are regulated by federal and state statutes pertaining to the disposal of hazardous waste. Guidance on environmental testing is beyond the scope of this manual. Applicants are referred to the Virginia Hazardous Waste Regulations (9VAC20-60) for more information on hazardous waste transport and disposal.

## 10.4.7 Maintenance of Mechanical Components

Each type of BMP may have mechanical components that need to be properly maintained to ensure optimal performance. For example, valves, sluice gates, fence gates, locks, and access hatches must be functional at all times. The routine inspection, exercise, and preventive maintenance of such mechanical components should be incorporated into routine maintenance schedules for all BMPs.

## 10.4.8 Insect Control

Ponded water can function as a breeding site for mosquitoes and other insects. Mosquito problems can be minimized through proper design and maintenance. The most effective control technique for prevention of mosquito breeding is to ensure that permanent impoundments do not develop stagnant areas. BMPs with permanent pools should include a source of steady dry weather flow. Promptly removing floatable debris from the drainage path helps eliminate areas in which water can collect and then stagnate. In larger basins, fish that feed on mosquito larvae can be stocked. Additionally, splash aerators can be employed to prevent stagnant water.

However, aerators require electricity at the site, increase maintenance costs, and must be designed to not decrease the settling efficiency of the BMP.

## 10.4.9 Winter Operation

During winter months, cold and freezing weather is a potential concern. Certain BMPs, such as rainwater harvesting systems, should be disconnected to prevent damage at connection pipes during freezing and thawing.

Another potential maintenance task for the winter months involves filters and infiltration systems that are part of a treatment train. When possible, runoff subject to high sediment loads resulting from road maintenance (e.g., sanding and salting) should be diverted to bypass these BMPs while still passing through downstream controls.

As there is an increased risk of groundwater contamination from road salt associated with winter operation of infiltration facilities that receive road runoff, these facilities should be cleaned more frequently or bypassed during the winter months.

## 10.4.10 Maintenance of Other Project Features

All other devices and features associated with BMPs should be monitored and maintained appropriately. These additional items could affect the safety or aesthetics of the facility, which can be as important as (if not more important than) the operational efficiency of the facility. Such items might include:

- Fences (e.g., security fences and gates);
- Access roads;
- Trails;
- Signage (e.g., no trespassing, emergency notification contact information);
- Platforms; and
- Watering systems.

## 10.4.11 Monitoring

Although not typically performed by private owners, stormwater monitoring may be conducted on privately owned sites by municipal or utility staff to meet municipal permit requirements or for research purposes. Stormwater monitoring is typically conducted at two levels:

- **Watershed and Subwatershed Monitoring.** As noted previously, stormwater is best managed within the context of a Watershed and Subwatershed Plan. These plans will normally contain a monitoring component to track implementation. The monitoring program will typically include administrative monitoring, water chemistry, biological monitoring, flow, and erosion monitoring. These monitoring programs are essential to the success of the plan. Subwatershed monitoring will normally be conducted or administered by the local conservation authority or municipality.
- **Facility Monitoring.** The consensus among practitioners is that monitoring for chemistry or biotic parameters cannot be justified for each individual facility because, to have any scientific validity, a large and costly sampling program is required. The approaches generally used are: (1) physical operation monitoring by the owner or municipality to verify that the facility is operating as designed, and/or (2) detailed monitoring of a typical installation through a research program to evaluate design and performance issues. The designer is advised to consult with authorities regarding site-specific requirements because some jurisdictions impose additional monitoring requirements.

## 10.4.12 Emergency Maintenance

Maintenance after floods and other emergencies requires immediate mobilization. The response can include replanting vegetation and repairing damaged structures. Living systems are likely to need at least minor repairs after emergencies. Following an emergency, such as a flood, standing water may pose health risks because of mosquitoes or contact pollutants. Mosquito control and blocking access should be considered if this becomes a problem.

Obstructions and debris deposited during storm events should be removed immediately from all installations. Formation of sinkholes or other evidence of subsidence within a BMP footprint or its drainage pathways indicates failure of the BMP. The practice should be repaired as soon as feasible after the first observation using appropriate engineering techniques (e.g., Virginia Department of Transportation IIM228 – Sinkholes: Guidelines for the Discharge of Stormwater at Sinkholes; WVDEP 2004; MDE 2000).

***Figure 10-5 BMP Sinkhole Collapse***

*Source: Robert Denton*

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# APPENDIX A HYDROLOGIC AND HYDRAULIC METHODS AND COMPUTATIONS

**Contents:**

# A.1 Introduction

This Hydrologic and Hydraulic Methods and Computations appendix describes statistical rainfall patterns and response characteristics of natural and developed landscapes as elements of the hydrologic cycle. Hydrology is the study of the properties, distribution, and effects of water on the earth's surface and in soils, underlying rocks and groundwater, and the atmosphere.

The purpose of this appendix Is to convey the minimum acceptable post-development water quantity design and construction guidelines required to ensure the general health, safety, and welfare of citizens of the Commonwealth and to protect the quality and quantity of state waters from potential harms caused by unmanaged stormwater. These Hydrologic and Hydraulic Methods and Computations should be used as guidance for preparing calculations for various elements of the hydrologic and hydraulic analysis of a watershed under the Virginia Erosion and Stormwater Management Regulation (Regulation). Guidelines are included for performing various engineering calculations associated with the design of stormwater management facilities such as hydrograph routing, orifice design and multi-stage outlet structures, sheet flow, and level spreaders.

These post-development water quantity design and construction guidelines are designed to supplement the provisions of existing federal and state laws and regulations. Nothing contained herein shall be deemed to waive or modify other requirements of existing laws or regulations. Except as expressly stated otherwise in this document, the Virginia Department of Environmental Quality (VDEQ) is the designated entity charged with the administration of the post-development water quantity design and construction guidelines contained herein.

Where VDEQ has approved a locality's Virginia Erosion and Stormwater Management Program (VESMP) - establishing a VESMP authority - the VESMP authority may allow for exceptions to given water quantity and water quality technical criteria in accordance with 9 Virginia Administrative Code (VAC) 25-875-170 (i.e., section 170 of the Regulation, which is in Title 9, Agency 25, Chapter 875 of the VAC.

# A.2 Precipitation Data

Precipitation is a random event that cannot be predicted with certainty based on historical data. However, any given precipitation event has several distinct and independent characteristics which can be quantified as follows:

**Duration** – The length of time over which precipitation occurs (hours).

**Depth** – The amount of precipitation occurring throughout the storm duration (inches).

**Frequency** – The recurrence interval of events having the same duration and volume.

**Intensity** – The depth divided by the duration (inches per hour).

The Virginia Erosion and Stormwater Management Regulation (9VAC25-875- 620) identifies the required design storms as follows: Unless otherwise specified, the prescribed design storms are the 1-year, - year, 2 year, and 10-year 24-hour storms using the site-specific rainfall precipitation frequency data recommended by NOAA Atlas 14. Partial duration time series shall be used for the precipitation data.

Predictive models can analyze years of rainfall records and forecast future rainfall patterns. The longer the period of record that is considered, the more accurate the statistical analysis. In a non-stationary environment, additional models and tools may be considered so that design rainfall events reflect conditions forecast to occur throughout a project's lifespan and not only those at the beginning. The Mid-Atlantic Regional Integrated Sciences and Assessments program, in partnership with the RAND Corporation and the Chesapeake Bay Program, has developed a "Projected Intensity-Duration-Frequency (IDF) Curve Data Tool for the Chesapeake Bay Watershed and Virginia https://midatlantic-idf.rcc-acis.org/

The basis for the rainfall depths, frequencies, and intensities used for design must reference the National Oceanographic and Atmospheric Administration (NOAA) Atlas 14 "Precipitation-Frequency Atlas of the United States" Volume 2, Version 3.0 (NOAA Atlas 14), unless a more stringent requirement is directed by the VESMP Authority.

## A.2.1 Frequency

The frequency of a specified design storm can be expressed either in terms of exceedance probability or return period.

**Exceedance Probability** is the probability that an event having a specified volume and duration will be exceeded in one time period, which is most often assumed to be one year.

**Return Period** is the average length of time between events having the same volume and duration.

If a storm of a specified duration and volume has a 1 percent chance of occurring in any given year, then it has an exceedance probability of 0.01 and a return period of 100 years. The return period concept is often misunderstood in that it implies that a 100-year flood will occur only once in a 100-year period. This will not always hold true because storm events cannot be predicted deterministically. Because storm events are random, the exceedance probability indicates that there is a finite probability (0.01 for this example) that the 100-year storm may occur in any given year or consecutive years, regardless of the historic occurrence of that storm event.

## A.2.2 Intensity-Duration Frequency Curves

The U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) is replacing the use of its legacy rainfall distributions (Type I, Type IA, Type II, and Type III) with rainfall distributions based on NOAA Atlas 14 precipitation-frequency data. Regional Virginia rainfall distributions have been developed for use in the NOAA Engineering EFH-2 software program, WinTR-55, and WinTR-20. Rainfall data is accessible through an online Precipitation Frequency Data Server (PFDS):

https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=va.

When using the Rational Method, the designer should no longer use the IDF curves found in previous versions of the Virginia Erosion and Sediment Control Handbook or Virginia Stormwater Management Handbool to determine the rainfall intensity for the calculated time of concentration (Tc), but should rely upon the curves and rainfall intensity data provided in NOAA Atlas 14, unless a more stringent requirement is directed by the VESMP Authority. The latest version of VDOT's Drainage Manual has rational coefficients conforming to NOAA Atlas 14. See Chapter 6 Appendices 6C-1 and 6C-2.

# A.3 Runoff and Peak Discharge Calculations

The practice of estimating runoff as a fixed percentage of rainfall has been used in the design of storm drainage systems for over 100 years. Despite its simplification of the complex rainfall-runoff processes, it is still the most commonly used method for urban drainage calculations. It can be accurate when drainage area land cover is highly impervious and/or homogeneous.

For urbanizing watersheds or drainage areas comprised of pervious cover such as open space, woods, lawns, or agricultural land uses, with varying amounts of impervious cover mixed in throughout the entire area, the rainfall/runoff relationship becomes more complex.

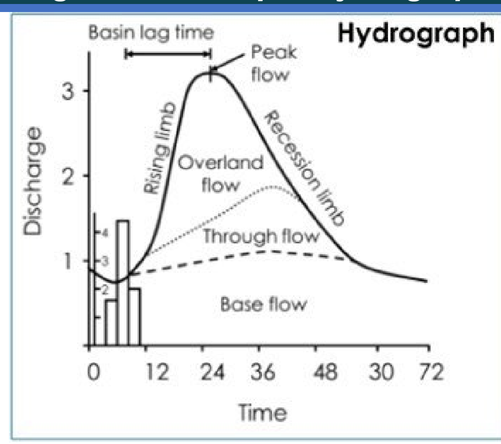
This section will provide a very brief overview of the methods acknowledged in the Regulation: the Rational Method, the Modified Rational Method, and NRCS Methods. The NRCS Methods include numerous modeling and predictive techniques. However, the use of the NRCS basic hydrologic principles of Curve Number (CN), Time of Concentration (Tc), and a runoff hydrograph and peak discharge are covered here as described in Technical Release 55: Urban Hydrology for Small Watersheds (TR-55).

Per 9VAC25-875-620 B, all water quantity design computations shall be based on the existing watershed characteristics and the ultimate development condition of the proposed land-disturbing activity.

## A.3.1 Hydrographs

A hydrograph is a plot of discharge or runoff, on the vertical axis, versus time, on the horizontal axis, as shown in Figure A-1. A hydrograph shows the volume of runoff as the area beneath the curve, and the time-variation of the discharge rate.

***Figure A-1 Sample Hydrograph***



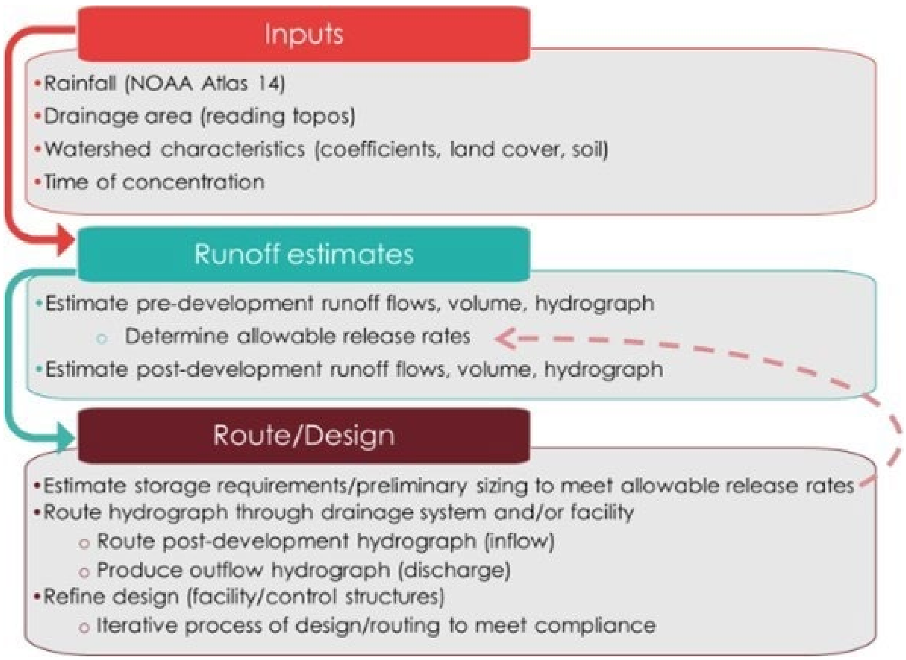

Characteristics of all hydrographs as shown in the previous figure include:

1. Rising limb – Stage (elevation) and discharge are increasing with time
2. Crest or Peak – The maximum stage and discharge for the measured or hypothetical storm event.
3. Receding limb – Stage and discharge are decreasing with time.
4. Base flow – Water emanating from the groundwater table into the stream.
5. Through flow – Water from rainfall that moves laterally through the soil and then returns to the surface, as overland flow, prior to entering a stream.
6. Overland flow – Water from rainfall that flow over land surface which contributes to direct runoff volume (typically includes through flow)

7. Interflow (not shown) – Water from rainfall which moves laterally through the soil before returning to overland flow, streams, or groundwater.

Approaching water quantity compliance for the designer can start with the estimation of hydrograph metrics needed for the determination of compliance targets, all of which then serve as inputs for ultimate stormwater management design elements.

***Figure A-2 Water Quantity Compliance Flowchart***




Many software programs are available which develop these methodologies, utilizing the rainfall-runoff relationship described previously. Many of these programs also “route” the runoff hydrograph through a stormwater management facility, calculating the peak rate of discharge and a discharge hydrograph. These programs are discussed in greater detail later in this section.

## A.3.2 Time of Concentration

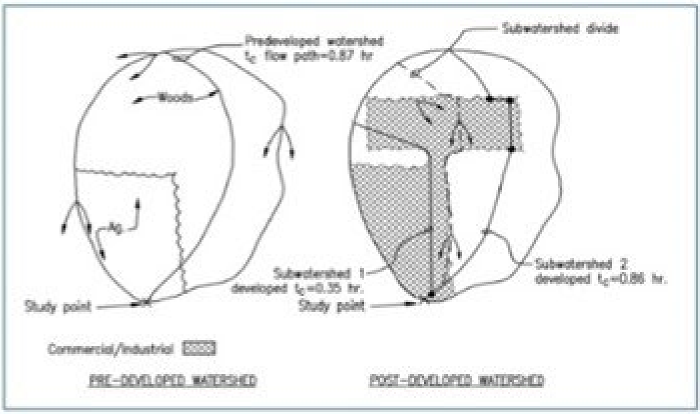
The Time of Concentration, Tc, is the length of time required for a drop of water to travel from the most hydraulically distant point in the watershed or sub-watershed to the point of analysis. The hydraulically most distant point is the point with the longest travel time to the watershed outlet, and not necessarily the point with the longest flow distance to the outlet. Time of concentration is generally applied only to surface runoff and may be computed using many different methods.

The time of concentration plays an important role in developing the peak discharge for a watershed, whether by rational, NRCS, or other runoff estimation methods. Urbanization usually decreases the Tc, which results in an increase in peak discharge. For this reason, to accurately model a watershed or drainage area, any conditions which may act to decrease the flow time, such as channelization and channel improvements, must be taken into consideration. Conditions that may lengthen the flow time, such as surface ponding above undersized conveyance systems and culverts, must also be considered.

Time of concentration will vary depending upon slope and character of the watershed and the flow path. In hydrograph analysis, time of concentration is the time from the end of excess rainfall to the point on the falling limb of the dimensionless unit hydrograph (point of inflection) where the recession curve begins.

In cases where only a peak discharge and/or hydrograph are desired at the watershed outlet and watershed characteristics are fairly homogenous, the watershed may be treated as a single area. A time of concentration for that single area is required. A hydrograph is then developed (see NEH630.16 for description of methods). However, if land use, hydrologic soil group (HSG), slope, or other watershed characteristics are not homogeneous throughout the watershed, the approach is to divide the watershed into a number of smaller subareas, which requires a time of concentration estimation for each subarea. Hydrographs are then developed for each subarea and routed appropriately to a point of reference using routing methods (see the NRCS National Engineering Handbook, NEH630.17 for a description of flood routing methods).

***Figure A-3 Pre and Post Developed Watersheds***




Described below are the three most common methods of determining time of concentration. Two primary methods of computing time of concentration were developed by NRCS: the watershed lag method and the travel time (velocity) method.

## A.3.2.1 Watershed Lag Method

In the watershed lag method (which is the TR-20 default method), flow length is defined as the longest path along which water flows from the watershed divide to the outlet. Flow length can be measured using aerial photographs, quadrangle sheets, or GIS techniques.

*Equation A-1 Watershed Lag Method*

Watershed Lag Method $$L = \frac{l^{0.8}(S+1)^{0.7}}{1{,}900Y^{0.5}}$$

$$substitute\ L = 0.6T_c: \quad T_c = \frac{l^{0.8}(S+1)^{0.7}}{1{,}140Y^{0.5}}$$

$L$ = lag, hours
$T_c$ = time of concentration, hours
$l$ = flow length, ft
$Y$ = average watershed land slope, %
$S$ = maximum potential retention, in
$= \frac{1{,}000}{CN} - 10$

## A.3.2.2 Kirpich Method

The Kirpich method is generally acceptable for natural basins up to 200 acres that are dominated by channel flow. An adjustment factor of 0.2 can be used to correct for paved channels. It is similar to the Lag method but will give shorter times compared to the Lag method.

*Equation A-2 Kirpich Method*

$Tc = 0.007\ L^{0.77} S^{-0.385}$

where:

Tc = time of concentration, min

L = length of channel from headwater to outlet, ft

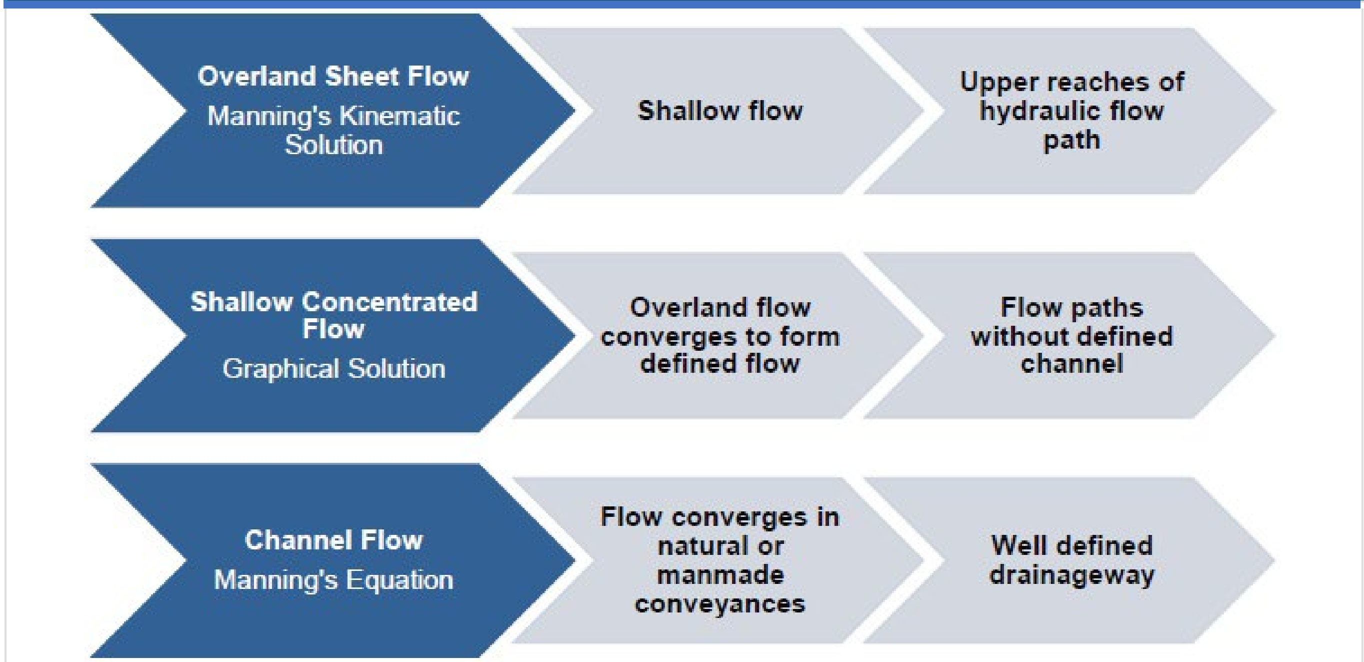
S = slope of the longest hydraulic length, ft/ft

## A.3.2.3 Travel Time (Velocity) Method

The travel time, Tt, is the time it takes a drop of water to travel from one location to another in a watershed and is a component of the Tc. The NRCS method of computing Tc is by summing all the travel times for consecutive components of the drainage conveyance system.

The time of concentration is the sum of the time increments for each flow segment present in the Tc flow Tpath, such as overland or sheet flow, shallow concentrated flow, and channel flow. These flow types are influenced by surface roughness, channel shape, flow patterns, and slope, and are discussed below:

***Figure A-4 Flow Types***




**Overland (sheet) flow** is shallow flow over plane surfaces. For the purposes of determining time of concentration, overland flow usually exists in the upper reaches of the hydraulic flowpath (at or near the drainage divides).

- The flow depth is most likely below 0.05 feet, and most certainly not greater than 0.1 feet (WinTR-55, 2009)

The length of sheet flow may be calculated using the following equation below (NRCS National Engineering Handbook, Equation 15-9):

NOTE: The actual length of overland flow varies considerably according to actual field conditions. The length of overland flow should be verified by field investigation, if possible. Maximum length for sheet flow of 100 feet is stipulated in two technical guidance documents issued by the NRCS: Small Watershed Hydrology, WinTR-55 User Guide (January 2009); and the National Engineering Handbook (NEH, 2010).

*Equation A-3 Maximum length of overland flow*

$$L_{SF} = \frac{100\sqrt{S}}{n}$$

Where:

$L_{SF}$ = maximum length of sheet flow (feet)

S = land slope (foot/foot)

n = Manning's roughness coefficient (see table below).

**Table A-1 Manning's Roughness Coefficients for Sheet Flow (flow depth generally ≤ 0.1 foot)**

| Land Cover | Manning's n |
|---|---|
| Smooth surface (concrete, asphalt, gravel, or bare soil) | 0.011 |
| Fallow (no residue) | 0.05 |
| Cultivated soils: | |
| Residue cover: ≤ 20% | 0.06 |
| Residue cover: > 20% | 0.17 |
| Grass: | |
| Short-grass prairie | 0.15 |
| Dense grasses* | 0.24 |
| Bermudagrass | 0.41 |
| Range (natural) | 0.13 |
| Woods: ** | |
| Light underbrush | 0.40 |
| Dense underbrush | 0.80 |

**Notes:**

Source: NRCS National Engineering Handbook, Table 15-1

* Includes weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

** When selecting n, consider cover to a height of about 0.1 feet, as this is the only part of the plant cover that will obstruct sheet flow.

NOTE: Sheet flow can influence the peak discharge of small watersheds dramatically because the ratio of flow length to flow velocity is usually very high. Surface roughness, soil types, and slope will dictate the distance before sheet flow transitions into shallow concentrated flow. The roughness coefficient is the primary culprit in the misapplication of the Tc equation. Care should be taken to accurately identify the surface conditions for overland flow.

Manning's kinematic solution is used to compute Tc for overland sheet flow.

*Equation A-4 Manning's kinematic solution*

$$Tt = 0.007 \times \frac{(nL)^{0.8}}{P_2^{0.5} \times s^{0.4}}$$

Tt = travel time (hours)

L = length of overland flow (feet)

n = Manning's roughness coefficient

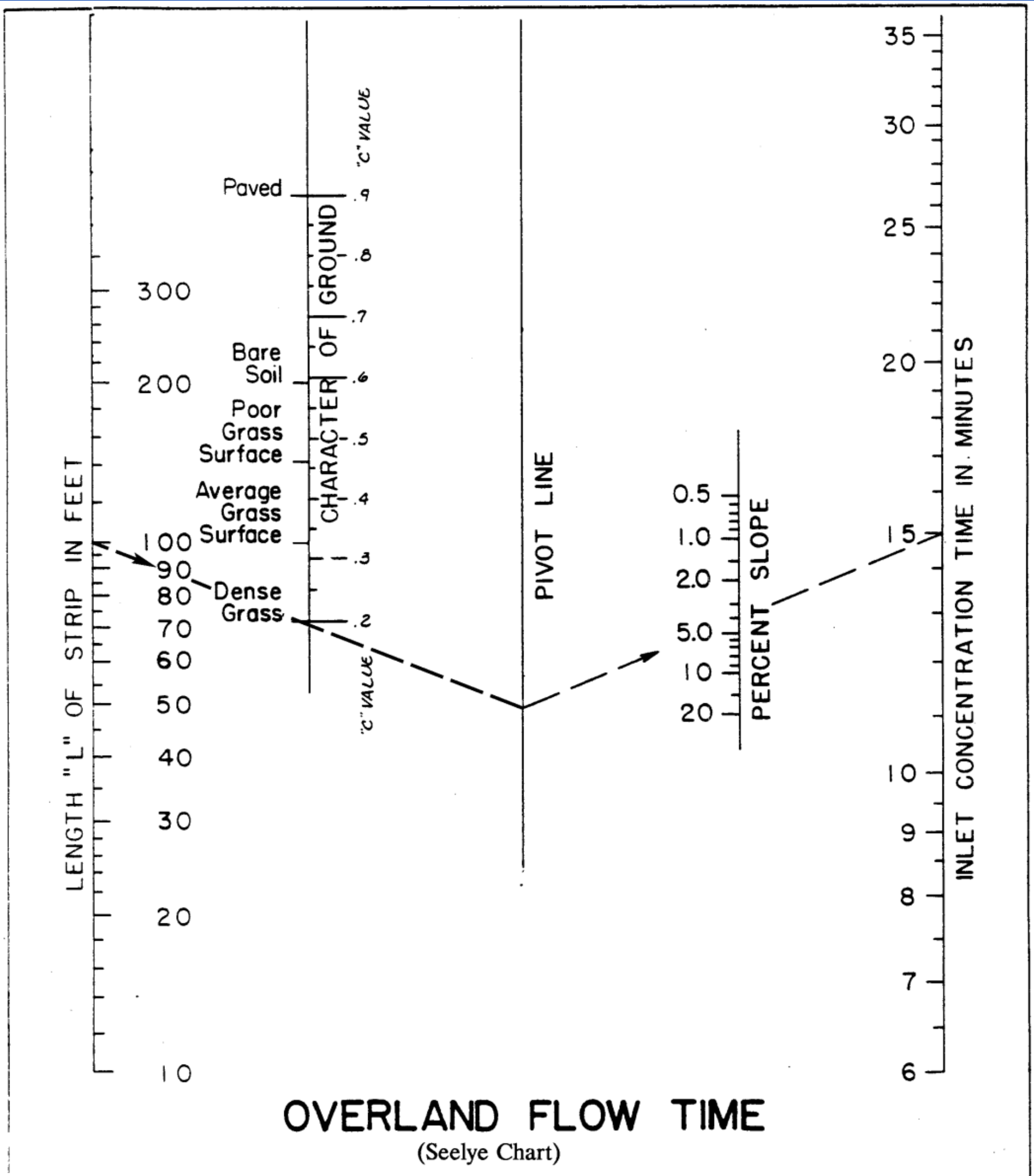
$P_2$ = 2 year, 24-hour rainfall in inches (NOAA Atlas 14)

s = slope (feet/feet)

**Manning's Kinematic Solution (TR-55, 1986)**

Overland flow can also quickly be determined by graphical solution using the Seelye Chart.

**Figure A-4A Seelye Chart (Overland Flow Time)**

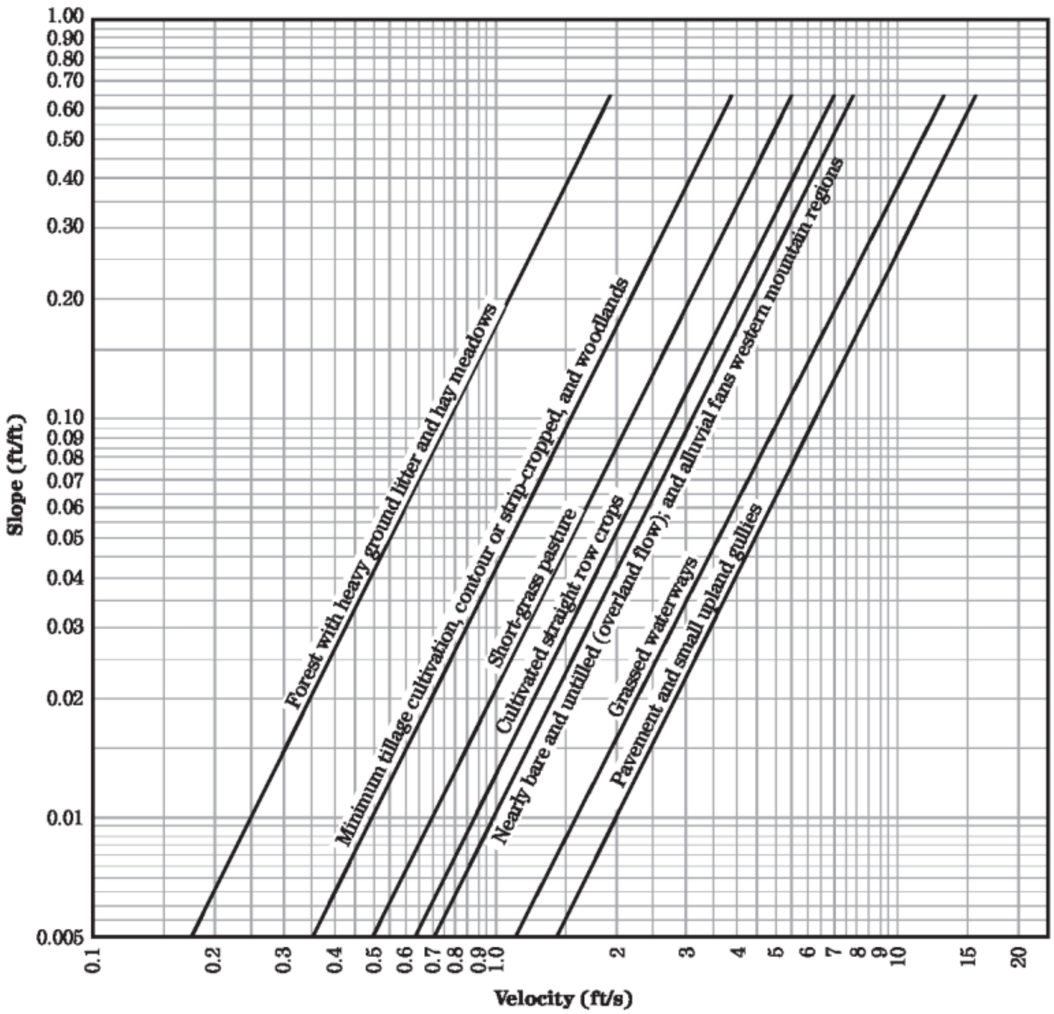



Source: *Data Book for Civil Engineers*, E.E. Seelye

Note that although the Seelye Chart does provide a solution for sheet flows greater than 300ft, the maximum length for sheet flow for purposes of estimating travel time is 100 feet.

## Figure A-5 Average Velocities for Estimating Travel Time for Shallow Concentrated Flow

Velocity versus slope for shallow concentrated flow




Equations and assumptions developed from figure above

| Flow type | Depth (ft) | Manning's *n* | Velocity equation (ft/s) |
|---|---|---|---|
| Pavement and small upland gullies | 0.2 | 0.025 | $V = 20.328(s)^{0.5}$ |
| Grassed waterways | 0.4 | 0.050 | $V = 16.135(s)^{0.5}$ |
| Nearly bare and untilled (overland flow); and alluvial fans in western mountain regions | 0.2 | 0.051 | $V = 9.965(s)^{0.5}$ |
| Cultivated straight row crops | 0.2 | 0.058 | $V = 8.762(s)^{0.5}$ |
| Short-grass pasture | 0.2 | 0.073 | $V = 6.962(s)^{0.5}$ |
| Minimum tillage cultivation, contour or strip-cropped, and woodlands | 0.2 | 0.101 | $V = 5.032(s)^{0.5}$ |
| Forest with heavy ground litter and hay meadows | 0.2 | 0.202 | $V = 2.516(s)^{0.5}$ |

**Shallow Concentrated Flow** usually begins where overland flow converges due to surface irregularities (uneven ground, litter, rocks, etc.) to form small rills or gullies. Shallow concentrated flow can exist in small manmade drainage ditches (paved and unpaved) and in curb and gutters.

TR-55 provides a graphical solution for shallow concentrated flow which is included here. The input information needed to solve for this flow segment is the land slope and the surface condition (paved or unpaved).

Assumed not to have a well-defined channel and has flow depth of 0.1 to 0.5 feet (NEH, 2010) and

the flow length is no greater than 100 feet.

Shallow concentrated flow travel time is calculated using the following equation:

*Equation A-5 Shallow Concentrated Flow Travel Time*

$$Tt = \left( \frac{L}{V \times t} \right)$$

*Tt* = Travel time (hours)
*L* = flow length (feet)
*V* = average velocity (feet/second)
*t* = conversion factor, 3600 seconds/hr)

- The input information needed to solve for this flow segment (specifically for the average velocity in the above equation) is the land slope and the surface condition (paved or unpaved) (NEH, 2010):

**Channel flow** occurs where flow converges in gullies, ditches or swales, and natural or manmade water conveyances (including storm drainage pipes). Channel flow is assumed to exist in perennial streams or wherever there is a well-defined channel cross-section.

The Manning Equation is used for open channel flow and pipe flow, and usually assumes full flow or bank-full velocity. Manning coefficients can be found in the Design Coefficients and Nomograph Appendix H) for open channel flow (natural and manmade channels) and closed channel flow. Coefficients can also be obtained from standard textbooks such as Open Channel Hydraulics or Handbook of Hydraulics.

$$V = \frac{1.49}{n} \times R^{(2/3)} \times \sqrt{s}$$

**Manning's Equation**

V = velocity (fps)
n = Manning's roughness coef.
R = hydraulic radius (A/P)
A= wetted cross sectional area
P=wetted perimeter(ft)
s = slope (ft/ft)

$$Tt = \left( \frac{L}{V \times t} \right)$$

*Tt* = Travel time (hours)
*L* = flow length (feet)
*V* = average velocity (feet/second)
*t* = conversion factor, 3600 seconds/hr)

→ *use Manning's equation*

Worksheet 3 from TR-55 (reproduced in the Design Coefficients and Nomograph Appendix H) provides an organized method for documenting inputs and computations for Time of Concentration (Tc) and Travel Time (Tt) Time of Concentrations Limitations

- Overland flow should be limited to 100 feet or less based on current guidance given in WinTR-55, NEH (2010), and VDEQ policy. This guidance has been developed based on a review of numerous technical papers on sheet flow. (Merkel, 2001)
- For watersheds with storm sewers, Tc will require that care be taken to accurately identify the hydraulic flow path.
- A culvert or bridge can act as detention structure if there is significant storage behind it. Detailed storage routing procedures can be used to determine the outflow through the culvert or bridge and will result in a reduction of the peak discharge.
- The minimum Tc used is 5 minutes or if in hours for TR-55, 0.1 hour.

## A.3.3 Selecting a Calculation Method

Depending upon the requirements of the plan, the designer can calculate the peak flow rate, in cubic feet per second, of the direct runoff from the watershed, or determine the runoff hydrograph and corresponding volume for the direct runoff from the watershed.

If the purpose of a hydrologic study is to measure the impact of various developments on the drainage network within a watershed or to design flood control structures, then a hydrograph is needed. If the purpose of a study is to design a roadway culvert or other simple drainage improvement, then only the peak rate of flow is needed.

Therefore, the purpose of a given study will dictate the methodology which should be used. Procedures such as the Rational Method and TR-55 Graphical Peak Discharge Method do not generate a runoff hydrograph. The TR-55 Tabular Method and the Modified Rational Method do generate runoff hydrographs.

Unless otherwise noted, the NRCS synthetic 24-hour rainfall distribution models, including but not limited to, NRCS Technical Release 55 and NRCS Technical Release 20, should be used to perform the water quantity design computations herein. Hydrologic and hydraulic methods developed by the U.S. Army Corps of Engineers may also be used (9VAC25-875-620). The local plan approving authority may also require or accept other calculation methods deemed more appropriate for local conditions.

## A.3.4 Rational Method

For drainage areas of 200 acres or less, the Rational Method may be used for storm sewer, culvert, and stormwater conveyance channel (i.e., open channel) sizing (9VAC25-870-72 D).

The Rational Method was introduced in 1880 to determine peak discharges from drainage areas. It is a simplistic approach, but this same simplicity has made the Rational Method one of the most widely used techniques today for calculating peak discharge from urban land uses.

The Rational Formula estimates the peak rate of runoff at any location in a drainage area as a function of the runoff coefficient, mean rainfall intensity, and drainage area. The Rational Formula is expressed as follows:

| *Equation A-6 Rational Formula* |
| --- |
| $Q = CIA$ |

Where:

$Q$ = maximum rate of runoff (cfs)

$C$ = dimensionless runoff coefficient, dependent upon land use (refer to Design Coefficients and Nomograph Appendix H for reference to acceptable runoff coefficients).

$I$ = design rainfall intensity (in./hr.), for a duration equal to the time of concentration of the watershed

$A$ = drainage area (acres)

While use of the Rational Method may be appropriate for calculating peak discharge, it is not sufficient for quantifying the volume of stormwater runoff from a modeled event. The Rational Method should not be used for post-construction stormwater BMP design. Alternative methodologies, discussed below, should be considered.

## A.3.5 Modified Rational Method: Critical Storm Duration

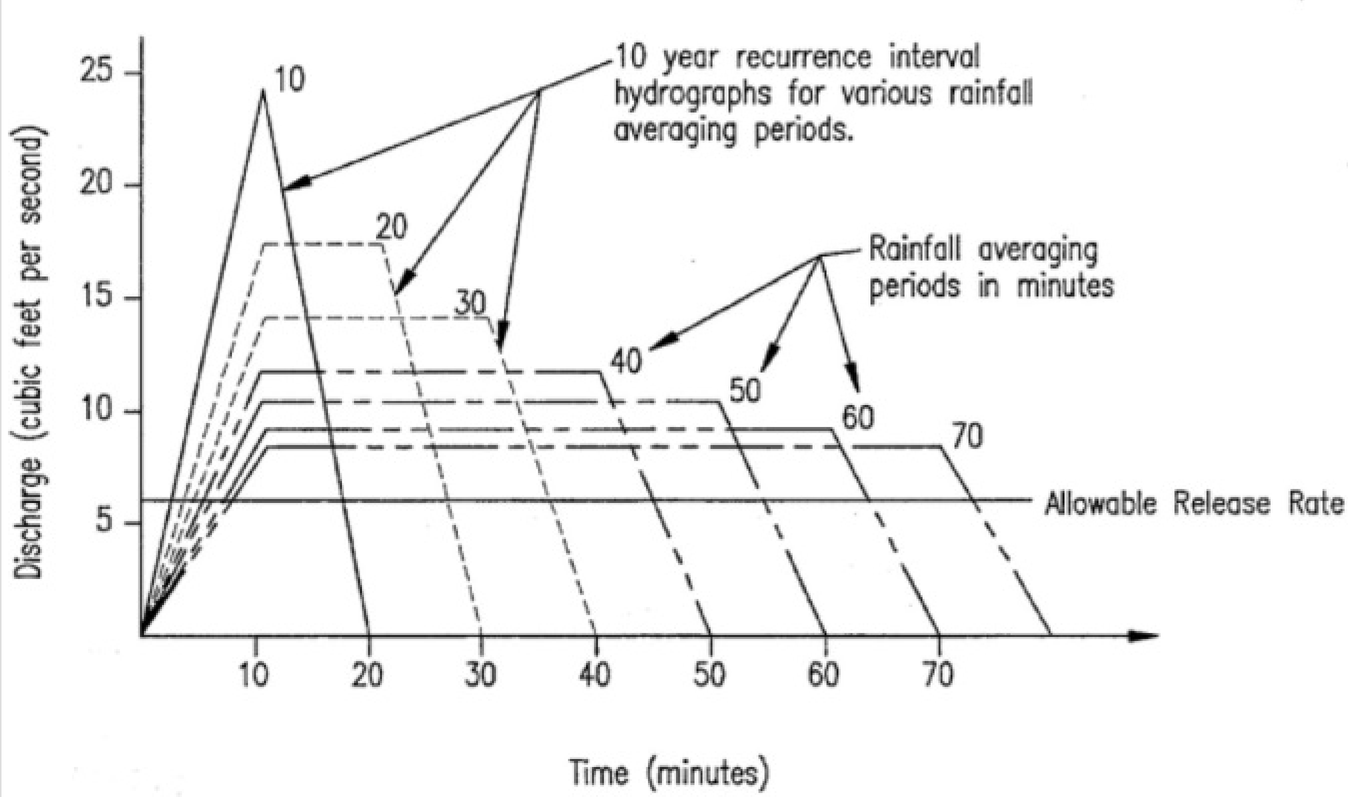
For drainage areas of 200 acres or less, the VESMP authority or department as the Virginia Stormwater Management Program (VSMP) authority may allow for the use of the Modified Rational Method for evaluating volumetric flows to stormwater conveyances (9VAC25-875-620 E).

The Rational Method generates the peak discharge that occurs when the entire watershed is contributing to the peak (at a time $t = T_c$) of a triangular hydrograph and ignores the effects of a storm which lasts longer than time t.

> The storm duration that generates the greatest volume of runoff may not necessarily produce the greatest peak rate of discharge.

The modified rational method, on the other hand, considers storms with a longer duration than the watershed $T_c$, which may result in a smaller or larger peak rate of discharge, but will produce a greater volume of runoff (area under the triangular or trapezoidal hydrograph) associated with the longer duration of rainfall.

**Figure A-6 Modified Rational Method Family of Runoff Hydrographs**




All the limitations listed for the Rational Method also apply to the Modified Rational Method. The key difference is the assumed shape of the resulting runoff hydrograph. The modified rational method allows the designer to analyze several different storm durations to determine the one that requires the greatest storage volume with respect to the allowable release rate. This storm duration is referred to as the critical storm duration and is used as a basin sizing tool.

The designer might perform an iterative calculation to determine the rainfall duration which produces the maximum storage volume requirement when sizing a detention basin. Or a simpler approach would be to calculate the Modified Rational Method Critical Storm Duration Direct Solution which uses rainfall “a” and “b” constants. These constants have been updated to reflect the NOAA Atlas 14 rainfall data, however, there are no values for the 1-year storm event and therefore may not be applicable to the VESMP channel protection criteria.

The updated “a” and “b” constants can be found in the Virginia Department of Transportation (VDOT) Drainage Manual Appendix 11-H-1 and 11H-2

Chapter 11.5.4.2 of the VDOT Drainage Manual provides important usage instructions for the “a” and “b” constants.

## A.3.6 NRCS Methods

The USDA-NRCS published Technical Release Number 55 (TR-55), 2nd edition, in June of 1986, entitled Urban Hydrology for Small Watersheds. The TR-55 method is suitable for watersheds < 2,000 acres in area. NRCS has digitized this hydrologic model and currently uses and refers to “WinTR-55,” and there is no longer a printed reference book.

The techniques outlined in TR-55 require the same basic data as the rational method: drainage area, time of concentration, land use and rainfall. The NRCS approach, however, is more sophisticated in that it allows the designer to manipulate the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and the moisture condition of the soils prior to the storm.

In most cases, the designer will use the NRCS methods to develop the base hydrology (CN, Tc, graphical peak discharge [qp], etc.), and use that data in one of the numerous hydrologic/hydraulic computer models (including TR-55, TR-20, HEC 1, etc.), rather than completing the calculations long hand.

In most cases, the designer will use the NRCS methods to develop the base hydrology (CN, Tc, graphical peak discharge [qp], etc.), and use that data in one of the numerous hydrologic / hydraulic computer models (including TR-55, TR-20, HEC 1, etc.), rather than completing the calculations long hand.

TR-55 presents two general methods for estimating peak discharges from urban watersheds: the graphical method and the tabular. The graphical method is limited to watersheds whose runoff characteristics are fairly uniform and whose soils, land use, and ground cover can be represented by a single Runoff Curve Number (CN).

The tabular method is a more complete approach and can be used to develop a runoff hydrograph at any point in a watershed. For large watersheds, it may be necessary to divide the area into sub-watersheds in order to account for major land use changes, analyze specific study points within sub-watersheds, or locate stormwater drainage facilities and assess their effects on peak flows. The tabular method can generate a hydrograph for each sub-watershed for the same storm event. The hydrographs can then be routed through the watershed and combined to produce a partial composite hydrograph at the selected study point. The tabular method is particularly useful in evaluating the effects of an altered land use in a specific area within a given watershed.

The runoff equation (found in TR-55) provides a relationship between rainfall and runoff as a function of the CN (discussed later in this section). For drainage areas larger than 2,000 acres other methods such as TR-20, HEC-1, HEC-HMS should be considered.

Runoff Depth Q: The runoff depth is the measure of the fraction of rainfall that becomes runoff. The NRCS runoff equation (TR-55 2-1) is used to solve for runoff depth, Q, in inches, as a function of rainfall depth and CN:

*Equation A-7 NRCS Runoff Equation, Q [TR-55 Eq. 2-1]*

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

*Equation A-8 NRCS Runoff Equation, Ia [TR-55 Eq. 2-2]*

$$I_a = 0.2S$$

*Equation A-9 Modified NRCS Runoff Equation [TR-55 Eq. 2-3]*

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

*Equation A-10 NRCS Runoff Equation, S [TR-55 Eq. 2-4]*

$$S = \frac{1000}{CN} - 10$$

Where:

Q = runoff depth (inches)

P = rainfall depth (inches)

Ia = initial abstraction (inches)

S = potential maximum retention after runoff begins (inches)

CN = curve number

These terms are further described, as follows:

- The Runoff Depth (Q) is measured in inches and can also be referred to in units of watershed-inches, meaning it represents the depth of runoff across the watershed or drainage area as described by the CN, and can easily be converted into a volume of runoff.
- The term Q is often used in stormwater designs to refer to peak discharge measured in cubic feet per second.
- However, NRCS methodology uses Q to refer to runoff depth, in inches, as noted in the NRCS Runoff Equation above.
- The rainfall depth (P) as required by the Regulation] is as follows:
  - 1-year 24-hour storm, 2-year 24-hour storm, and/or the 10-year 24-hour storm rainfall depths, as derived from NOAA Atlas 14 (see 9VAC25-875-620), as required for addressing the water quantity (stream channel and flood protection) requirements (9VAC25-875-600 Water Quantity), unless a more stringent requirement is directed by the VESMP Authority.
  - For the VRRM, which is used to address the annual pollutant load reduction requirements (9VAC25-875-590), the water quality target rainfall event is 1-inch of rainfall.
- Initial abstraction (Ia) is the combination of all rainfall losses before runoff begins, and consists mainly of interception, infiltration during early parts of the storm, and surface depression storage. It is measured in inches and can be described as the depth of rainfall that occurs before runoff begins. Infiltration during the early part of the storm is highly variable and dependent on such factors as rainfall intensity, soil crusting, and soil moisture (antecedent condition); however, it is generally correlated with soil and land cover parameters. Values for Ia can be obtained in TR-55.
- The potential maximum retention (S) after runoff begins is dependent upon the soil cover complex and, in principle, should not vary from storm to storm. It is the depth of rainfall that is captured and retained on the landscape in excess of the initial abstraction. The application of Runoff Reduction practices serves to increase the maximum retention (S), thereby decreasing the CN.

TR-55 provides a graphical solution for the runoff equation, provided in Appendix H. Also, the National Engineering Handbook provides the runoff depths for selected CNs in tabular form, also provided in Appendix H. Additional information on the derivation, assumptions, and limitations of the Runoff Equation can be found in Part 630 of the NRCS National Engineering Handbook.

*Equation A-11 NRCS Peak Flow Equation [TR-55 Eq. 2-7]*

$q_p = q_u A Q$

*where:*

*$q_p$ = peak discharge, cfs*

*$q_u$ = unit peak discharge, cfs/ac/in*

*A = watershed drainage area, ac*

*Q = runoff volume, in*

## A.3.7 Runoff Curve Number Selection

The NRCS Curve Number (CN) is used to develop the rainfall-runoff relationship and estimate the depth of runoff (Q) in inches. This method is described in detail in Part 630 of the NRCS National Engineering Handbook (NEH, NRCS, 1985). The CN is a measure of the land's ability to infiltrate or otherwise detain rainfall, with the excess becoming runoff. The CN is a function of the land cover (woods, pasture, agricultural use, percent impervious, etc.), hydrologic condition, and soils. The CN does not account for on-site attenuation which may be occurring within the watershed.

For purposes of computing predevelopment runoff, all pervious lands on the site shall be assumed to be in good hydrologic condition in accordance USDA-NRCS standards, regardless of conditions existing at the time of computation. See 9VAC25-875-600 E. Predevelopment runoff calculations utilizing other hydrologic conditions may be utilized provided that it is demonstrated to and approved by the VESMP authority that actual site conditions warrant such considerations.

All water quantity design computations shall be based on the existing watershed characteristics and the ultimate development condition of the proposed land-disturbing activity.

Predevelopment and post development site conditions and site hydrology should be verified by site inspections, topographic surveys, available soil mapping or studies, and calculations consistent with good engineering practices. See 9VAC25-25-875-600 F.

Curve Number: the Regulation in 9VAC25-875-600 (Water Quantity) identifies the level of effort required to collect the data needed to establish the CN:

> The designer should note that TR-55 and the VRRM use the term Open Space differently.

- Soils mapping (to determine the HSG): Appendix C of this handbook provides information on soil classification and further details on soil descriptions can be found in Chapter 7 of NEH 630. The designer should consult this section of this Appendix for guidance on determining the equivalent HSG for soils that have been disturbed by prior development or other impacts.
- Land cover type (impervious, woods, grass, etc.).
- Treatment (cultivated or agricultural land).
- Hydrologic condition (for design purposes, the hydrologic condition should be considered "GOOD" for the pre-development condition).
- Urban impervious area modifications (connected, unconnected, etc.).
- Topography – detailed enough to accurately identify drainage divides, $t_c$ and $T_t$ flow paths and channel geometry, and surface condition (roughness coefficient).

Except where specifically supplemented herein, runoff curve number (CN) selection should be performed consistent with Chapter 9, Part 630, of the NRCS National Engineering Handbook.

### A.3.7.1 Pre-Development Curve Number Selection

A. All impervious and water surfaces should be assigned a CN of 98. See Chapter 9, Part 630, NRCS National Engineering Handbook.

B. All artificial turf with no runoff reduction potential should be assigned a CN of 98.

C. All pervious lands should be assumed to be in good hydrologic condition, regardless of conditions existing at the time of pre-development runoff computation. Other hydrologic conditions may be used provided it is demonstrated to and approved by the Department that actual site conditions warrant such considerations. See 9VAC25-875-600 E.

D. The HSG used for pre-development CN selection should be based on the soil conditions existing at the time of pre-development runoff computation. For previously disturbed soils (e.g., native soil profiles that have been mixed or removed or fill material from other areas has been previously introduced), the design professional should:

   1. Perform an onsite investigation to determine the appropriate pre-development HSG consistent with Appendix A, NRCS Technical Release 55 (1986); OR

   2. Perform an onsite investigation to determine the appropriate pre-development HSG consistent with Chapter 7, Part 630, NRCS National Engineering Handbook. Guidelines for determining HSG from field saturated hydrologic conductivity observations can be found in the NRCS Soil Survey Manual (1993).

### A.3.7.2 Post-Development Curve Number Selection

A. All impervious and water surfaces should be assigned a CN of 98. See Chapter 9, Part 630, NRCS National Engineering Handbook.

B. All artificial turf with no runoff reduction potential (i.e., no subsurface infiltration) should be assigned a CN of 98.

C. All pervious lands should be assumed to be in good hydrologic condition.

D. The HSG used for post-development CN selection should be based on the ultimate development condition of the subject land-disturbing activity. See 9VAC25-875-620 B. For disturbed soils (e.g., pre-development soil profiles that will be mixed or removed or fill material from other areas will be introduced), the design professional should:

   1. Adjust the pre-development HSG by at least one factor (i.e., HSG A → HSG B; HSG B → HSG C; HSG C → HSG D) when selecting the post-development CN. See Table A-2 herein; OR

   2. Use the pre-development HSG and specify the full implementation of Section 8 of VDEQ Stormwater Design Specification No. 4 (Soil Compost Amendment) immediately prior to establishing permanent stabilization; OR

   3. Specify an appropriate post-development HSG during plan preparation and subsequently perform an onsite investigation prior to project closeout to determine the actual post-development HSG consistent with Appendix A, NRCS Technical Release 55 (1986). A revised plan with associated computations should be submitted to VDEQ if it is determined that the field verified HSG does not correspond to the HSG originally specified; OR

   4. Specify an appropriate post-development HSG during plan preparation and subsequently perform an onsite investigation prior to project closeout to determine the actual post-development HSG consistent with Chapter 7, Part 630, NRCS National Engineering Handbook. Guidelines for determining HSG from field saturated hydrologic conductivity observations can be found in the NRCS Soil Survey Manual (1993). A revised plan with associated computations should be submitted to VDEQ if it is determined that the field verified HSG does not correspond to the HSG originally specified; OR

   5. An alternative decompaction plan as approved by the Department on a case-by-case basis.

E. Unadjusted and adjusted post-development CNs for the specified land cover categories within the VRRM should be as follows:

| Table A-2 Unadjusted and Adjusted Post-development Curve Numbers for Land Cover Categories in the VRRM | | | | |
|---|---|---|---|---|
| **Land Cover** | **HSG A** | **HSG B** | **HSG C** | **HSG D** |
| Forest Cover | 30 | 55 | 70 | 77 |
| Forest Cover (adjusted) | 55 | 70 | 77 | 77 |
| Mixed Open | 34 | 59 | 72 | 79 |
| Mixed Open (adjusted) | 59 | 72 | 79 | 79 |
| Managed Turf | 39 | 61 | 74 | 80 |
| Managed Turf (adjusted) | 61 | 74 | 80 | 80 |
| Impervious Cover | 98 | 98 | 98 | 98 |

### A.3.7.3 Curve Number Selection During Construction (Erosion Control Sizing)

Bare earth CNs for the purposes of performing runoff computations for erosion and sediment controls (temporary sediment traps, temporary sediment basins, etc.) should be as follows:

| Table A-3 Bare Earth Curve Number Sizing Erosion and Sediment Controls | | | | |
|---|---|---|---|---|
| **Land Cover** | **HSG A** | **HSG B** | **HSG C** | **HSG D** |
| Bare Earth | 77 | 86 | 91 | 94 |

Velocity calculations should be performed for vegetated channels assuming a bare earth condition to prevent erosion during plant establishment and to determine if a temporary or permanent channel lining is required.

### A.3.7.4 Curve Number Adjustment for Unconnected Impervious Areas

When stormwater runoff from an impervious area occurs as sheet flow over a pervious area prior to entering the stormwater conveyance system, the impervious area is considered unconnected. The runoff curve numbers published in Chapter 9, Part 630, of the NRCS National Engineering Handbook (and NRCS Technical Release 55); however, were developed assuming that all impervious areas were directly connected to the stormwater conveyance system. To determine the runoff CN when all or part of the impervious area is not directly connected to the stormwater conveyance system, the design professional should use one of the CN adjustment methods detailed below.

Refer to Chapter 6 Section 6.3.1.5 for procedures to disconnect (unconnect) runoff from solar panel arrays.

#### A.3.7.4.1 Curve Number Adjustment by VRRM

Post-development runoff CN adjustment should be performed consistent with Section 7.1 (Runoff Volume and CN Tab) of the VRRM User Guide. The following steps outline the process for reflecting the adjusted curve number in the VRRM spreadsheet:

Step 1 – On the “Site” tab, input land cover areas using HSG determinations per the pre-development NRCS web soil surveys or existing on-site soil investigations.

Step 2 – On the “D.A.” tab(s), input land cover areas using HSG determinations reflecting the ultimate post-development soil conditions (as outlined in the “Post-Development Curve Number Selection” section contained herein).

Step 3 – The “D.A.” tab data automatically populates the “Runoff Volume and CN” tab.

Step 4 – The adjusted CN associated with the use of any runoff volume-reducing BMPs is calculated on the “Runoff Volume and CN” tab and can be used in subsequent water quantity calculations, where applicable.

When using the VRRM, all runoff reduction (RR) practices should be designed and sized according to the minimum requirements of the VDEQ Stormwater Design Specifications included in Chapter 8 of this handbook.

#### A.3.7.4.2 Curve Number Adjustment by NRCS Method

The following equation should be used to compute the composite runoff curve number ($CN_c$) when all or part of the impervious area is not directly connected to the stormwater conveyance system **AND** the total impervious area is less than 30% of the total drainage area:

| *Equation A-12 Disconnect Impervious Area Curve Number Adjustment* |
|---|
| $CN_c = CN_p + (Pimp / 100)(98 - CN_p)(1 - 0.5R)$ |

Where:

$CN_c$ = composite runoff curve number

$CN_p$ = pervious runoff curve number

Pimp = percent imperviousness

R = ratio of unconnected impervious area to total impervious area

The following equation should be used to compute the composite runoff curve number (CNc) when all or part of the impervious area (including the solar panels) is not directly connected to the stormwater conveyance system AND the total impervious area is greater than or equal to 30% of the total drainage area:

$CN_c = CN_p + (Pimp / 100)(98 - CNp)$

Where:

$CN_c$ = composite runoff curve number

$CN_p$ = pervious runoff curve number

Pimp = percent imperviousness

R = ratio of unconnected impervious area to total impervious area

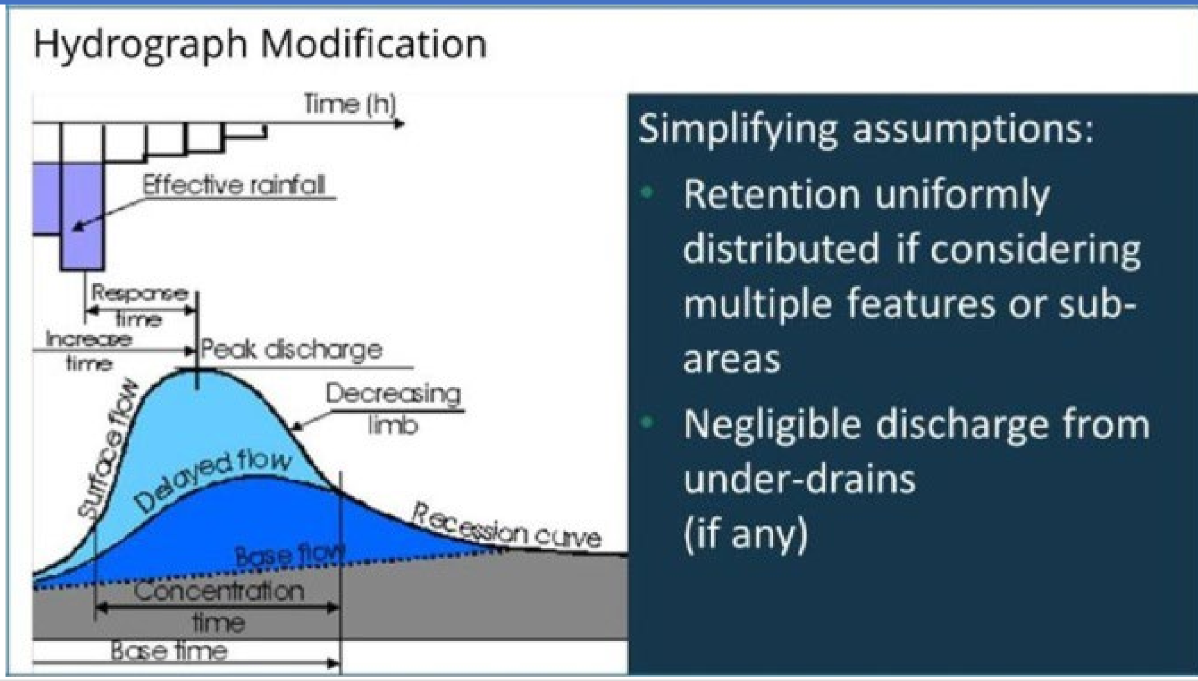
### A.3.7.5 Curve Number Adjustment for Runoff Reduction Practices

The mandate from § 62.1-44.15:28 of the Code of Virginia to establish regulations that encourage Low Impact Development (LID) created a challenge to accurately documenting the benefits posed by reducing stormwater runoff with multiple decentralized stormwater practices. The objectives included:

- Provide quantity “credit” for distributed retention practices;
- Avoid Complex routing/modeling of multiple practices;
- Allow designers to target volume as a primary metric (quantity and quality);

Some simplifying assumptions were allowed:

***Figure A-7 Hydrograph Modification***




The discharge from underdrains is considered negligible in the VRRM based on research on the discharge characteristics of various practices fitted with underdrains. The RR practices fitted with underdrains are considered to provide ‘extended filtration’ and is accepted as reducing runoff in many stormwater programs across the country. This acceptance is based on the body of evidence that underdrain systems slowly release the runoff detained in the soil either during or after the storm.

The extended nature of the discharge from bioretention basins with underdrains typically occurs over a period of days such that the hydrograph to the receiving stream mimics pre-development hydrology. In this way, impacts from larger post-construction flows to receiving streams are mitigated. (Hunt et al. 2010). Even permeable pavement with a stone reservoir (clean #57 stone) demonstrates significant runoff reduction and an extended discharge such that it can be considered negligible in comparison to the surface runoff from other areas of the site (Drake et al. 2012).

The VRRM utilizes the CN adjustment as a simple and conservative method for crediting specific runoff reduction values toward peak flow reduction. The method converts the total annual runoff reduction credit from all the BMPs in the drainage area from cubic feet (or acre-feet) to watershed-inches of retention storage, and then uses the NRCS TR-55 runoff equations 2-1 through 2-4 to derive a Curve Number adjustment that reflects the reduced runoff depth. This new CN can then be used for computing the large storm peak discharge from the drainage area for determining the storage volume needed for downstream channel or flood protection requirements.

The total retention storage provided by RR practices, represented by the term R, is subtracted from the runoff at the end of the storm event, providing a new value for S. A new CN is then back-calculated from the new value of S using TR-55 Equation 2-4.

*Equation A-13 Modified Equation 11.3 NRCS Runoff Equation, Q [TR55 Eq. 2-1] for Retention Storage*

$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where:

*Q* = runoff depth (in),

*R* = Retention Storage

*P* = rainfall depth (in),

*S* = potential maximum retention after runoff begins (in),

*CN* = Curve Number

*Equation A-14 Modified Equation 11.3 NRCS Runoff Equation, Q [TR55 Eq. 2-1] for Retention Storage*

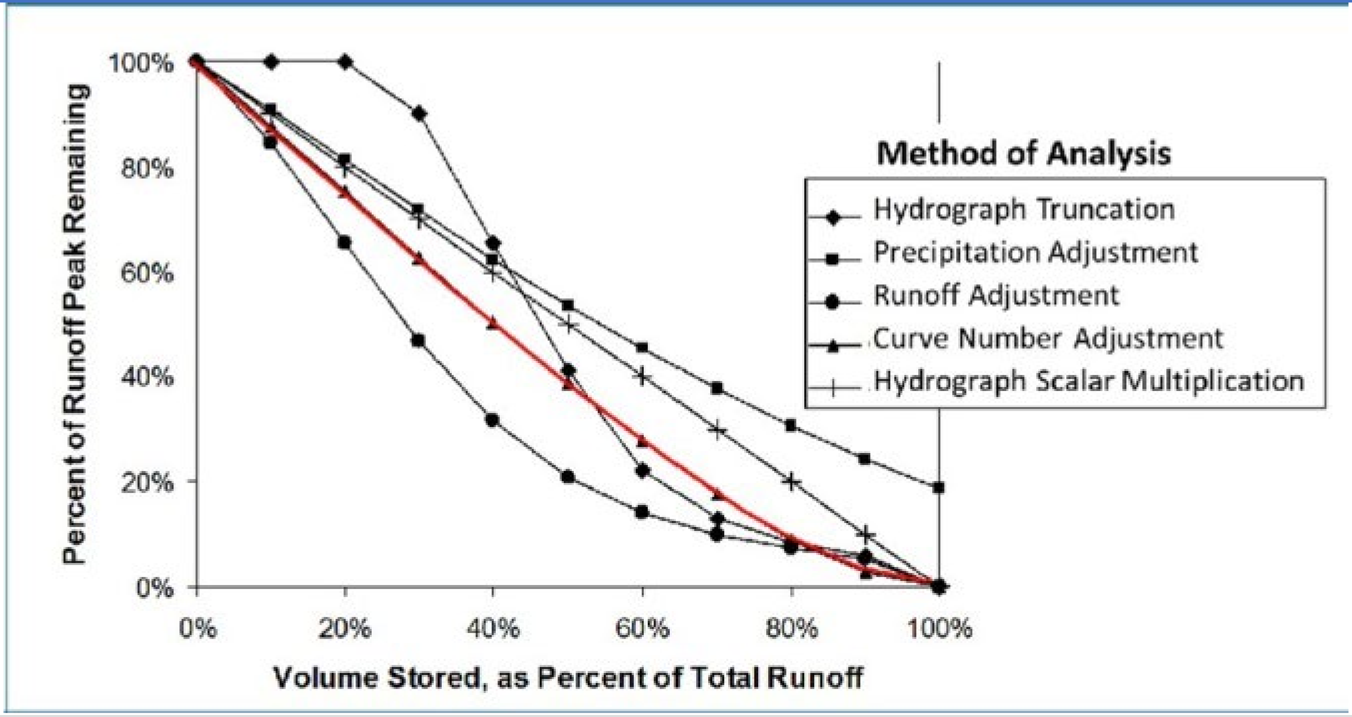
$$Q - R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

While it is not easy to predict the absolute runoff hydrograph modification provided by reducing stormwater runoff volumes, reduced runoff volumes will have an impact on the runoff hydrograph of a development site. Simple routing exercises have verified that this Curve Number adjustment approach represents a conservative estimate of peak reduction.

Several theoretical methods for modifying the runoff hydrograph to account for retention storage were considered:

1. Hydrograph Truncation
2. Hydrograph Scalar Multiplication
3. Precipitation Adjustment
4. Runoff Adjustment
5. Curve Number Adjustment

**Figure A-8 Hydrograph Modification Procedures**




*Excerpted from work by Paul R. Koch, Ph.D., P.E.*

It is important to note that the Curve Number adjustment associated with the retention of one watershed-inch of runoff volume will decrease as the rainfall depth increases (meaning 1-inch of volume reduction has less of an impact on a 5-inch rain event than it will on a 2-inch rain event). Therefore, the CN adjustment must be computed for each design storm depth.

## A.4 Water Quality Calculations

Compliance with the water quality design criteria set out 9VAC25-875-580 shall be determined by utilizing the Virginia Runoff Reduction Method or another equivalent methodology that is approved by VDEQ.

Water quality calculations include the steps of calculating the pollutant loading from the developed site (Equation A-15) and developing a combined strategy of site design and BMP implementation that meets the requirements of the Regulation.

For the VRRM, the total phosphorus load of new land-disturbing activities should not exceed 0.26 pounds per acre per year.

When a land-disturbing activity drains to more than one 6th order (12-digit) hydrologic unit code, the total phosphorus load requirement in this section should be applied independently within each hydrologic unit code.

Water quality calculations are typically used in support of demonstrating compliance with the Water Quality Design Criteria. The basis of the VRRM is the use of site design strategies that increase runoff abstraction and the implementation of stormwater BMPs that include retention storage to reduce the volume of runoff discharging from the site as a pathway to reduce pollutant loads. Additional pollutant load reduction can be achieved with BMPs that do not necessarily retain runoff. The volume and pollutant reduction credit are combined as a percent reduction and applied to the calculated pollutant load to demonstrate compliance with the site-based load limit.

Equation A-15 provides the computation for the pollutant load reduction requirement. The BMP implementation strategy must achieve a total load reduction (runoff volume reduction plus pollutant removal) efficiency to achieve the required reduction.

| *Equation A-15 Water Quality Pollutant Load Requirement* |
|---|
| $L_{reduction} = L_{postdevelopment}$ – (0.26 pound per acre per year) × A |

Where:

$L_{reduction}$ = load reduction requirement (pounds)

$L_{postdevelopment}$ = postdevelopment pollutant load

0.26 lb/ac/yr = site based TP load limit

A = drainage or site area (acre [ac.])

## A.4.1 Post-Construction BMP Sizing Using the VRRM Treatment Volume

The Regulation requires an annual pollutant load reduction. To achieve this performance goal, the VRRM uses a rainfall depth of 1 inch as the design storm for sizing Post Construction BMPs. The rationale for using the 90$^{th}$ percentile event is that it represents most of the runoff volume on an annual basis, and that targeting larger events would not be cost effective in terms of BMP implementation.

The Post-Development Treatment Volume Tv is computed in the VRRM Compliance Spreadsheet:

- On the Site Data tab for the entire site ($Tv_{SITE}$);
- For each drainage area on the D.A. tabs ($Tv_{DA}$); and
- For each BMP selected in the D.A. tab, based on the Credit Area of turf acres and impervious acres draining to the practice ($Tv_{BMP}$). This is the Tv that is used to size the Post Construction BMP.

The $Tv_{BMP}$ used to size the Post Construction BMP (the last bullet above), is not summed for the designer in the VRRM Compliance Spreadsheet. Rather, the designer has to determine the design TvBMP by summing the Runoff Reduction (D.A. tab Column G) and the Remaining Runoff Volume (D.A. tab Column H). This sum also includes the additional runoff volume (if any) delivered from an upstream practice (Column F). Or the designer may use the Stormwater Treatment Volume Equation to compute the volume independent of the spreadsheet. The required $Tv_{BMP}$ for level 2 designs must be computed manually.

## A.4.2 Volumetric Runoff Coefficients (Rv)

Appendix A of this handbook describes the VRRM three-step compliance strategy. The compliance objective is still to meet the site-based pollutant load limit for Total Phosphorus. Therefore, the three-step strategy represents the suggested means to achieve that load limit, beginning with site design and runoff reduction practices. In that context, the regulatory requirement is not to incorporate all three steps for every development site. Depending on site characteristics and load reduction requirements, a site may incorporate one, two, or all three of the steps. Nevertheless, the three steps are a sound way to start developing a compliance strategy. The three steps are as follows:

**Step 1: Apply Stormwater Site Design practices to minimize impervious cover, grading, and loss of forest cover.** This step includes the conservation of open spaces where the natural soil horizon and native vegetation is preserved. Employing these practices can result in a reduction of the required water quality Treatment Volume (*Tv*) and pollutant load generated by the site, *before any BMPs are selected and applied to the site design*.

**Step 2: Apply Runoff Reduction (RR) BMPs to reduce the runoff volume generated by the developed portions of the site.** This step includes the selection of those BMPs that have demonstrated the ability to retain runoff volume through evapotranspiration, infiltration, extended filtration, and alternative use (such as rainwater harvesting). This step also includes the restoration or the protection of established hydrologically functional areas of the site, such as buffers, conserved open space, reforested areas, addition of soil amendments, etc.; and

**Step 3: Apply Pollutant Removal (PR) BMPs to achieve any remaining pollutant removal that may be required to achieve the required annual load limit of 0.26 lb/ac.** This step can also include the purchase of nutrient offsets or other off-site compliance options.

The primary objective of Step 1 is to reduce the overall site runoff volume. The computational equivalent would be to reduce the runoff depth (*Q*) described in the **NRCS Methods** of this appendix. In some cases, the implementation of Stormwater Site Design practices will be self-crediting; that is, designs that reduce impervious cover and/or maintain forested areas will have a lower *CN* and thereby a lower overall runoff depth computed, using the NRCS Runoff Equation. Likewise, the VRRM computational procedure for computing the annual pollutant load and the corresponding runoff *Tv* for BMP sizing will self-credit when areas of the site are undisturbed or designated for restoration and/or protection. Table A-11.1 provides the relevant volumetric runoff coefficients (*Rv*).

**Table A-11.1 Land Cover Volumetric Runoff Coefficients (Rv)**

| Land Cover | Runoff Coefficients | | | |
|---|---|---|---|---|
| | HSG-A | HSG-B | HSG-C | HSG-D |
| **Forest** | 0.02 | 0.03 | 0.04 | 0.05 |
| **Mixed Open** | 0.08 | 0.11 | 0.13 | 0.15 |
| **Disturbed Soil or Managed Turf** | 0.15 | 0.20 | 0.22 | 0.25 |
| **Impervious Cover** | 0.95 | | | |

Source: Virginia Tech, Virginia Runoff Reduction Method Compliance Spreadsheet User's Guide & Documentation (Version 4.0, June 2023)

As illustrated by the *Rv* values in Table A-11.1, the effect of grading, site disturbance, and soil compaction greatly increases the runoff coefficient compared to forested areas. These values are based on research that includes small storm hydrology factors in order to correlate the 1-inch rainfall event to an annual volume of runoff. That is, by managing the runoff from the 1-inch rainfall event, the total annual volume of rainfall that is managed can be translated to an equivalent annual volume of runoff and pollutant load computation.

The designer will enter the acres of *Forest, Mixed Open*, *Managed Turf*, and *Impervious Cover* into the User Input cells of the Site Data tab and the appropriate drainage area (D.A.) tabs of the VRRM Compliance Spreadsheet. The spreadsheet will generate a composite *Rv* for the site and the drainage areas. This composite *Rv* is comparable to a NRCS *CN* or the Rational Method runoff coefficient in that it describes how much rainfall becomes runoff.

The proper assignment of *Rv* values to the different land covers requires that the designer have accurate soil information for the site. Another element in selecting *Rv* values is verifying that any acreage that is to be designated as *Forest* will in fact be preserved, both during construction and after construction. This means that these areas must be designated to be protected on the erosion and sediment control plan, and an enforceable recorded protective documentation (e.g., easement) must be developed and executed prior to plan approval.

**Treatment Volume (Tv)**

Treatment Volume (*Tv*) is the calculated design volume of runoff that must be managed to meet the VESMP water quality requirements. The VESMP water quality load limit for TP is a site-based limit, meaning that the *Tv* does not need to be "zeroed out." The *Tv* is reduced to the point where the site-base load limit is achieved. In other words, if enough total load reduction (TR) is achieved through runoff reduction (RR), Pollutant removal (PR), or a combination of the two in one portion of the site or drainage area, the remaining area does not require treatment. (On the other hand, every point of stormwater discharge from the site must be analyzed to show compliance with the VESMP water quantity requirements.)

**NOTE: Terminology Alert –** The term Treatment Volume (*Tv*) refers to the volume associated with a particular drainage or land area based on the land cover and resulting volumetric Runoff Coefficient (*Rv* – see **Section Volumetric Runoff Coefficients (Rv)**). There can be a *Tv* for the entire site (based on the composite Runoff Coefficient), a *Tv* for a particular drainage area within the site (for instance, for each drainage area tab in the VRRM Compliance Spreadsheet), and a *Tv* for an individual BMP based on the contributing drainage area and/or volume from an upstream practice. These can be referred to as $Tv_{SITE,}$ $Tv_{DA,}$ and $Tv_{BMP}$ respectively.

It is important to note that the $Tv_{SITE}$ is the most important for overall compliance purposes, as it relates directly to computing the post-developed pollutant load and the corresponding load reduction required to meet the site-based TP load limit. Any adjustments to a Drainage Area tab land cover based on the site design BMP selection, i.e., the selection of a BMP such as *P-FIL-07, Sheetflow to a Vegetated Filter Strip/Open Space*, or preservation of forest or reforestation should also be reflected on the Site Data tab land cover, as this will reduce the overall site-based reduction requirement.

The $Tv_{BMP}$ is most important for sizing individual BMPs in accordance with the specifications, because each BMP is sized based on the *Tv* generated by the contributing drainage area (CDA) draining to that BMP.

Most of the BMP Design Specifications include a Level 1 and Level 2 design standard. The Level 1 standard generally requires a storage or treatment function sized for the *Tv.* The Level 2 design standard increases the *Tv* storage or treatment function sizing by a factor of 1.1, 1.25, or 1.5. This *Tv* multiplier is included in the BMP Design Specifications and was derived for each practice based on the available BMP performance data relative to the annual volume of runoff treated. (Refer to the complete Design Specifications for Post-Construction BMPs in Chapter 8 of this handbook.)

The VRRM *Tv* is calculated by multiplying the 1-inch rainfall depth by the composite *Rv* based on the four site cover runoff coefficients: *Forest (F), Mixed Open* (MO), *Managed Turf* (M*T*), and *Impervious Cover* (*I*) present at the site, as shown below (CWP et al., 2008). This method generates a *Tv* of close to 1 inch for highly impervious sites and a gradually decreasing *Tv* for decreasing levels of imperviousness.

*Equation A-16 Stormwater Treatment Volume (Tv) Equation*

$$Tv = \frac{P \times [Rv_{composite}] \times SA}{12}$$

*Equation A-17 Composite Volumetric Runoff Coefficient ($Rv_{composite}$) Equation*

$$Rv_{composite} = (Rv_I \times \%I) + (Rv_{MT} \times \%MT) + (Rv_{MO} \times \%MO) + (Rv_F \times \%F)$$

where:

*Tv* = Stormwater treatment volume in acre feet

$Rv_{composite}$ = Composite or weighted runoff coefficient

*P* = Depth of rainfall; "water quality" P = 1-inch

*RvI* = Runoff coefficient for Impervious cover (Table A-11.1)

*RvMT* = Runoff coefficient for Turf cover or disturbed soils (Table A-11.1)

*RvMO* = Runoff coefficient for Mixed Open cover (Table A-11.1)

*RvF* = Runoff coefficient for Forest cover (Table A-11.1)

*% I* = Percent of site in Impervious cover (fraction)

*%MT* = Percent of site in Managed Turf cover or disturbed soils (fraction)

*%MO* = Percent of site in Mixed Open cover (fraction)

*%F* = Percent of site in Forest (fraction)

*SA* = Total site area, in acres

As discussed in the **Terminology Alert Number** above, this computation can be for the site, a drainage area within the site, or an individual BMP drainage area.

## A.4.3 Water Quality Design Tv Peak Flow Rate (qpTv)

The peak flow rates for the 1-year 24-hour storm and larger storms are readily computed using accepted hydrologic methods outlined in this appendix. However, there has not previously been a standard method for computing the water quality design peak flow rate. The water quality design peak flow rate is needed for the design and sizing of pretreatment cells, level spreaders, by-pass diversion structures, overflow riser structures, grass swales and water quality swale geometry, etc. All require a peak rate of discharge to ensure non-erosive conditions and flow capacity.

Of the hydrologic methods available, the Rational Formula is highly sensitive to the time of concentration and rainfall intensity, and therefore should be used cautiously. The NRCS CN methods are very useful for characterizing complex sub-watersheds and drainage areas and estimating the peak discharge from large storms (greater than 2 inches) but can significantly underestimate the discharge from small storm events (Claytor and Schueler 1996). Since the Tv is based on a 1-inch rainfall, this underestimation of peak discharge can lead to undersized diversion and overflow structures, resulting in a significant volume of the design Tv potentially bypassing the runoff reduction practice. Undersized overflow structures and outlet channels can cause erosion of the BMP conveyance features which can lead to costly and frequent maintenance.

In order to maintain consistency and accuracy, the following Modified CN Method is recommended to calculate the peak discharge for the 1-inch rain event. The method uses the Small Storm Hydrology Method (Pitt, 1994) and NRCS Graphical Peak Discharge Method (USDA 1986) to provide an adjusted Curve Number that is more reflective of the runoff volume from impervious areas within the drainage area. The design rainfall is a NRCS Type II distribution, so the method incorporates the peak rainfall intensities common in the eastern United States. The time of concentration is computed using the method outlined in TR-55.

The following provides a step-by-step procedure for calculating the Water Quality Treatment Volume's peak rate of discharge, $q_{pTv}$:

**Step 1:** Calculate the adjusted CN for the site or contributing drainage area. The following equation is derived from the NRCS CN Method and is described in detail in the Part 630 (Hydrology) of the NRCS National Engineering Handbook:

*Equation A-18 Derivation of NRCS Curve Number and Runoff Equation*

$$CN = \frac{1000}{[10 + 5P + 10Q_a - 10(Q_a^2 + 1.25Q_aP)^{0.5}]}$$

Where:

CN = adjusted curve number.

P = rainfall (inches), (1.0" in Virginia).

$Q^a$ = runoff volume (watershed inches), equal to Tv ÷ drainage area.

Notes:

- $Q_a$ is units of watershed inches. The VRRM Spreadsheet provides Tv in both acre-ft and $ft^3$.
- When using a hydraulic/hydrologic model for sizing a runoff reduction BMP or calculating the $q_{pTv}$, designers must use this modified CN for the drainage area to generate runoff equal to the Tv for the 1-inch rainfall event.

**Step 2:** Compute the Time of Concentration (Tc) for the site or drainage area.

**Step 3:** Calculate the Water Quality Treatment Volume's peak discharge ($q_{pTv}$), which is computed using the following equations and the procedures outlined in Chapter 4 (Graphical Peak Discharge Method) of TR-55.

*Equation A-19 Modified NRCS TR-55 Eq. 4-1*

$$q_{pTv} = q_u \times A \times Q_a$$

Where:

$q_{pTv}$ = treatment volume peak discharge (cfs).

$q_u$ = unit peak discharge (cfs/mi2/in).

A = drainage area (mi2).

$Q^a$ = runoff volume (watershed inches – Tv/A).

### A.4.4 MTD Sizing

Refer to Chapter 8 of this Handbook for Manufactured Treatment Device (MTD) sizing using the $q_{pTv}$ treatment volume peak discharge and the approved "hydraulic loading rate" (HLR) and "maximum treatment flow rate" (MTFR) for each device.

## A.5 Water Quantity Calculations

The Regulation divides the quantity control requirements into Channel Protection criteria (9VAC25-875-600.B), Flood Protection criteria (9VAC25-875-600.C), and Sheet Flow (9VAC25-875-600.D).

### A.5.1 Channel Protection Criteria

Channel protection requirements are outlined in 9VAC25-875-600. Concentrated stormwater runoff from a land-disturbing activity should be discharged into a stormwater conveyance system in a manner that meets the channel protection design criteria at each point of discharge.

The Channel Protection Criteria establish the requirements for discharges of stormwater to one of three types of systems, specifically referred to as “Stormwater Conveyance Systems” which are defined in the Regulation as a combination of drainage components that are used to convey stormwater discharge, either within or downstream of the land-disturbing activity as follows:

*(A) “Manmade stormwater conveyance system” means a pipe, ditch, vegetated swale, or other stormwater conveyance system constructed by man except for restored stormwater conveyance systems;*

*(B) “Natural stormwater conveyance system” means the main channel of a natural stream and the flood-prone area adjacent to the main channel ; or*

*(C) “Restored stormwater conveyance system” means a stormwater conveyance system that has been designed and constructed using natural channel design concepts. Restored stormwater conveyance systems include the main channel and the flood-prone area adjacent to the main channel.*

9VAC25-875-20.

The following are excerpts from and explanations of the Channel Protection Criteria (9VAC25-875-600 B):

## A.5.1.1 Manmade Stormwater Conveyance System.

When stormwater from a development is discharged to a manmade stormwater conveyance system:

a. “The manmade stormwater conveyance system shall convey the post-development peak flow rate from the 2-year 24-hour storm event without causing erosion of the system” AND the system should be analyzed from the point of discharge until it reaches the limits of analysis.

   If the point of discharge is at or below the limits of analysis, then no additional downstream stormwater conveyance system analysis is required.

   If a natural stormwater conveyance system is encountered before the limits of analysis is reached or is coincidental with the limits of analysis, the stormwater peak discharge should satisfy the requirements for discharges to natural stormwater conveyance systems (see subsection 3herein); OR

b. The stormwater peak discharge should satisfy the requirements for discharges to natural stormwater conveyance systems (see subsection 3 herein). If these requirements are met or exceeded, then no downstream stormwater conveyance system analysis is required.

Limits of Analysis. The limits of analysis is the point at which either:

a. The site’s contributing drainage area is less than or equal to 1.0% of the total watershed area; OR
b. The site’s un-attenuated (prior to implementation of any stormwater quantity control measures) post-developed peak flow rate from the 1-year 24-hour storm is less than or equal to 1.0% of the existing peak flow rate from the 1-year 24-hour storm.

NOTE: Temporary stabilization products are intended to temporarily support the soil and vegetative growth until full stabilization is achieved. However, the design should address the occurrence of erosive peak flows prior to the establishment of the vegetation.

### A.5.1.1.1 Evaluating Manmade Stormwater Conveyance Systems

Manmade stormwater conveyance systems should be analyzed to determine whether the post-development stormwater velocity exceeds the permissible (non-erosive) velocity for each portion of the system. Post-development stormwater velocities should be computed based on existing slopes, materials, linings, and soil types as applicable.

1. Open stormwater conveyance channels.
    a. For the first 150 feet, field surveyed cross-sections should be analyzed every 50 feet and wherever there is a substantial change in channel geometry, roughness coefficient, or slope. Non-uniform channels may require analysis of additional cross-sections, particularly at constrictions or changes in flow characteristics.
    b. After the first 150 feet, to the downstream limit of analysis, a narrative based on visual inspection should be provided. Field surveyed cross-section should be analyzed at constrictions and areas with flatter (<1%) slopes, as well as at the limits of analysis.
    c. If field surveyed cross-sections are not available due to property access constraints, aerial/LIDAR generated cross-sections will be accepted.
2. Permissible (non-erosive) velocities.
    a. Reinforced Concrete Pipe (RCP). Post-development stormwater velocities should be less than or equal to 10 feet per second (ft./sec.) (VDOT Drainage Manual, Chapter 9).
    b. Corrugated Aluminized Metal Pipe (CAMP). Post-development stormwater velocities should be less than or equal to 5 ft./sec. (VDOT Road and Bridge Standards, PC-1).
    c. Plastic Pipe (HDPE, PP, etc.). Post-development stormwater velocities should be less than the scour velocity provided by manufacturer.
    d. Open stormwater conveyance channels. Post-development velocities should be less than or equal to the values in Table A-5:

**Table A-5 Permissible Velocity for Surface and Channel Linings[1]**

| Cover | Slope Range (percent) | Permissible Velocity[2] (ft/s) | |
|---|---|---|---|
| | | Erosion Resistant Soils[3] | Easily Erodible Soils[4] |
| Bermuda grass | 0-5 | 8 | 6 |
| | 5-10 | 7 | 5 |
| | >10 | 6 | 4 |
| Reed canary grass, | 0-5 | 7 | 5 |
| Tall fescue. | 5-10 | 6 | 4 |
| Kentucky bluegrass | >10 | 5 | 3 |
| Grass-legume mixture | 0-5 | 5 | 4 |
| | 5-10 | 4 | 3 |
| | Not recommended for slopes greater than 10% | | |
| Red fescue, | 0-5 | 3.5 | 2.5 |
| Redtop, Annual lespedeza, Small grains, Temporary vegetation | Not recommended for slopes greater than 5% | | |
| Sand & Gravel | | | |
| Fine Sand | Any | 2 | 1.5 |
| Coarse Sand | Any | 4 | 3 |
| Fine Gravel | Any | 6 | 4.5 |

| Table A-5 Permissible Velocity for Surface and Channel Linings[1] | | | |
|---|---|---|---|
| Cover | Slope Range (percent) | Permissible Velocity[2] (ft/s) | |
| | | Erosion Resistant Soils[3] | Easily Erodible Soils[4] |
| Earth<br>Sandy Silt<br>Silt Clay<br>Clay | Any | 2<br>3.5<br>6 | 1.5<br>2.6<br>4.5 |
| Poor Rock<br>Soft Shale<br>Soft Sandstone<br>Sedimentary | Any | 3.5<br>8<br>10 | N/A |
| Good Rock<br>Igneous or metamorphic | Any | 20 | N/A |

**Notes:**

1 Source: NRCS National Engineering Handbook, Part 654, Chapter 8, Table 8-4 & Table 8-6 (2007).

2 Greatest mean velocity that will not cause the channel boundary to erode.

3 Those with a high clay content and high plasticity. Typical soil textures are silty clay, sandy clay, and clay.

4 Those with a high content of fine sand or silty and lower plasticity or non-plastic. Typical soil textures are fine sand, silt, sandy loam, and silty loam. Also includes soils regardless of composition with an erodibility factor [K factor] greater than 0.35.

## A.5.1.2 Restored Stormwater Conveyance Systems.

"Restored stormwater conveyance system" means a stormwater conveyance system that has been designed and constructed using natural channel design concepts to ensure the restored and stabilized stream conveys its bankfull storm event within its banks and allows larger flows to access its floodplain. Restored stormwater conveyance systems include the main channel and the flood-prone area adjacent to the main channel.

When stormwater from a development is discharged to a restored stormwater conveyance system:

Stormwater runoff, in combination with other offsite stormwater runoff, shall be consistent with the design parameters of the restored stormwater conveyance system that is functioning in accordance with the design objectives AND the system should be analyzed from the point of discharge until it reaches the limits of analysis;

a. If the point of discharge is at or below the limits of analysis, then no additional downstream stormwater
b. conveyance system analysis is required; OR
c. The stormwater peak discharge should satisfy the requirements for discharges to natural stormwater conveyance systems. If these requirements are met or exceeded, then no downstream stormwater conveyance system analysis is required.

Limits of Analysis. The limits of analysis is the point at which either:

a. The site's contributing drainage area is less than or equal to 1.0% of the total watershed area; OR

b. The site's un-attenuated (prior to implementation of any stormwater quantity control measures) post-developed peak flow rate from the 1-year 24-hour storm is less than or equal to 1.0% of the existing peak flow rate from the 1-year 24-hour storm.

This standard requires that the designer verify that the restored stormwater conveyance system was designed to accommodate the stormwater discharge from the subject development, as well as "other stormwater runoff", meaning the discharges from other new or existing developments. The primary goal is to ensure that the restored stormwater conveyance system is adequate and will not be impacted by the new stormwater discharge.

Similar to subsection 1, a stormwater detention system may be incorporated into the site design so that the outflow does not exceed the design capacity of the restored system for the designated design storms. Also similar to subsection 1, the safe harbor provision of compliance may be available if the discharge is not consistent with the design parameters of the restored system.

## A.5.1.3 Natural Stormwater Conveyance Systems.

"Natural stormwater conveyance system" means the main channel of a natural stream and the flood-prone area adjacent to the main channel. This includes any natural or perennial or intermittent streams, unimproved ephemeral channels, wetlands, or swales. A manmade lake or reservoir not created for the purpose of managing post-development stormwater should be considered a natural stormwater conveyance system.

When stormwater from a development is discharged to a natural stormwater conveyance system, the maximum peak flow rate from the one-year 24-hour storm following the land-disturbing activity shall be calculated either:

a. In accordance with the following methodology:

| *Equation A-14 Energy Balance Method* |
| --- |
| $Q_{Developed} \leq I.F.* (Q_{Pre\text{-}developed} * RV_{Pre\text{-}Developed})/RV_{Developed}$ |

Under no condition shall $Q_{Developed}$ be greater than $Q_{Pre\text{-}Developed}$ nor shall $Q_{Developed}$ be required to be less than that calculated in the equation $(Q_{Forest} * RV_{Forest})/RV_{Developed}$;

Where:

*I.F. (Improvement Factor) equals 0.8 for sites > 1 acre or 0.9 for sites ≤ 1 acre.*

$Q_{Developed}$ *= allowable peak flow rate of runoff from the developed site.*

$RV_{Developed}$ *= volume of runoff from the site in the developed condition.*

$Q_{Pre\text{-}Developed}$ *=peak flow rate of runoff from the site in the pre-developed condition.*

$RV_{Pre\text{-}Developed}$ *= volume of runoff from the site in pre-developed condition.*

$Q_{Forest}$ *= peak flow rate of runoff from the site in a forested condition.*

$RV_{Forest}$ *= volume of runoff from the site in a forested condition; or*

b. In accordance with another methodology that is demonstrated by the VSMP Authority to achieve equivalent results and is approved by the board (See Section 1.5.8 of this appendix).

The allowable peak flow rate for the 1-year 24-hour storm should be based on the area of the site that drains to the point of discharge (i.e., outfall) in the pre-development condition.

### A.5.1.3.1 Channel Protection Computations: Energy Balance

The Energy Balance method is an effective strategy for targeting volume reduction and/or release rates so that channel flows are protected from extended impactful flows (i.e., near bank-full flows that keep channel banks wet and susceptible to erosion).

The Regulation provides the energy balance method for the calculation of the allowable discharge for channel protection (required for natural channels, option for manmade and restored channels):

When the Energy Balance criterion is applied, no analysis of the downstream Stormwater Conveyance System is required, unless specified by the VESMP authority.

**Runoff Volume**

Runoff Volume (RV) for pre- and post-development drainage areas must be in volumetric units (e.g., acre-feet or cubic feet) when using the Energy Balance Equation. Runoff measured in watershed-inches and shown in the spreadsheet as RV(watershed-inch) can only be used in the Energy Balance Equation when the pre- and post-development drainage areas are equal. Otherwise RV(watershed-inch) must be multiplied by the drainage area.

**What is the Improvement Factor?**

The Improvement Factor (IF) is a statutory hold over from § 62.1-44.15:28 of the Code of Virginia that requires the stormwater regulations to improve upon the contributing share of the existing predevelopment runoff characteristics and site hydrology if stream channel erosion or localized flooding is an existing predevelopment condition. The Channel Protection criterion for discharges to a Natural Stormwater Conveyance System assumes that the natural channel is not adequate and therefore requires that the Energy Balance Method be used to determine the allowable peak discharge (and storage requirements). It is conceivable that the post developed volume could be reduced through the use of runoff reduction and ESD strategies resulting in the ratio of Pre Vol1 to Post Vol1 increasing to 1. The IF then becomes the basis for "improving upon the existing condition" by a factor of 10% or 20% (equivalent to IF of 0.9 or 0.8 depending on the site area, respectively).

**Energy Balance Terminology**

Both the designer and plan reviewer should become familiar with the terminology of the Energy Balance method as it is documented in the Regulation, as well as how various hydrologic methods use the same values with possibly different definitions.

For example, the most common symbol in stormwater management documentation is that of runoff peak discharge, Q, measured in cubic feet per second. However, the NRCS TR-55 method, the foundation for computing urban runoff using NRCS methods, designates the same runoff peak discharge, measured in the same units of cubic feet per second, with a lower case q. To keep things interesting, TR-55 designates the depth of runoff measured in watershed inches as upper case Q.

Another important value that can be the cause of possible confusion is the use of RV as the symbol for Runoff Volume in the Energy Balance equation as published in the Regulation and noted above. (Notice that the rearranged Energy Balance equation version substitutes these values with Pre Vol1 and Post Vol1.) The VRRM Compliance spreadsheet uses the term RV to refer to runoff depth in inches, which can be used in the Energy Balance equation in place of the runoff volume.

Table A-4 provides a summary of the different terms used by the different published sources, along with the corresponding units. There is no absolute right or wrong version of the units, as long as they are used consistently within the design.

**Table A-4 Hydrology Terminology**

| Description | Units | Term |
|---|---|---|
| **NRCS TR 55 Urban Hydrology for Small Watersheds**[1] | | |
| Runoff Depth | inches | Q |

| Table A-4 Hydrology Terminology | | |
|---|---|---|
| **Description** | **Units** | **Term** |
| Runoff Volume | cubic feet or acre feet | Vr |
| Storage Volume | cubic feet or acre feet | Vs |
| Peak Discharge | cubic feet per second | qp |
| **VRRM Treatment Volume Runoff Coefficients** | | |
| Unitless Volume Runoff Coefficients | | Rv |
| VRRM Curve Number Adjustment | | |
| Runoff Depth | inches | RV |
| **VSMP Regulations: Channel Protection Criteria** | | |
| Peak Discharge | cubic feet per second | Q |
| Runoff Volume[2] | cubic feet or acre feet | RV |

**Notes:**

1. U.S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS). 1986. Technical Release 55 Urban Hydrology for Small Watersheds (TR-55). U.S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division. Available online at: https://nationalstormwater.com/urban-hydrology-for-small-watersheds-tr-55/.
2. Units of volume in the Virginia Erosion and Stormwater Management Regulation Channel Protection Criteria (9VAC25-875-600 B) can also be expressed in terms of watershed-inches or inches – consistent with runoff depth as expressed in Virginia Runoff Reduction Method (VRRM) curve number (CN) adjustment.

Considering the nomenclature distinction in Table A-4, the Energy Balance Equation:

*Equation A-15 Energy Balance*

$$Q_{1post} \leq Q_{1pre}\left(\frac{RV_{1pre}}{RV_{1post}}\right)(IF)$$

can be re-written as:

*Equation A-16 Revised Energy Balance*

$$q_{1post} \leq q_{1pre}\left(\frac{Vr_{1pre}}{Vr_{1post}}\right)(IF)$$

NOTE: Terminology Alert: Some of the terms included the terminology of the VESMP Channel Protection Criteria should be used with caution so as to not misrepresent any of the hydrologic parameters. The term Q for the pre- and post-development conditions as defined in 9VAC25-875-600 B 3 is inconsistent with the traditional nomenclature of the NRCS Runoff Equation. All the related values are summarized in Table A-4 above.

Unfortunately, the various computational methods use similar (and in some cases identical) terms to represent very different parameters. Designers should be very careful to ensure the proper value (and corresponding unit) are being used for each designated parameter.

## A.5.2 Identifying Acceptable Locations of Flood-Prone Areas for Determining Points of Discharge

The limits of a natural stormwater conveyance system's flood-prone area for the purposing of determining stormwater outfall locations should be determined by mapping the water surface elevation associated with the pre-development 1-year 24-hour storm event. Computations and cross-sections supporting the natural system's 1-year 24-hour water surface elevation should be provided with the plan.

VDEQ may consider discharges to other areas adjacent to main channel (e.g., mapped Federal Emergency Management Agency (FEMA) floodplain, FEMA floodway, FEMA floodway fringe, wetlands, riparian buffers, Resource Protection Areas) on a case-by-case basis. Discharges to these locations should be evaluated based on actual field conditions, i.e., slope, existing ground cover, etc. A site specific narrative with a description of the elements of the stormwater conveyance system, outfall, and adjoining properties should be provided with the plan.

## A.5.3 Channel Protection Analysis Points

Each point of discharge (i.e., outfall) from the site should be analyzed independently. Where applicable, the allowable peak flow rate should be based on the area of the site that drains to the point of discharge in the pre-development condition.

## A.5.4 Pre-Development versus Post-Development Drainage Areas / Divides

Post-development drainage areas and drainage divides should replicate, as nearly as practicable, the pre-development drainage areas and drainage divides. See Va. Code § 62.1-44.15:28 A 10.

Post-development drainage areas should deviate from the pre-development condition by no more than plus or minus 10%. Where a deviation greater than 10% is needed due to existing site constraints or where documented stream erosion or localized flooding exists in the pre-development condition, the 1-year 24-hour and 10-year 24-hour post-development peak discharge rates and volumes should not exceed the respective pre-development peak discharge rates and volumes.

## A.5.5 Flood Protection Criteria

Flood protection requirements are outlined in 9VAC25-875-600 C. Concentrated stormwater runoff from a land-disturbing activity should be discharged into a stormwater conveyance system in a manner that meets the flood protection design criteria at each point of discharge. The applicable flood protection criteria depends on whether or not pre-development localized flooding exists within or downstream from the site.

### A.5.5.1 No Pre-Development Localized Flooding

"Localized flooding" means smaller scale flooding that may occur outside a stormwater conveyance system. This may include high water, ponding, or standing water from stormwater runoff, which is likely to cause property damage or unsafe conditions.

“Flood-prone area” means the component of a natural or restored stormwater conveyance system that is outside the main channel. Flood-prone areas may include, but are not limited to, the floodplain, floodway, flood fringe, wetlands, riparian buffers, or other areas adjacent to the main channel.

“Point of discharge” means a location at which concentrated stormwater runoff is released.

When concentrated stormwater runoff is discharged to a stormwater conveyance system that does not experience pre-development localized flooding (within the limits of analysis) during the 10-year 24-hour storm, the stormwater conveyance system should confine the post-development peak flow rate from the 10-year 24-hour storm within the system AND the system should be analyzed from the point of discharge until it reaches the limits of analysis (see Section 3.303.1.C herein).

If the point of discharge is at or below the limits of analysis, then no additional downstream stormwater conveyance system analysis is required.

Stormwater detention or downstream stormwater conveyance system improvements may be used to meet this criteria.

Limits of Analysis. The limit of analysis is the point at which either:

a. The site’s contributing drainage area is less than or equal to 1.0% of the total watershed area; OR
b. The site’s un-attenuated (prior to implementation of any stormwater quantity control measures) post-developed peak flow rate from the 10-year 24-hour storm is less than or equal to 1.0% of the existing peak flow rate from the 10-year 24-hour storm.
c. The stormwater conveyance system enters a mapped FEMA floodplain or other flood-prone area adopted by local ordinance.

## A.5.5.2 Pre-Development Localized Flooding

“Localized flooding” means smaller scale flooding that may occur outside a stormwater conveyance system. This may include high water, ponding, or standing water from stormwater runoff, which is likely to cause property damage or unsafe conditions.

“Point of discharge” means a location at which concentrated stormwater runoff is released.

When concentrated stormwater runoff is discharged to a stormwater conveyance system that experiences pre-development localized flooding (within the limits of analysis) during the 10-year 24-hour storm either:

a. The stormwater conveyance system should confine the post-development peak flow rate from the 10-year 24-hour storm within the stormwater conveyance system to avoid (i.e., eliminate) the localized flooding AND the system should be analyzed from the point of discharge until it reaches the limits of analysis. Stormwater detention or downstream stormwater conveyance system improvements may be used to meet this criteria.

   If the point of discharge is at or below the limits of analysis then no additional downstream stormwater conveyance system analysis is required; OR

b. The post-development peak flow rate for the 10-year 24-hour storm should be less than the pre-development peak flow rate from the 10-year 24-hour storm at the point of discharge. If these requirements are met or exceeded, then no downstream stormwater conveyance system analysis is required.

Limits of Analysis. The limit of analysis is the point at which either:

a. The site’s contributing drainage area is less than or equal to 1.0% of the total watershed area; OR

b. The site's un-attenuated (prior to implementation of any stormwater quantity control measures) post-developed peak flow rate from the 10-year 24-hour storm is less than or equal to 1.0% of the existing peak flow rate from the 10-year 24-hour storm.
c. The stormwater conveyance system enters a mapped FEMA floodplain or other flood-prone area adopted by local ordinance.

### A.5.5.3 Flood Protection Computations

Computations to demonstrate compliance with the flood protection requirements in both areas with or without pre-development localized flooding should be conducted as follows:

1. Open stormwater conveyance channels.
    a. For the first 150 feet, field surveyed cross-sections should be analyzed every 50 feet and wherever there is a substantial change in channel geometry, roughness coefficient, or slope. Non-uniform channels may require analysis of additional cross-sections, particularly at constrictions or changes in flow characteristics.
    b. After the first 150 feet, to the downstream limit of analysis, a narrative based on visual inspection should be provided. Field surveyed cross-section should be analyzed at constrictions and areas with flatter (<1%) slopes, as well as at the limits of analysis.
    c. If field surveyed cross-sections are not available due to property access constraints, aerial/LIDAR generated cross-sections will be accepted.
2. Storm Sewers. Storm sewer systems should be analyzed to determine if the potential for surcharge of the system exists, and hydraulic grade line (HGL) computations and longitudinal profiles should be provided.
3. Culverts. Culverts should be analyzed to determine the controlling headwater using VDOT Design Form LD-269 or through a stormwater routing computation using U.S. Department of Transportation HY-8, or similar. Each point of discharge (i.e., outfall) from the site should be analyzed independently. Where applicable, the allowable peak flow rate should be based on the area of the site that drains to the point of discharge in the pre-development condition.

### A.5.5.4 Flood Protection: Determination of Pre-Development Localized Flooding

"Localized flooding" means smaller scale flooding that may occur outside a stormwater conveyance system. This may include high water, ponding, or standing water from stormwater runoff, which is likely to cause property damage or unsafe conditions.

A. Stormwater conveyance systems should be analyzed using existing conditions to determine if pre-development localized flooding exists during the 10-year 24-hour storm.
B. Open stormwater conveyance channels. If the 10-year 24-hour pre-development water surface elevation is determined to be higher than the bank of the channel, then an existing localized flooding condition is present.
C. Storm sewers. If the 10-year 24-hour pre-development HGL is not confined with the storm sewer system, then an existing localized flooding condition is present.
D. Culverts. If the 10-year 24-hour pre-development headwater or tailwater elevation is determined to be higher than the bank of the channel, then an existing localized flooding condition is present.

## A.5.6 Sheet Flow and Level Spreader Computations

Increased volumes of sheet flow resulting from pervious or disconnected impervious areas, or from physical spreading of concentrated flow through level spreaders, should be identified and evaluated for potential impacts on downgradient properties or resources. See 9VAC25-875-600 D.

Increased volumes of sheet flow that will cause or contribute to erosion, sedimentation, or flooding of downgradient properties or resources should be diverted to a stormwater management facility or a stormwater conveyance system that conveys the runoff without causing downgradient erosion, sedimentation, or flooding.

See 9VAC25-875-600 D.

### A.5.6.1 Discharges of Sheet Flow from Pervious or Disconnected Impervious Areas

In the case where pre- and post-development stormwater runoff occur as sheet flow and the runoff volume and velocity will not increase from pre-development to post-development, the plans, narrative, computations, and existing and proposed grades should demonstrate no increase in the 10-year 24-hour storm post-development runoff volume and velocity as compared to the pre-development volume and velocity.

In the case where pre- and post-development stormwater runoff occur as sheet flow AND the runoff volume will increase from pre-development to post-development:

1. The 10-year 24-hour post-development sheet flow velocity should be less than or equal to the permissible velocities in Table A-42 - Permissible Velocity for Sheet Flow from Level Spreaders.
2. The 10-year 24-hour post-development sheet flow depth should be less than or equal to 0.1 feet for the entire length of the flow path to the downgradient stormwater conveyance system.
3. The length of sheet flow should be less than or equal to the following:

*Equation A-20 Maximum Length of Sheet Flow (NRCS National Engineering Handbook, Equation 15-9)*

$$L_{SF} = \frac{100\sqrt{S}}{n}$$

Where:

$L_{SF}$ = maximum length of sheet flow (feet)

S = land slope (foot/foot)

n = Manning's roughness coefficient (see table A-a1 Manning's Roughness Coefficients for Sheet Flow)

**Table A-1a Manning's Roughness Coefficients for Sheet Flow (flow depth generally ≤ 0.1 foot)**

| Land Cover | Mannin's *n* |
|---|---|
| Smooth surface (concrete, asphalt, gravel, or bare soil) | 0.011 |
| Fallow (no residue) | 0.05 |
| Cultivated soils: | |
| Residue cover: ≤ 20% | 0.06 |
| Residue cover: > 20% | 0.17 |

| Table A-1a Manning's Roughness Coefficients for Sheet Flow (flow depth generally ≤ 0.1 foot) | |
|---|---|
| **Land Cover** | **Mannin's *n*** |
| Grass: | |
| Short-grass prairie | 0.15 |
| Dense grasses* | 0.24 |
| Bermudagrass | 0.41 |
| Range (natural) | 0.13 |
| Woods: ** | |
| Light underbrush | 0.40 |
| Dense underbrush | 0.80 |

**Notes:**

Source: NRCS National Engineering Handbook, Table 15-1

* Includes weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.

** When selecting n, consider cover to a height of about 0.1 feet, as this is the only part of the plant cover that will obstruct sheet flow.

4. Documentation/computations should be provided demonstrating that increased volumes of sheet flow:
   a. Will not adversely impact any downgradient property (i.e., cause erosion and/or cause or worsen localized flooding).
   b. Will not adversely impact any downgradient environmental features.
   c. Will be conveyed within any downgradient manmade stormwater conveyance system without causing erosion of the system for the 2-year 24-hour storm and will be confined within any downgradient manmade stormwater conveyance system without causing or worsening localized flooding for the 10-year 24-hour storm.
   d. Will meet the design parameters of any downgradient restored stormwater conveyance system.
   e. Will be conveyed within any downgradient natural stormwater conveyance system without causing erosion of the system for the 1-year 24-hour storm and will be confined within any downgradient natural stormwater conveyance system without causing or worsening localized flooding for the 10-year 24-hour storm.
5. Remediation of any active erosion, sedimentation, or flooding in the sheet flow path should be specified on the plans.

## A.5.6.2 Discharges of Sheet Flow from Level Spreaders

Piped or channelized stormwater runoff converted to sheet flow prior to discharge should comply with 9VAC25-875-600 D or "Safe Harbor" (see Section A.5.9 herein).

In the case where pre- and post-development stormwater runoff occur as sheet flow AND the runoff volume and velocity will not increase from pre-development to post-development, the plans, narrative, computations, and existing and proposed grades should demonstrate no increase in the 1-year 24-hour and 10-year 24-hour storm post-development runoff volumes and velocities as compared to the respective pre-development volumes and velocities.

In the case where pre- and post-development stormwater runoff occur as sheet flow AND the runoff volume will increase from pre-development to post-development, the following criteria should be used to verify the increased volumes of sheet flow will not cause or contribute to erosion, sedimentation, or flooding of down gradient properties or resources:

1. The 10-year 24-hour post-development sheet flow velocity should be less than or equal to the following to ensure that re-concentration does not prematurely occur:

**Table A-42 Permissible Velocity for Sheet Flow from Level Spreaders [1]**

| Cover | Slope Range (percent) [3] | Permissible Velocity [2] (ft/s) | |
|---|---|---|---|
| | | Erosion Resistant Soils [4] | Easily Erodible Soils [5] |
| Bermuda grass | 0-5 | 6 | 4.5 |
| | 5-10 | 5 | 3.8 |
| | >10 | 4 | 3 |
| Reed canary grass, | 0-5 | 5 | 3.8 |
| Tall fescue. | 5-10 | 4 | 3 |
| Kentucky bluegrass | >10 | 3 | 2.3 |
| Grass-legume mixture | 0-5 | 4 | 3 |
| | 5-10 | 3 | 2.3 |
| | Not recommended for slopes greater than 10% | | |
| Red fescue, Redtop, Annual lespedeza, Small grains, Temporary vegetation | 0-5 | 2.5 | 1.9 |
| | Not recommended for slopes greater than 5% | | |
| Sand & Gravel | | | |
| Fine Sand | Any | 2 | 1.5 |
| Coarse Sand | | 4 | 3 |
| Fine Gravel | | 6 | 4.5 |
| Earth | | | |
| Sandy Silt | Any | 2 | 1.5 |
| Silt Clay | | 3.5 | 2.6 |
| Clay | | 6 | 4.5 |

| Table A-42 Permissible Velocity for Sheet Flow from Level Spreaders [1] | | | |
|---|---|---|---|
| Cover | Slope Range (percent) [3] | Permissible Velocity [2] (ft/s) | |
| | | Erosion Resistant Soils [4] | Easily Erodible Soils [5] |
| Poor Rock | | | |
| Soft Shale | Any | 3.5 | N/A |
| Soft Sandstone | | 8 | |
| Sedimentary | | 10 | |
| Good Rock | | | |
| Igneous or metamorphic | Any | 20 | N/A |
| Mulch | Any | 1 | 0.75 |

**Notes:**

1 Source: Adapted from NRCS National Engineering Handbook, Part 654, Chapter 8, Table 8-4 & Table 8-6 (2007).

2 Greatest mean velocity that will not cause the channel boundary to erode.

3 Refer to Post Construction Specification P-FIL-07 Sheet Flow to Veg. Filter Strip Open Space for additional slope requirements for level spreaders used for water quality.

4 Those with a high clay content and high plasticity. Typical soil textures are silty clay, sandy clay, and clay as indicated in the NRCS web soil survey.

5 Those with a high content of fine sand or silty and lower plasticity or non-plastic. Typical soil textures are fine sand, silt, sandy loam, and silty loam NRCS web soil survey. Also includes soils regardless of composition with an erodibility factor [K factor] greater than 0.35 as indicated in the NRCS web soil survey.

2. The 10-year 24-hour post-development sheet flow depth should be less than or equal to 0.1 feet for the entire length of the flow path to the downgradient stormwater conveyance system.
3. The length of sheet flow path to the downgradient stormwater conveyance system should be less than or equal to the following:

*Equation A-21 Maximum Length of Sheet Flow (NRCS National Engineering Handbook, Equation 15-9)*

$$L_{SF} = \frac{100\sqrt{S}}{n}$$

Where:

$L_{SF}$ = maximum length of sheet flow (ft)

S = land slope (ft/ft)

n = Manning's roughness coefficient (see table A-1 Manning's Roughness Coefficients for Sheet Flow)

4. Documentation/computations should be provided demonstrating that discharges of sheet flow from level spreaders:
   a. Will not adversely impact any downgradient property (i.e., cause erosion and/or cause or worsen localized flooding).

    b. Will not adversely impact any downgradient environmental features.

6. Remediation of any active erosion, sedimentation, or flooding in the sheet flow path should be specified on the plans.
7. The area of sheet flow should be located outside the limits of clearing and grading and be protected by erosion and sediment controls, or the area should undergo soil restoration via full implementation of VDEQ Stormwater Design Specification No. 4 (Soil Compost Amendment) immediately prior to establishing permanent stabilization.
8. Level spreader lengths should be computed using the following equation (minimum level spreader length should be no less than 10 feet; maximum level spreader length should be no more than 200 feet):

*Equation A-22 Level Spreader Length*

$$L_{SF} = \frac{100\sqrt{S}}{n}$$

Where:

$L_{LS}$ = Length of level spreader (ft)

Q = 10-year 24-hour post-development peak flow rate (cfs)

$C_W$ = Weir Coefficient (assume 3.3 for rectangular weir)

H = Depth of water immediately upslope of level spreader (assume 0.1 ft)

8. 10-year 24-hour post-development sheet flow velocities downgradient of level spreader should be computed using the following equation (Manning's equation):

*Equation A-23 Manning's Equation*

$$V = \frac{1.486}{n} \times R^{2/3} \times S^{1/2}$$

Where:

V = Velocity (fps)

n = Manning's roughness coefficient (see Table A-1 herein)

R = Hydraulic radius (ft) = A / P

S = Land slope (ft/ft)

and:

A = Flow area ($ft^2$) = LLS x 0.1 ft

P = Wetted perimeter (ft) = LLS + 0.1 ft + 0.1 ft

9. Detailed level spreader designs should be provided on the plans (to include construction details, dimensions, materials, layout, and site-specific details to ensure the level spreader ties into adjacent slopes and stormwater runoff does not short circuit and flow around the level spreader).
10. Level spreaders should be oriented parallel to downgradient contours.
11. Level spreaders (top or lip elevation) should be no higher than 3 to 4 inches above the downgradient land surface. A smooth transition between the level spreader and downgradient land surface should be provided.

12. Level spreaders should be constructed of concrete or other non-erodible material (e.g., rock).
13. A maintenance plan should be provided on the plans.

## A.5.7 Limits of Analysis Computations

The VESMP Quantity Control criteria includes provisions that establish how far downstream the designer must analyze the stormwater conveyance system to demonstrate compliance. For the VESMP Channel Protection Criteria (9 VAC25-875-600 B 4):

- If the VESMP Channel Protection criteria for Natural Stormwater Conveyance Systems is used, there is no requirement for a downstream analysis;
- If the VESMP Channel Protection criteria for Manmade or Restored Stormwater Conveyance Systems is used, then the stormwater conveyance systems shall be analyzed for compliance to a location that:
    - Based on land area, the point of discharge contributing drainage area is less than or equal to 1.0% of the total watershed area [draining to that point]; or
    - Based on peak flow rate, the peak flow rate from the one-year 24-hour storm at the point of discharge is less than or equal to 1.0% of the existing peak flow rate from the one-year 24-hour storm prior to the implementation of any stormwater quantity control measures.

The VESMP Flood Protection criterion (9VAC25-875-600 C 3) similarly establishes a limit of analysis when determining capacity of the stormwater conveyance system for the 10-year storm.

- If the point of discharge complies with the criteria for releasing the developed 10-year 24-hour storm peak discharge at below the pre-development rate in a system that experiences pre-development flooding, then no downstream analysis is required.
- If the point of discharge of the 10-year 24-hour storm is proposed to be contained within the stormwater conveyance system, then an analysis of the system to ensure the discharge stays within the system must be conducted to a point where:
    - The site's contributing drainage area is less than or equal to 1.0% of the total watershed area draining to a point of analysis in the downstream stormwater conveyance system;
    - Based on peak flow rate, the site's peak flow rate from the 10-year 24-hour storm event is less than or equal to 1.0% of the existing peak flow rate from the 10-year 24-hour storm event prior to the implementation of any stormwater quantity control measures; or
    - The stormwater conveyance system enters a mapped FEMA floodplain or other flood prone area, adopted by ordinance, of any VESMP Authority.

The limits of analysis establish how far downstream the designer must verify the adequacy of the Stormwater Conveyance System. The requirement to analyze the downstream system, and therefore the criteria for how far downstream to carry the analysis applies only in cases where the energy balance criteria is not being utilized.

Channel protection analysis is carried to a point where:

- The site's contributing drainage area is less than or equal to 1.0% of the total watershed area draining to a point of analysis in the downstream stormwater conveyance system; or
- Based on peak flow rate, the site's peak flow rate from the 1-year 24-hour storm event is less than or equal to 1.0% of the existing peak flow rate from the 1-year 24-hour storm event prior to the implementation of any stormwater quantity control measures.
- The designer must analyze the stormwater conveyance system using acceptable hydrologic and hydraulic methodologies to the defined limit of analysis.

*Figure A-10 Limits of Analysis Example by Drainage Area*

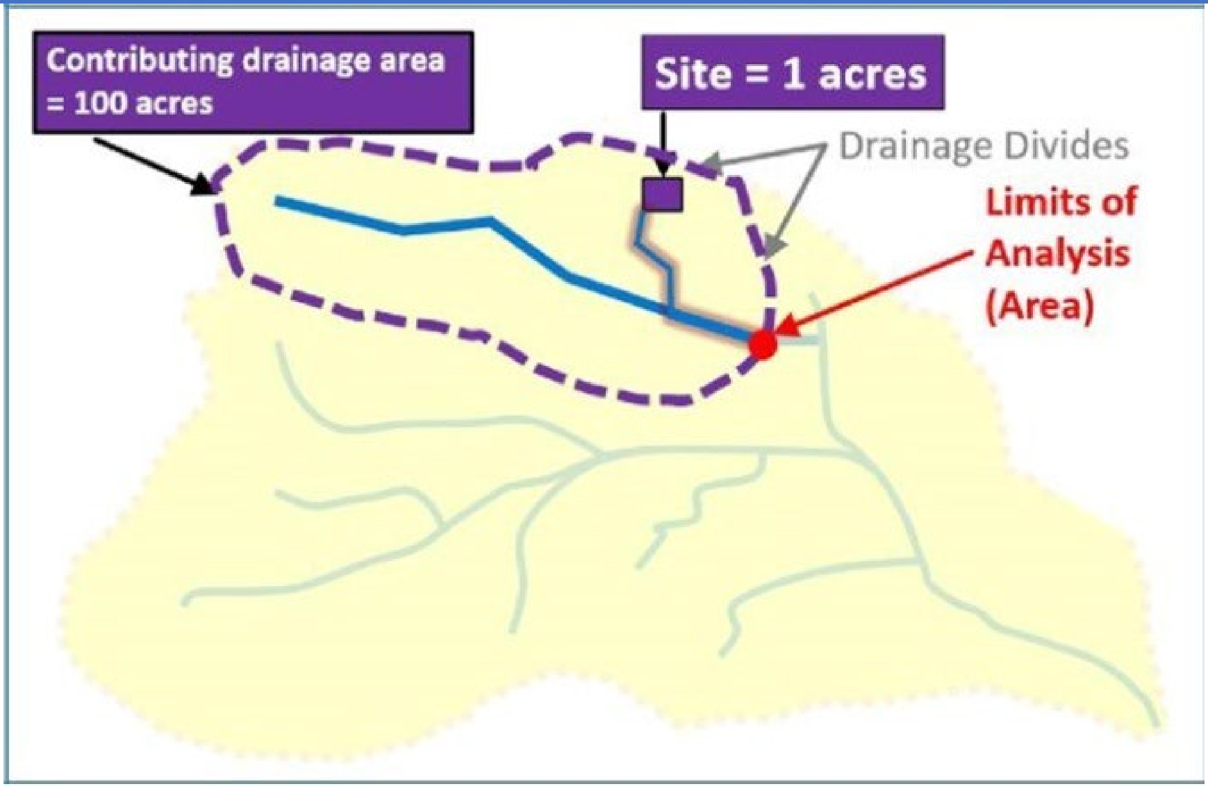
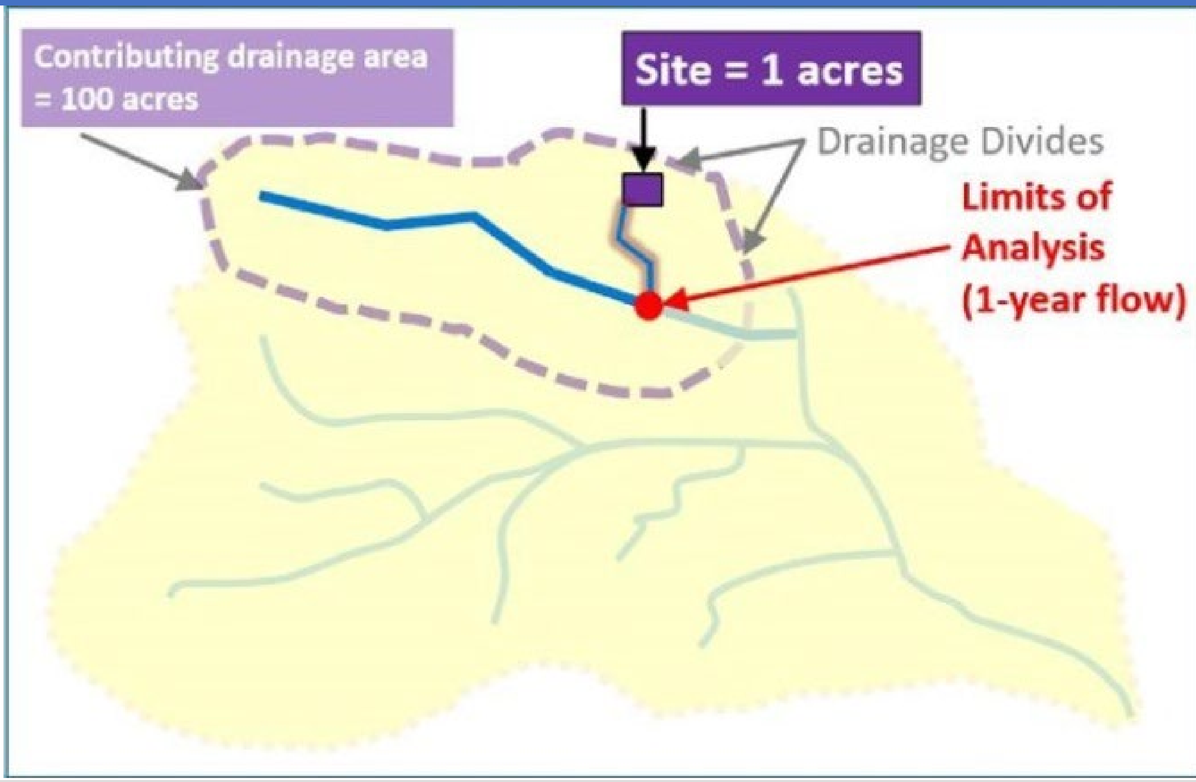


*Figure A-11 Limits of Analysis Example by Flow*




## A.5.8 Other Acceptable Methodologies

Energy Balance is the primary regulatory requirement which is allowed for the demonstration of the stormwater management statute. However, the Regulation provides for a VESMP authority to submit for VDEQ approval another methodology that is demonstrated to achieve equivalent results.

The primary driver of the method comes from two places: First is the Fairfax County "safe harbor" provision that includes the proportional reduction in the allowable peak discharge from a range of design storms.

The second is the mandate from § 62.1-44.15:28 of the Code of Virginia to establish regulations that encourage Low Impact Development (LID). The use of the post development runoff volume (Post Vol1) in the peak discharge formula allows the designer to take credit for the various LID or Stormwater Site Design strategies that ultimately decrease the post-developed condition volume of runoff.

[Additional text to be added for Virginia Beach and Northern VA localities approved approaches.]

## A.5.9 Safe Harbor Provision

This criterion was originally adopted in 2004 as a "safe harbor" for development projects that proposed a stormwater discharge to an eroded channel. The "safe harbor" was considered necessary to address a provision in Minimum Standard 19 that requires that all stormwater discharges must be to an adequate channel (and an eroded channel was considered, by definition, to be not adequate, regardless of on-site detention or volume reduction).

If all three criteria (1, 2, and 3) identified below are met or exceeded, no additional water quantity control or downstream stormwater conveyance system analysis is required at the point of discharge:

1. Detain the water quality volume and release it over 48 hours;

   a. "Water quality volume" means the volume equal to the first half inch of runoff multiplied by the impervious surface of the land development project. See 9VAC25-875-670
   b. Drawdown time (i.e., time to empty) should be greater than or equal to 48 hours.
2. Detain and release over a 24-hour period the expected rainfall resulting from the one year, 24-hour storm; Stormwater management facility or best management practice outflow routing should be greater than or equal to 24 hours.
3. Reduce the allowable peak flow rate resulting from the 1.5, 2, and 10-year, 24-hour storms to a level that is less than or equal to the peak flow rate from the site assuming it was in a good forested condition, achieved through multiplication of the forested peak flow rate by a reduction factor that is equal to the runoff volume from the site when it was in a good forested condition divided by the runoff volume from the site in its proposed condition.
   a. The 1.5-year 24-hour rainfall should be computed using linear interpolation with the 1- and 2-year 24-hour rainfall data from NOAA Atlas 14.
   b. Curve numbers for the purposes of performing runoff computations should be indicated in Table A-9:

**Table A-9 Safe Harbor Curve Number Selection**

| Land Cover | HSG A | HSG B | HSG C | HSG D |
|---|---|---|---|---|
| Woods, good condition | 30 | 55 | 70 | 77 |

   c. The allowable peak flow rate should be computed using the following equation:

*Equation A-24 Allowable Peak Flow Rate Safe Harbor*

$$Q_{developed} \leq Q_{forest} \times \frac{RV_{forest}}{RV_{developed}}$$

Where:

$Q_{developed}$ = the allowable peak flow rate of runoff from the developed site

$RV_{developed}$ = the volume of runoff from the site in the developed condition

$Q_{forest}$ = the peak flow rate of runoff from the site in good forested condition

$RV_{forest}$ = the volume of runoff from the site in the good forested good condition

## A.6 Calculations for Development on Prior Developed Land

The stormwater quality requirements for development on prior developed land are defined in 9VAC25-875-580 (Water Quality Design Criteria Requirements), discussed in Chapter 5 of this handbook, and outlined below. The required load reduction is a percent reduction rather than a pollutant load calculated based on the existing developed condition. In addition, within the redeveloped site, any increase of impervious cover (if any) must be considered as new development and therefore requires a load reduction comparable to that of new development for the acreage of new impervious (0.26 lb/ac). Therefore, the required load reduction for redevelopment is the total load reduction computed for the two conditions: the redeveloped site plus the new impervious cover on the site.

Requirements for water quantity as outlined in 9VAC25-875-600 (Water Quantity) do not distinguish the difference between new and re-development. Rather, the channel and flood protection requirements are defined by the downstream stormwater conveyance system. These stormwater quantity requirements are applied to the development project regardless of the status as new development or redevelopment and are discussed below and covered in detail in Section 1.5 of this appendix.

Note that existing stormwater management facilities or BMPs may require modifications to comply with current requirements and specifications in order to utilize those facilities to meet the water quantity and quality requirements for redevelopment. However the existing facility's original water quality and quantity treatment should be also maintained or improved. This may require review of old hydrologic computations.

## A.6.1 Water Quality Criteria for Development on Prior Developed Land

For the purposes of the stormwater criteria, prior developed land is defined as land that has been previously utilized for residential, commercial, industrial, institutional, recreation, transportation or utility facilities or structures and that will have the impervious areas associated with those uses altered during a land-disturbing activity.

Therefore, any land disturbing activity on a site that meets this definition must comply with the requirements of 9VAC25-875-580 A 2, as follows:

1. Development on prior developed lands.
    a. For land-disturbing activities disturbing greater than or equal to one acre that result in no net increase in impervious cover from the predevelopment condition, the total phosphorus load shall be reduced at least 20% below the predevelopment total phosphorus load.
    b. For regulated land-disturbing activities disturbing less than one acre that result in no net increase in impervious cover from the predevelopment condition, the total phosphorus load shall be reduced at least 10% below the predevelopment total phosphorus load.
    c. For land-disturbing activities that result in a net increase in impervious cover over the predevelopment condition, the design criteria for new development shall be applied to the increased impervious area. Depending on the area of disturbance, the criteria of subdivisions a or b above, shall be applied to the remainder of the site.
    d. In lieu of subdivision c, the total phosphorus load of a linear development project occurring on prior developed lands shall be reduced 20% below the predevelopment total phosphorus load Linear utility projects which will not result in changes to the predevelopment runoff characteristics of the land may be eligible for a waiver.
    e. The total phosphorus load shall not be required to be reduced to below the applicable standard for new development unless a more stringent standard has been established by a local stormwater management program locality.
    f. Compliance should be determined by using the VRRM.
    g. When a land-disturbing activity discharges stormwater runoff to more than one 6th order (12-digit) hydrologic unit code, the total phosphorus load reduction requirements in this section should be applied independently within each hydrologic unit code.

The same principles outlined in this appendix for computing the pollutant load (for both the pre-development and post-development condition) apply to the compliance computations for development on prior developed land. The difference in the computations will be in determining the pollutant load reduction requirement based on the disturbance thresholds and the amount of additional impervious cover (if any), as outlined above. The following section provides a description of the steps for computing the load reduction requirement.

NOTE: For simplicity, the term Redevelopment will be used for Development on Prior Developed Land. Likewise, the term VRRM Redevelopment Compliance Spreadsheet will be used to refer to the VRRM Compliance Spreadsheet for Development on Prior Developed Lands.

The general procedure for computing the load reduction requirement on redevelopment projects is applied to 2 general categories of redevelopment:

1. Redevelopment sites that do not result in net increase in impervious cover in the post-development (or post-redevelopment) land cover; and
2. Redevelopment sites that do result in a net increase in impervious cover in the post-development (or post-redevelopment) land cover.

A third category of project is linear development occurring on prior developed lands. In order for a development project to be subject to a load reduction requirement there must be a change in the land cover from the pre- to post-development (or post-redevelopment) condition, or other hydrologic change such as grading or drainage infrastructure improvements. Linear development as defined in the Regulation can include a variety of activities that are linear in nature but may not necessarily reflect a land cover change, i.e., above and below ground utility installation. Therefore, it is important to consider the definitions of the land cover categories (as defined in the VRRM User Guide) in order to verify if a change occurs, or if a management practice can be used to offset the change.

The most common type of linear development that will require a load reduction is the construction of transportation infrastructure. Linear roadway projects that construct additional traffic lanes, new turn lanes or intersection improvements in urban areas, etc., are redevelopment projects that clearly include a net increase in impervious cover. However, the Regulation specifically requires that these projects achieve a 20% load reduction below the predevelopment condition; the criterion for new development (the site-based load limit) is not applied to the new impervious cover.

Another important distinction for linear transportation projects is that of pavement maintenance, i.e., milling and repaving or otherwise maintaining the roadway surface and right of way. These activities maintain the original grade, alignment, and footprint of impervious cover and are generally considered maintenance and not subject to the stormwater management requirements.

## A.6.1.1 Redevelopment Sites that Do Not Increase Impervious Cover

The first procedure described here is for the sites that do not result in a net increase in impervious cover. In general this scenario requires a load reduction such that the post-development load is either 10 or 20% lower (depending on the acreage of land disturbance; see Subdivision 2-a or 2-b of 9VAC25-875-580 A) than the load from the land cover of the original site.

**Step 1:** Resource Mapping and Environmental Site Assessment

The Resource Mapping and Environmental Site Assessment will ideally identify the available locations for runoff reduction and/or pollutant removal practices on redevelopment projects within the existing and proposed site infrastructure prior to establishing a final design and grading plan. At urban and ultra-urban redevelopment sites, the proposed micro-topography and resulting drainage divides can often be manipulated to direct runoff to these favorable locations without significant impacts to the overall site design.

The designer can implement the stormwater practices to achieve the load reduction requirement by treating the new, redeveloped, or existing site areas within the limits of the project (as defined by the project site). The project site should incorporate all of the disturbed area and proposed improvements (including existing buildings when being renovated), and any additional area of the site needed for vehicle access, material and equipment staging, and the construction of the stormwater BMPs.

**Step 2:** Site Hydrology and Pollutant Loads

Determine the pre-development land cover (forest mixed open, managed turf, or impervious).

1. The pre-development (or pre-redevelopment) land cover is defined as the land cover that exists at the time that plans for the land development of a tract of land are submitted to the VESMP authority. Where a development is phased, or where plan submittal and approval is broken down into steps such as demolition of existing structures, preliminary grading, or construction of roads or utilities, etc., the land cover at the time of the first item submitted establishes the pre-development conditions.
2. Determine the post-development land cover (forest, mixed open, managed turf, or impervious).
3. The post-development (or post-redevelopment) land cover is defined as the land cover that reasonably may be expected or anticipated to exist after completion of the land development activity on a specific site (i.e., the land cover as defined by the approved plans for the redevelopment project).
4. Compute the pre-development and post-development Site Rv , Tv , and corresponding pollutant load (.
5. Compute the load reduction requirement using Equation A-25 for redevelopment projects that disturb one acre or more (land disturbance > 1 acre: subdivision 2-a of 9VAC25-875-580 A), or Equation A-26 for re-development projects that disturb less than one acre (land disturbance < 1 acre: subdivision 2-b of 9VAC25-875-580 A):

*Equation A-25 Load Reduction Requirement for Redevelopment (Z 1 acre of disturbance)*

$$L_{reduction} = L_{Post\text{-}ReDevelopment} - L_{Pre\text{-}ReDevelopment}(1 - 0.2)$$

Where:

$L_{reduction}$ = Load reduction requirement (lb/yr)

$L_{Post\text{-}reduction}$ = Post-development (or post-redevelopment) load (lb/yr)

$L_{Pre\text{-}reduction}$ = Pre-development (or pre-redevelopment) load (lb/yr)

**OR**

*Equation A-26 Load Reduction Requirement for Redevelopment (< 1 acre of disturbance)*

$$L_{reduction} = L_{Post\text{-}ReDevelopment} - L_{Pre\text{-}ReDevelopment}(1 - 0.1)$$

Where:

$L_{reduction}$ = Load reduction requirement (lb/yr)

$L_{Post\text{-}reduction}$ = Post-development (or post-redevelopment) load (lb/yr)

$L_{Pre\text{-}reduction}$ = Pre-development (or pre-redevelopment) load (lb/yr)

6. Verify that the load reduction requirement computed in item 4 does not exceed that which would be required to meet the load limit standard for new development (0.26 lb/ac):

*Equation A-27 Redevelopment Load Reduction Limit*

$$L_{reduction} = L_{Post\text{-}ReDevelopment} - (0.26\ lb/ac/yr) \times A$$

Where:

$L_{reduction}$ = total load reduction requirement (lb) for the redevelopment project computed in Step 4

$L_{Post\text{-}redevelopment}$ = post-redevelopment pollutant load

0.26 lb/ac/yr = site based TP load limit

A = redevelopment site area (acres)

NOTE: The VRRM Redevelopment Compliance Spreadsheet provides for these computations. The user must enter the total disturbed acreage and the pre-development and post-development land cover acres on the Site Data tab. The spreadsheet will compute the total load reduction requirement.

**Step 3:** Drainage Area Hydrology, Peak Discharge, and Treatment Volume (Tv)

Repeat the procedures of Step 2 as needed to determine the post-development Land Cover and corresponding Site Rv and Tv in each drainage area.

**Step 4:** Apply volume (or load) reduction BMPs to the redevelopment site in order to achieve the required reduction calculated in Step 2 or by Equation A-27, whichever is less.

## A.6.1.2 Redevelopment Sites that Increase Impervious Cover

The following procedure is for re-development sites that result in a net increase in impervious cover in the post-development condition.

**Step 1:** Resource Mapping and Environmental Site Assessment

The Resource Mapping and Environmental Site Assessment will ideally identify the available locations for runoff reduction and/or pollutant removal practices on redevelopment projects within the existing and proposed site infrastructure prior to establishing a final design and grading plan. At urban and ultra-urban redevelopment sites, the proposed micro-topography and resulting drainage divides can often be manipulated to direct runoff to these favorable locations without significant impacts to the overall site design.

The designer can implement the stormwater practices to achieve the load reduction requirement by treating the new, redeveloped, or existing site areas within the limits of the project (as defined by the project site). The project site should incorporate all of the disturbed area and proposed improvements (including existing buildings when being renovated), and any additional area of the site needed for vehicle access, material and equipment staging, and the construction of the stormwater BMPs.

**Step 2:** Site Hydrology and Pollutant Loads

1. Determine the pre-development land cover (forest, mixed open, managed turf, or impervious).
2. Determine the post-development land cover (forest, mixed open, managed turf, or impervious).
3. Determine the adjusted pre-development land cover.

   The adjusted pre-development land cover is the pre-development land cover minus the pervious acreage (forest, mixed open or turf based on soil types) proposed for new impervious cover.

4. Determine a comparably adjusted post-development land cover.

   This is the post-development land cover minus the net acreage of new impervious cover.

   The adjusted pre-development land cover acreage is now the same as the post-development land cover, and is considered the redevelopment acreage used to compute the 10 or 20% load reduction requirement (Equation A-29 or A-30 based on the acreage of disturbance.)

   The net acreage of increased impervious cover is considered new development and is used to compute the load reduction required to meet the load limit for new development (subdivision 2-c of 9VAC25-875-580 A).

5. Compute the pre-development, adjusted pre-development, post-development, and new impervious Rv , Tv, and corresponding pollutant loads.

NOTE: An adjusted pre- and post-development land cover is required in order to accommodate the computation of dual load reduction criteria for redevelopment sites with a net increase in impervious cover.

The required total load reduction for the redevelopment site is the sum of the load reduction from these two computations:

- The load reduction required for the new impervious cover to meet the site based load limit of 0.26 lb/ac/yr; and
- The load reduction required for the balance of the site to meet the 10 or 20% load reduction from that of the existing (pre-development) land cover.

6. Compute the new development area load reduction requirement for the net acreage of new impervious cover (Equation A-27)
7. Compute the redevelopment area load reduction requirement using Equation A-25 for redevelopment projects that disturb one acre or more (land disturbance ≥ 1 acre; subdivision 2-a of 9VAC25-875-580 A), or Equation A-26 for redevelopment projects that disturb less than one acre (land disturbance < 1 acre; subdivision 2-b of 9VAC25-875-580 A):
8. Add the load reduction requirements of parts 6 and Step 7 of this procedure for the total redevelopment site load reduction.
9. Verify that the load reduction requirement computed in item 8 does not exceed that which would be required to meet the load limit standard for new development (0.26 lb/ac) using Equation A-27.

**Step 3:** Drainage Area Hydrology, Peak Discharge, and Treatment Volume (Tv)

Repeat the procedures of Step 2 as needed to determine the post-development Land Cover and corresponding Site Rv and Tv in each drainage area.

**Step 4:** Apply volume (or load) reduction BMPs to the redevelopment site in order to achieve the required reduction calculated in Step 2 or by Equation A-27, whichever is less.

# A.7 Calculations Relating to Common Plans of Development

A common plan of development or sale is a contiguous area where separate and distinct construction activities may be taking place at different times on different schedules (9VAC25-875-20). Permit coverage is required if one acre or greater of land will be disturbed, regardless of the size of the individually owned or developed sites. For example, if a developer buys a 20-acre lot and builds roads with the intention of building homes or other structures in the future, or if the land is parceled off or sold, and construction occurs on plots that are less than an acre by separate, independent builders, these activities would still be subject to stormwater permitting requirements, including address all stormwater technical criteria of the Regulation. A larger common plan of development or sale applies to various types of land development including but not limited to residential, commercial or industrial use.

Often common plans of development utilize a comprehensive design approach to stormwater management plan development which specifies how the water quality components, quantity components, or both of stormwater are to be managed for the entire development or a portion thereof.

## A.7.1 Demonstrating Water Quality and Quantity Compliance for Multiphase Projects

While the final stie design must meet all water quality and quantity technical criteria for the ultimate development, each individual phase must all meet all aspects of stormwater compliance independently. Phases of construction may occur over long periods of time, thus the design should plan for the ultimate development known for that phase. Any subsequent phases over an acre or less than an acre but part of the original common plan of development will be required to demonstrate compliance with the technical criteria of the Regulation at the time of submission to the VESMP authority.

When portions of a common plan of development are implemented in a phased approach, the designer must ensure the latter phases have not been subsequently modified or amended in a manner resulting in an increase in the amount of phosphorus leaving each point of discharge, and such that there is no increase in the volume or rate of runoff.

Phases for which construction is delayed for an extended period of time, such as beyond the current Construction General Permit cycle, portions of the project not under construction may become subject to any new technical criteria adopted by the board.

# A.8 Engineering Calculations

## A.8.1 Estimating Storage Volume for Detention Basins

Stormwater management facilities are designed using a trial and error process. The designer does many iterative routings to select a minimum facility size with the proper outlet controls. Each iterative routing requires that the facility size (stage-storage relationship) and the outlet configuration (stage-discharge relationship) be evaluated for performance against the watershed requirements. A graphical evaluation of the inflow hydrograph versus an approximation of the outflow rating curve provides the designer with an estimate of the required storage volume. Starting with this assumed required volume, the number of iterations is reduced.

The graphical hydrograph analysis requires that the evaluation of the watershed's hydrology produce a runoff hydrograph for the appropriate design storms. The Virginia Erosion and Stormwater Management Regulation allows the use of NRCS methods or the modified rational method (critical storm duration approach) for analysis. Many techniques are available to generate the resulting runoff hydrographs based on the methods. It is the designer's responsibility to be familiar with the limitations and assumptions of the methods as they apply to generating hydrographs.

### A.8.1.1 TR-55 Storage Volume Estimation Method

Shortcut procedures are sometimes used to allow the engineer to approximate storage volume requirements as a first approach. Final design should be refined using a more accurate hydrograph routing procedure. It should be noted that the TR-55 tabular hydrograph method does not produce a full hydrograph, it generates only the portion of the hydrograph that contains the peak discharge and some of the time steps just before and just after the peak. The missing values must be extrapolated, thus potentially reducing the accuracy of the hydrograph analysis. Where NRCS methods are used, a full hydrograph should be generated using one of the available computer programs. The accuracy of the analysis can only be as accurate as the hydrograph used.

Chapter 6 of TR-55 discusses ways to control peak discharges by delaying runoff through detention or attenuation. It also includes a simplified procedure for estimating the storage volume required to maintain peak discharges to a specified level.

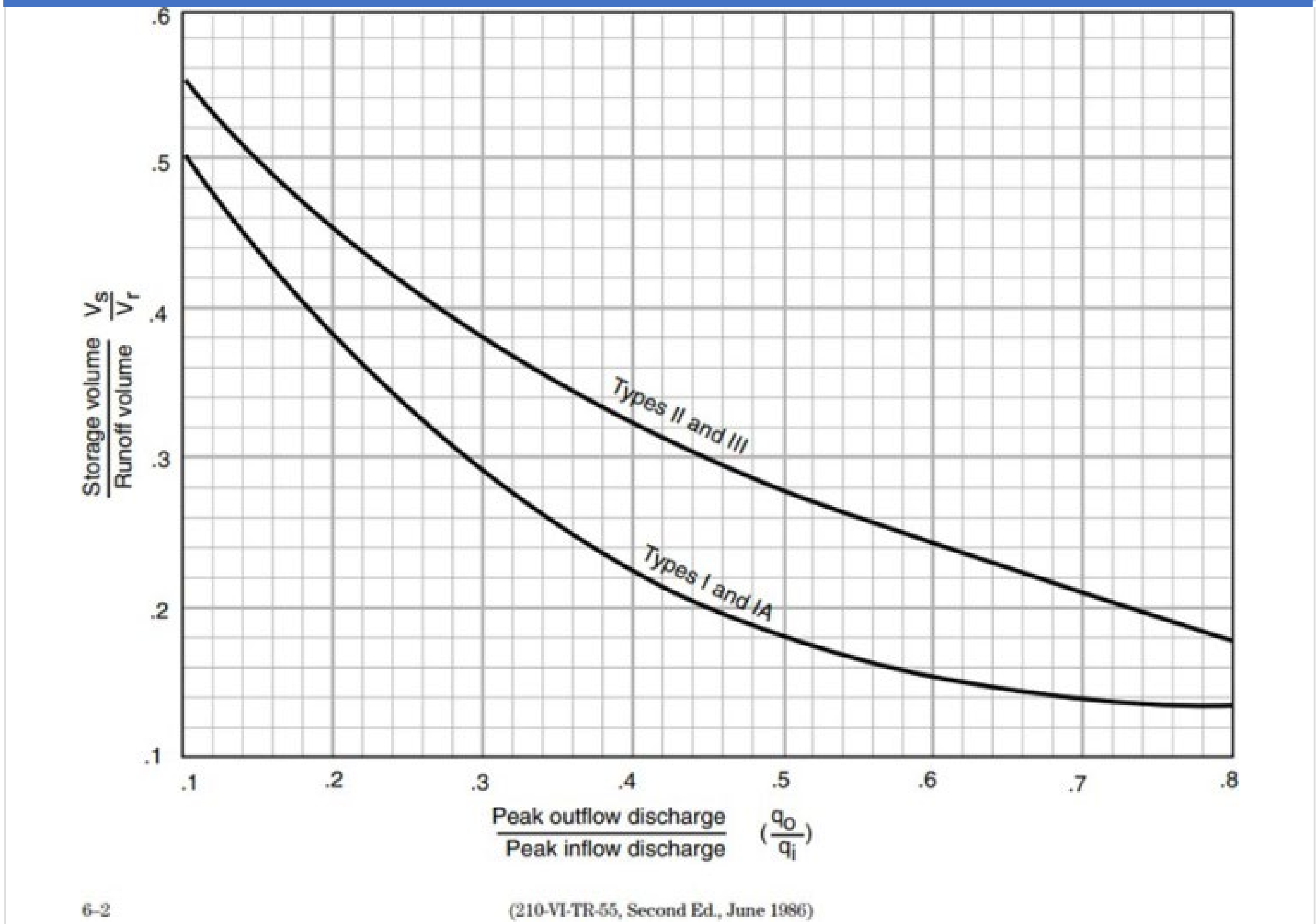
While stormwater site design and runoff reduction practices will significantly move a design toward water quantity compliance in addition to water quality compliance, detention is still a popular measure for controlling peak discharges. It is generally less expensive and reliable but may not always be the most practical volume control measure, especially when the discharge must meet energy balance for channel protection compliance.

Detention facilities can be designed to fit a variety of sites and accommodate spillways to meet requirements for control of outflow for multiple events. Chapter 6 of TR-55 contains a manual method for estimates of the effects of detention on peak discharge. The method is based on average storage and routing and is suitable for estimating required storage for preliminary design or plan review, but it is not a suitable method for final design of a detention basin.

Figure 6-1 (reproduced here of TR-55 relates two ratios: peak outflow to peak inflow discharge (qo/qi) and storage volume runoff volume ($V_s/V_r$) for all rainfall distributions (see Figure A-19). The relationships in Figure 6-1 were determined on the basis of single stage outflow devices. Some were controlled by pipe flow, others by weir flow.

Verification runs were made using multiple stage outflow devices, and the variance was similar to that in the base data. The method can therefore be used for both single- and multiple-stage outflow devices. The only constraints are that each stage requires a design storm and a computation of the storage required for that design storm, and that the discharge of the upper stages includes the discharge of the lower stages.

**Figure A-19 Approximate Detention Basin Routing for Rainfall Types I, IA, II and III**




Required storage volume may also be a calculated using the following equation:

$V_S/V_r = 0.682 - 1.43\,(q_O/q_I) + 1.64\,(q_O/q_I)^2 - 0.804\,(q_O/q_I)^3$

where:

$V_S$ = required storage volume, acre-feet

$V_r$ = runoff volume, acre-feet

$q_O$ = peak outflow discharge, cfs

$q_I$ = peak inflow discharge, cfs

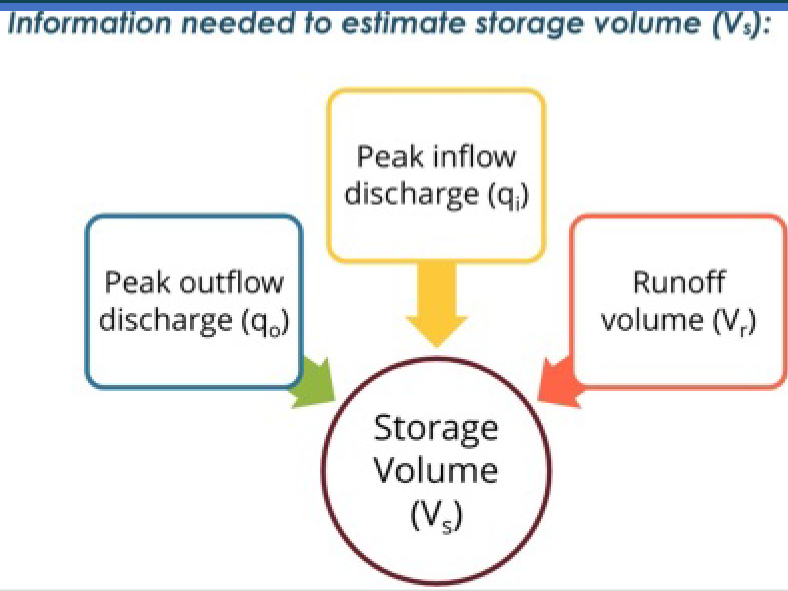
The brevity of the procedure allows a designer to examine many combinations of detention basins. When combined with the Tabular Hydrograph method, the procedure's usefulness is increased. Its principal use is to develop preliminary indications of storage adequacy and to allocate control to a group of detention basins.

## A.8.1.2 Limitations of TR-55 Storage Volume Estimation Method

1. This routing method is less accurate as the qo/qi ratio approaches the limits shown in Figure A-19. The curves in Figure A-19 depend on the relationship between available storage, outflow device, inflow volume, and shape of the inflow hydrograph.
2. When storage volume (Vs) required is small, the shape of the outflow hydrograph is sensitive to the rate of the inflow hydrograph.

3. Conversely, when Vs is large, the inflow hydrograph shape has little effect on the outflow hydrograph. In such instances, the outflow hydrograph is controlled by the hydraulics of the outflow device and the procedure yields consistent results.
4. When the peak outflow discharge (qo) approaches the peak flow discharge (qi), parameters that affect the rate of rise of a hydrograph, such as rainfall volume, CN, and Tc, become especially significant.
5. The procedure should not be used to perform final design if an error in storage of 25 percent cannot be tolerated. Figure A-19 is biased to prevent under sizing of outflow devices, but it may significantly overestimate the required storage capacity.

**Figure A-20 Information Needed to Estimate Storage Volume**




Use Figure A-19 (Figure 6-1 of TR-55) to estimate: (1) the storage volume (Vs) required to detain to an allowable peak outflow; or (2) the peak outflow discharge (qo) for a given storage volume provided.

**Table A-20 TR-55 Storage Volume Estimation Parameters 1**

| $V_s$ | $q_o$ estimate for a given storage volume |
|---|---|
| runoff volume ($V_r$) | runoff volume ($V_r$) |
| allowable peak outflow discharge ($q_o$)) | estimate storage volume ($V_s$) |
| peak inflow discharge ($q_i$) | peak inflow discharge ($q_i$) |

## A.8.1.3 TR-55 Storage Volume Estimation Method Design Procedure

1. Determine $q_o$. Many factors may dictate the selection of allowable peak outflow discharge. The most common is to limit downstream discharges to a desired level, such as pre-development discharge or as required by the energy balance method.
2. Estimate $q_i$ by procedures above (Chapters 4 or 5 of TR-55). Do not use peak discharges developed by other procedure. When using the Tabular Hydrograph method to estimate qi for a subarea, only use peak discharge associated with Tt = 0.
3. Compute ($q_o/q_i$) and determine value for ($V_s/V_r$) from Figure A-19:

Step 1: Start on the x-axis at value for (qo/qi) and draw a vertical (Line 1) perpendicular to the x-axis until the line intersects the curve for the appropriate storm distribution type (Types II or III for Virginia).

Step 2: At the intersection of Line 1 and the curve, draw a horizontal (Line 2) parallel to the x-axis until you intersect the y-axis. The value where Line 2 intersects the y-axis is ($V_s/V_r$).

4. Q (in inches) was determined when computing qi in step 2, but now it must be converted to the units in which Vs is to be expressed—most likely, acre-feet or cubic feet.
5. Use the results of steps 3 and 4 to compute Vs:

*Equation A-28 TR-55 Storage Volume Estimation*

$$V_s = V_r \times \left(\frac{V_s}{V_r}\right)$$

Where:

$V_r$ = runoff volume (acre-ftee).

$V_s$ = storage volume required (acre-feet).

($V_s/V_r$) from Figure A-19.

6. The stage in the detention basin corresponding to Vs must be equal to the stage used to generate $q_o$. In most situations a minor modification of the outflow device can be made. If the device has been preselected. Repeat the calculations with a modified $q_o$ value.

Worksheet 6a from TR-55 is useful for documenting inputs and results of estimating storage volume required, $V_s$.

To estimate peak outflow ($q_o$) for a given storage volume, use the following procedure:

1. Determine Vs. If the maximum stage in the detention basin is constrained, set $V_s$ by the maximum permissible stage.
2. Compute Q (in inches) by the procedures above from Chapter 2 of TR-55, and convert to the same units as Vs (see step 4 in "estimating $V_s$").
3. Compute ($V_s/V_r$) and determine the value ($q_o/q_i$) from Figure A-19:
   a. Step 1: Start on the y-axis at value for ($V_s/V_r$) and draw a horizontal (Line 1) perpendicular to the y-axis until the line intersects the curve for the appropriate storm distribution type (Types II or III for Virginia).
   b. Step 2: At the intersection of Line 1 and the curve, draw a vertical (Line 2) parallel to the y-axis until you intersect the x-axis. The value where Line 2 intersects the x-axis is ($q_o/q_i$).
4. Estimate qi by the procedures presented previously from Chapters 4 or 5 of TR-55. Do not use discharges developed by any other method. When using Tabular method to estimate qi for a subarea, use only the peak discharge associated with $T_t$ = 0.
5. From steps 3 to 4, compute $q_o$:

*Equation A-29 TR-55 Peak Outflow Volume Estimation*

$$q_o = q_i \times \left(\frac{q_o}{q_i}\right)$$ (Source: TR-55, Eq. 6-3)

Where:

$q_o$ = peak outflow (cfs).

$q_i$ = peak inflow (cfs).

($q_o/q_i$) from Figure A-19.

6. Proportion the outflow device so that the stage at qo is equal to the stage corresponding to Vs. If $q_o$ cannot be calibrated except in discrete steps (i.e., pipe sizes), repeat the procedure until the stages for $q_o$ and $V_s$ are approximately equal.

Worksheet 6b from TR-55 is useful for documenting inputs and results of estimating peak outflow ($q_o$) for a given storage volume.

**REMEMBER: Typical error is ±25%. Procedure should be limited to ESTIMATION and not used for final design.**

By using one of the methods in the previous section for determining the storage volume requirements, the engineer now has sufficient information to place and grade the proposed stormwater facility. Remember, this is a preliminary sizing which needs to be refined during the actual design. By trial and error, the approximate required volume can be achieved by designing the basin to fit the site geometry and topography.

## A.8.2 Hydrograph Routing Computations

Routing is a technique used to predict the changes in the shape of a hydrograph as runoff moves through a stormwater system (stormwater conveyance system, stormwater management facility, reservoir).

The goal of using a routing procedure in stormwater management is to design the facility and/or structures that will produce the desired outflow hydrograph (meets compliance and/or storage requirements) given the drainage area runoff contribution to the facility (the inflow hydrograph). Designers will plan a stormwater management facility and/or outlet structures based on how much runoff must be stored, how much storage is available, and the allowable or required discharge.

Given the complexity of the relationship between storage, flow hydraulics, and discharge, various routing procedures use a step by step process to predict the outflow hydrograph for a specific facility and outlet structure. The most common routing procedure is referred to as the storage indication method and briefly described here.

Two main factors control the effect of the stormwater system on the routed storm hydrograph.

- The area of the reservoir, which controls the volume of storage for a given elevation (see Stage-Storage Curves in this section),
- The flow dynamics (release rate) for a given elevation. The second important data item needed for reservoir routing is a relation of elevation or state with discharge through the principal spillway, auxiliary spillway, and over the top of the dam if overtopping is anticipated during the routing (See Multi-Stage Riser Design in this section).

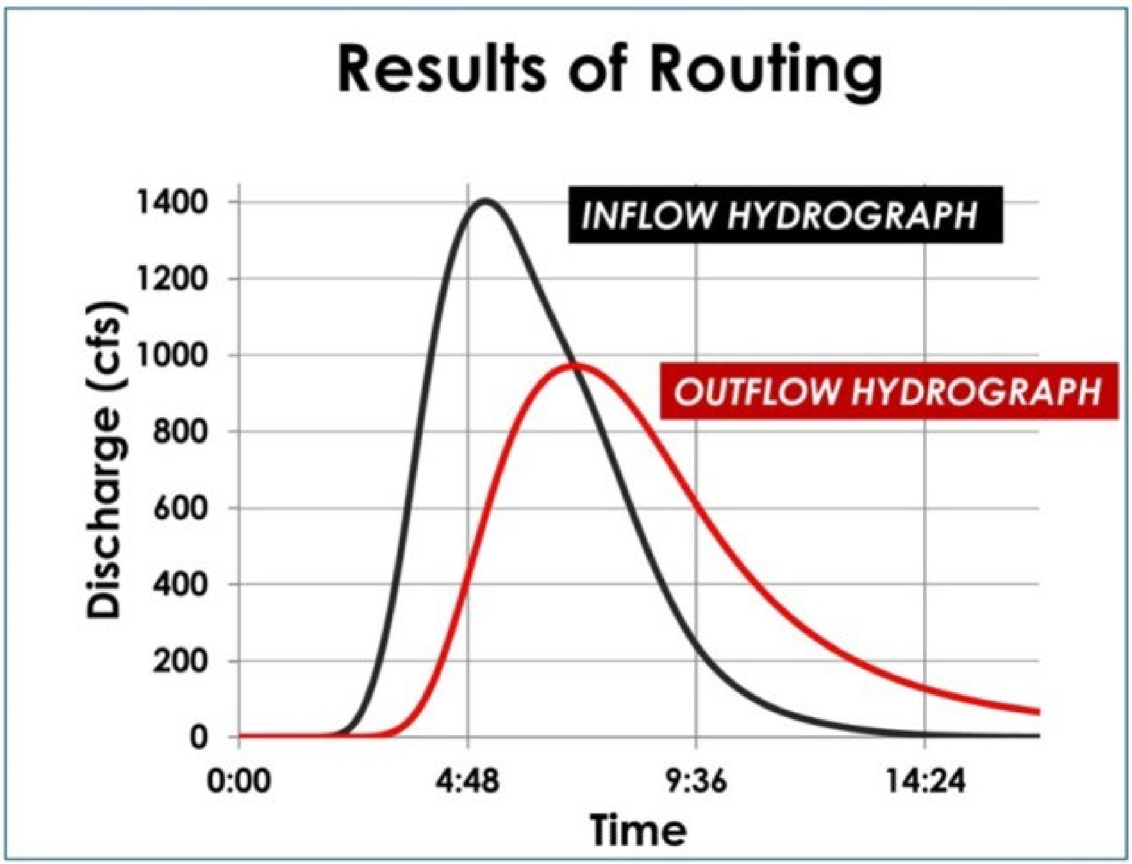
Both factors together are used to estimate the relationship between storage (represented by the elevation of the water surface above the bottom of the outlet) and the rate of outflow. For example, if a reservoir with relatively little attenuation (reduction in release rate) is desired, a broad, low weir on the outlet would be used. If greater peak flow control is desired and only a small area is available for facility placement, a high, narrow outlet would be designed which would force the water to accumulate to a high level in the reservoir in order to pass flood discharges.

<u>Storage Indication Method Procedure</u>

1. Generate an inflow hydrograph by appropriate means.
2. Determine stage-storage relationship for the facility .
3. Determine stage-discharge relationships for the facility and outlet device(s) selected.
4. Relate facility discharge to change in time (outflow hydrograph)
    a. Involves a series of computations where hydrograph timing is being related to stage-storage-discharge relationship via the routing continuity equation.
    b. Routing continuity equation: Inflow minus outflow equals change in storage over time.

Routing results - The outflow hydrograph represents a facility's discharge through time resulting from passage of the inflow hydrograph. A facility's outflow hydrograph should ultimately demonstrate compliance with regulatory requirements (presented for each discharge point from the proposed site).

***Figure A-20 Routing Results Example***

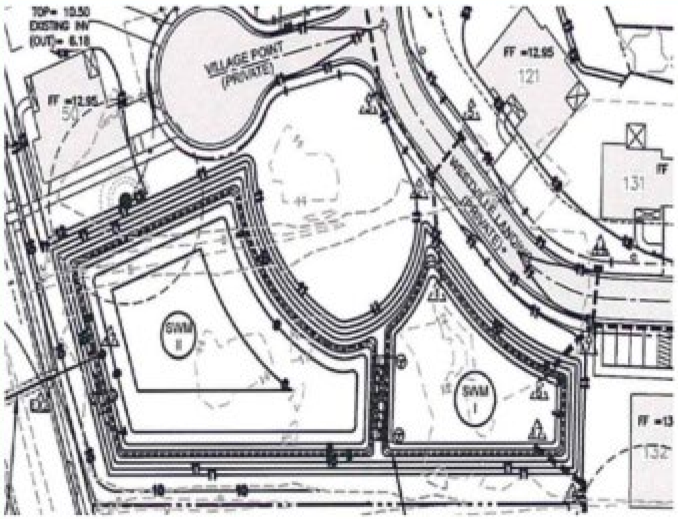



## A.8.3 Stage-Storage Curves

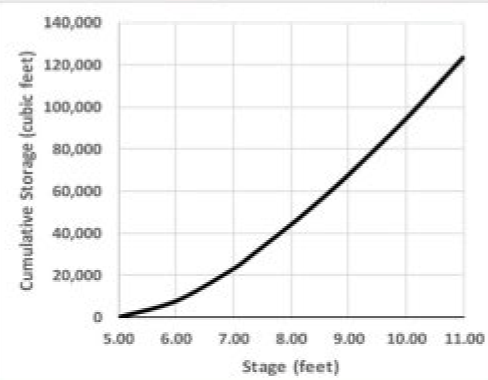
The stage storage relationship relates inflow to storage. Storage is represented in incremental elevations from the starting elevation.

A stage-storage curve defines the relationship between the depth of water and storage volume in a storage facility (see Figure A-22). Specifically, the stage-storage curve represents the volume provided (storage) at each contour elevation (stage). The volume of storage can be calculated by using simple geometric formulas expressed as a function of depth.

***Figure A-22 Stage-Storage Example***




| Elevation (feet) | Surface Area (sq-ft) | Inc. Store (cubic-feet) | Cum. Store (cubic-feet) |
|---|---|---|---|
| 5.00 | 4,534 | 0 | 0 |
| 6.00 | 11,081 | 7,808 | 7,808 |
| 7.00 | 19,742 | 15,412 | 23,220 |
| 7.25 | 20,372 | 5,014 | 28,234 |
| 8.00 | 22,357 | 16,023 | 44,257 |
| 8.50 | 23,723 | 11,520 | 55,777 |
| 9.00 | 25,128 | 12,213 | 67,990 |
| 10.00 | 28,042 | 26,585 | 94,575 |
| 11.00 | 30,685 | 29,364 | 123,939 |




For retention/detention basins with vertical sides, such as tanks and vaults, the storage volume is simply the bottom surface area times the height. For basins with graded (2H:1V, 3H:1V, etc.) side slopes or an irregular shape, the stored volume can be computed by the following procedure: (Note that other methods for computing basin volumes are available, such as the Conic Method for Reservoir Volumes, but they are not presented here.)

Procedure:

1. Measure the area enclosed by each contour The invert of the lowest control orifice represents zero storage. This will correspond to the bottom of the facility for dry extended-detention facilities, or the permanent pool elevation for wet ponds.
2. Calculate the average area between each contour.

   The average area between two contours is computed by adding the area of the first elevation, to the area of the second elevation, and then dividing their sum by 2.

   From Figure A-22:

| | |
|---|---|
| Average area, elevation 5-6: | $\frac{4{,}534+11{,}081}{2} = 7{,}808\ ft^2$ |
| Average area, elevation 6-7: | $\frac{11{,}081+19{,}742}{2} = 15{,}412\ ft^2$ |
| Average area, elevation 7-8: | $\frac{19{,}742+20{,}372}{2} = 20{,}057\ ft^2$ |

   This procedure is repeated to calculate the average area found between any two consecutive contours.

3. Calculate the volume between each contour by multiplying the average area from step 2 by the contour interval.

   Contour interval between 5 and 6 = 1 foot x 7,808 square feet = 7,808 cubic feet

   Contour interval between 6 and 7 = 1 ft. x 15,412 square feet = 15,412 cubic feet

   This procedure is repeated for each measured contour interval.

4. Sum the volume for each contour interval:

   Contour 5, Volume = 0

   Contour 6, Volume = 0 + 7,808 = 7,808 cubic feet

   Contour 7, Volume = 7,808 + 15,412 = 23,220 cubic feet

   This procedure is then repeated for each measured contour interval.

5. Plot the stage-storage curve with stage on the y-axis versus storage on the x-axis. Figure A-22 represents the stage-storage curve for the Stage Storage Example in units of feet (stage) versus cubic-feet (storage).

The stage-storage curve allows the designer to estimate the design high water elevation for each of the design storms if the required storage volume has been determined. This allows for a preliminary design of the riser orifice sizes and their configuration.

## A.8.4 Multi-Stage Riser Design

A principal spillway system that controls the rate of discharge from a stormwater facility will often use a multi-stage riser for the drop inlet structure.

A multi-stage riser is a structure that incorporates separate openings or devices at different elevations to control the rate of discharge from a stormwater basin during multiple design storms. Permanent multi-stage risers are typically constructed of concrete to help increase their life expectancy; they can be precast or cast-in-place. The geometry of risers will vary from basin to basin. The engineer can be creative to provide the most economical and hydraulically efficient riser design possible. Figure 3.02 in Chapter 3 provides some examples of multi-stage riser structures.

In a stormwater management basin design, the multi-stage riser is of utmost importance since it controls the design water surface elevations. In designing the multi-stage riser, many iterative routings are usually required to arrive at a minimum structure size and storage volume that provides proper control. Each iterative routing requires that the facility's size (stage-storage curve) and outlet shape (stage-discharge table or rating curve) be designed and tested for performance. Prior to final design, it is helpful to approximate the required storage volume and outlet shape using one of the "shortcut" methods. In doing this, the number of iterations may be reduced. The following procedures outline methods for approximating and then completing the design of a riser structure. (These design procedures are illustrated in the examples found in Chapter 6).

### A.8.4.1 Information Needed

1. The hydrology for the watershed or drainage area to be controlled, calculated by using one of the methods outlined in this Appendix, and
2. The allowable release rates for the facility, as established by ordinance or downstream conditions.

The design procedure provided here will incorporate the traditional 1-year and 10-year design storms and the pre-developed hydrology will establish the allowable discharge rates of the developed watershed. It should be noted that any design storm, 2-year, 5-year, etc., can be substituted into this design procedure, as required.

## A.8.4.2 Procedure

### Step 1 Determine Water Quality or Extended Detention Requirements

Calculate the water quality volume and decide what method (extended-detention or retention) will be used to treat it, and/or calculate the channel protection and flood protection control volumes for extended-detention, if required.

Refer to Chapter 8 for minimum BMP design standards and details.

### Step 2 Compute Allowable Release Rates

Compute the pre- and post-developed hydrology for the watershed. Sometimes, the pre-developed hydrology will establish the allowable release rate from the basin. Other times, the release rate will be established by downstream conditions. In either case, the post-developed hydrology will provide the peak inflow into the basin, as a peak rate (cfs) or a runoff hydrograph.

### Step 3 Estimate the Required Storage Volume

Estimate the storage volume required using one of the “shortcut” volume estimate methods. The information required includes the developed condition peak rate of runoff, or runoff hydrograph, and the allowable release rates for each of the appropriate design storms.

### Step 4 Grade the Basin; Create Stage-Storage Curve

After considering the site geometry and topography, select a location for the proposed stormwater management basin. By trial and error, size the basin such that it will hold the approximate required storage volume. Ensure that the storage volume is measured from the lowest stage outlet. Remember that this is a preliminary sizing which needs to be fine-tuned during the final design.

### Step 5a Design Water Quality Orifice (Extended-Detention)

A water quality BMP can utilize extended detention to treat the water quality volume by detaining it and releasing it over a specified amount of time. In theory, extended-detention of the water quality volume will allow the particulate pollutants to settle out of the first flush of runoff, functioning similarly to a permanent pool. The Design Specifications for Post-Construction Stormwater BMPs found in Chapter 8 of this handbook generally a 24-hour draw down time for the water quality volume. This is a brim draw down time, beginning at the time of peak storage of the water quality volume. Brim-draw down time means the time required for the entire calculated volume to drain out of the basin. This assumes that the brim volume is present in the basin prior to any discharge. In reality, however, water is flowing out of the basin prior to the full or brim volume being reached. Therefore, the extended detention orifice can be sized using either of the following methods:

1. Use the maximum hydraulic head associated with the water quality volume (WQv and calculate the orifice size needed to achieve the required draw down time, and route the water quality volume through the basin to verify the actual storage volume used and the drawdown time.

2. Approximate the orifice size using the average hydraulic head associated with the water quality volume (WQv) and the required draw down time.

The two methods for calculating the required size of the extended detention orifice allow for a quick and conservative design (Method 2 above) and a similarly quick estimation with a routing to verify the performance of the design (Method 1).

Method 1, which uses the maximum hydraulic head and maximum discharge in the calculation, results in a slightly larger orifice than the same procedure using the average hydraulic head (Method 2). The routing allows the designer to verify the performance of the calculated orifice size. As a result of the routing effect however, the actual basin storage volume used to achieve the draw down time will be less than the computed brim draw down volume. It should be noted that the routing of the extended detention of the runoff from storms larger than the water quality storm (such as the 1-year frequency storm for channel protection) will result in proportionately larger reduction in the actual storage volume needed to achieve the required extended detention. (Refer to Step 6 of this Section for channel protection.)

The procedure used to size an extended detention orifice includes the first steps of the design of a multi-stage riser for a basin controlling water quality and/or channel erosion, and peak discharge. These steps are repeated for sizing the 1-year and 10-year release openings. Other design storms may be used as required by ordinance or downstream conditions.

**METHOD 1: Water quality orifice design using maximum hydraulic head and routing of the water quality volume.**

A water quality extended-detention basin sized for the treatment volume will be used here to illustrate the sizing procedure for an extended-detention orifice.

Procedure:

1. Calculate the treatment volume required.

   Example 1:

   Tv = 0.76 acre-feet= 33,106 cubic feet.

2. Determine the maximum hydraulic head, hmax, corresponding to the required water quality volume.

   From the Example 1 stage vs. storage curve:

   0.76 acre-feet occurs at elevation 88 feet (approximate). Therefore, hmax = 88 – 81 = 7.0 feet.

3. Determine the maximum discharge, Qmax, resulting from the 24-hour drawdown requirement.

   The maximum discharge is calculated by dividing the required volume, in cubic feet, by the required time, in seconds, to find the average discharge, and then multiplying by 2, to determine the maximum discharge.

   From Example 1:

*Equation A-30 Discharge Rate for Water Quality Volume Drawdown*

$$Q_{avg} = \frac{33{,}106\ ft^3}{(24\ hr.)\,(3{,}600\ sec./hr.)} = 0.38\ cfs$$

$$Qmax = 2 \times 0.38\ cfs = 0.76\ cfs$$

4. Determine the required orifice diameter by rearranging the Orifice Equation to solve for the orifice area, in square feet, and then diameter, in feet. Insert the values for Qmax and hmax into the Rearranged Orifice Equation to solve for the orifice area, and then solve for the orifice diameter.

| *Equation A-31 Orifice Equation* | *Equation A-32 Rearranged Orifice Equation* |
|---|---|
| $Q = Ca\sqrt{2gh}$ | $a = \dfrac{Q}{C\sqrt{2gh}}$ |

where:
$Q$ = *discharge, cfs*
$C$ = *dimensionless coefficient* = 0.6
$a$ = *area of the orifice,* $ft^2$
$g$ = *gravitational acceleration, 32.2* $ft/sec^2$
$h$ = *head, ft.*

From Example 1:

*For orifice area:*

$$a = \frac{0.6}{0.6\sqrt{(2)(32.2)(7.0)}}$$

*For orifice diameter:*

$$a = 0.047\ ft^2 = \pi r^2 = \pi d^2/4$$

$$d = \sqrt{\frac{4a}{\pi}} = \sqrt{\frac{4(0.047\ ft^2)}{\pi}}$$

$d$ = *orifice diameter* = 0.245 *ft* = 2.94"

***Use a 3-inch diameter water quality orifice.***

Routing the water quality volume (WQv) of 0.76 acre-feet, occurring at elevation 88 feet, through a 3-inch water quality orifice will allow the designer to verify the draw down time, as well as the maximum elevation of 88 feet.

Route the water quality volume.

This calculation will give the engineer the inflow-storage-outflow relationship in order to verify the actual storage volume needed for the extended detention of the water quality volume. The routing procedure takes into account the discharge that occurs before maximum or brim storage of the water quality volume, as opposed to the brim drawdown described in Method 2. The routing procedure is simply a more accurate analysis of the storage volume used while water is flowing into and out of the basin. Therefore, the actual volume of the basin used will be less than the volume as defined by the Regulation.

The routing of water entering and discharging from the basin simultaneously will also result in the actual drawdown time being less than the calculated 24 hours. Judgement should be used to determine whether the orifice size should be reduced to achieve the required 24 hours or if the actual time achieved will provide adequate pollutant removal.

Continuing with Example 1, the procedure is as follows:

5. Calculate a stage-discharge relationship using the Orifice Equation and the orifice size determined in Step 4.

From Example 1, using the 3-inch diameter orifice, the calculation is as follows:

Equation A-33 Orifice Equation

$$Q = Ca\sqrt{2gh}$$

Where:

h = water surface elevation minus the orifice's centerline elevation*, in feet.

*Note: If the orifice size is small relative to the anticipated head, h, then values of h may be defined as the water surface elevation minus the invert of the orifice elevation.

6. Complete a stage-discharge table for the range of elevations in the basin, as shown in Table A-24 5-7:

**Table A-24 Stage-Discharge Table: Water Quality Orifice Design**

| Elevation | h (feet) | Q (cfs) |
|---|---|---|
| 81 | 0 | 0.0 |
| 82 | 1 | 0.2 |
| 83 | 2 | 0.3 |
| 84 | 3 | 0.4 |
| 85 | 4 | 0.4 |
| 86 | 5 | 0.5 |
| 87 | 6 | 0.5 |
| 88 | 7 | 0.6 |

7. Determine the time of concentration for the basin drainage area.

   From Example 1, the developed time of concentration, $t_c$ = 0.46 hours. The drainage area time of concentration, $t_c$= 0.09 hours, or 5.4 minutes.

8. Using $t_c$, the stage-discharge relationship, the stage-storage relationship, and the drainage area acreage (RCN = 98), route the water quality storm through the basin.

   The water quality volume may be routed using a variety of computer programs such as TR-20, HEC-1, or other storage indication routing programs. Alternatively, it can be routed by hand using the storage indication routing procedure.

9. Evaluate the discharge hydrograph to verify that the drawdown time from maximum storage to zero discharge is at least 30 hours. (Note that the maximum storage corresponds to the maximum rate of discharge on the discharge hydrograph.)

   The routing of the water quality volume using TR-20 results in a maximum storage elevation is 85.69 feet. Versus the approximated 88.0 feet. The brim drawdown time is 17.5 hours (peak discharge occurs at 12.5 hours and 0.01 discharge occurs at 30 hours). For this example, the orifice size may be reduced to provide a more reasonable drawdown time and another routing performed to find the new water quality volume elevation.

**METHOD 2: Water quality orifice design using average hydraulic head and average discharge.**

The procedure described in Method 2 is presented in this section. For the previous example, Method 2 results in a 2.5-inch orifice (versus a 3.0-inch orifice), and the design extended detention water surface elevation is set at 88 feet (versus 85.69 feet). (It should be noted that trial two of Method 1 as noted above may result in a design water surface elevation closer to 88 feet.) If the basin is to control additional storms, such as the 1-year and/or 10-year storms, the additional storage volume would be “stacked” just above the water quality volume. The invert for the 1-year control, for example, would be set at 88.1 feet.

Procedure:

1. Calculate the water quality volume required for treatment.

   *Example 2:*

   WQv = 0.76 acre-feet= 33,106 cubic feet.

2. Determine the average hydraulic head, $h_{avg}$, corresponding to the required channel erosion control volume.

   From Example 2 – Stage – Storage Curve: 1.0 acre-feet occurs at elevation 89.0 feet. Therefore,

   $h_{avg}$ = (89 – 81) / 2 = 4.0 feet.

3. Determine the average discharge, $Q_{avg}$, resulting from the 24-hour draw down requirement.

   The average discharge is calculated by dividing the required volume, in cubic feet, by the required time, in seconds, to find the average discharge.

   From Example 2:

$$Q_{avg} = \frac{43{,}560\ ft^3}{(24\,hr.)(3{,}600\,sec./hr.)} = 0.5\ cfs$$

4. Determine the required orifice diameter by rearranging the Orifice Equation to solve for the orifice area, in square feet, and then diameter, in feet.

   Insert the values for Qavg and havg into the Rearranged Orifice Equation to solve for the orifice area, and then solve for the orifice diameter.

| *Equation A-34 Orifice Equation* | *Equation A-35 Rearranged Orifice Equation* |
| --- | --- |
| $Q = Ca\sqrt{2gh}$ | $a = \frac{Q}{C\sqrt{2gh}}$ |
| where: $Q$ = *discharge, cfs*<br>$C$ = *dimensionless coefficient = 0.6*<br>$a$ = *area of the orifice, ft²*<br>$g$ = *gravitational acceleration, 32.2 ft/sec²*<br>$h$ = *head, ft.* | |

From Example 2:

*Equation A-36 Orifice Sizing*

*For orifice area:*

$$a = \frac{0.5}{0.6\sqrt{(2)(32.2)(4.0)}}$$

$$a = 0.052\ ft^2 = \pi r^2 = \pi d^2/4$$

*For orifice diameter:*

$$d = \sqrt{\frac{4a}{\pi}} = \sqrt{\frac{4(0.052\ ft^2)}{\pi}}$$

*d = orifice diameter = 0.257 ft = 3.09 inches*

***Use 3.0-inch diameter channel erosion extended detention orifice***

The use of Method 1, utilizing the maximum hydraulic head and a routing of the 1-year storm is illustrated in Chapter 6: Example 6.2. Method 1 results in a 3.7-inch-diameter orifice and a routed water surface elevation of 88.69 feet. Additional storms to may be “stacked” just above this volume if additional controls are desired.

### Step 5b Set Permanent Pool Volume (Retention)

In a wet pond, the permanent pool volume, from STEP 1, establishes the lowest stage outlet for the riser structure (not including a pond drain, if provided). The permanent pool elevation, therefore, corresponds to “0” storage for the design of the “dry” storage volume stacked on top of the permanent pool.

### Step 6 Size 1-Year Control Orifice

(The 1-year storm is used here to show the design procedure. Other design storms or release requirements can be substituted into the procedure.)

Knowing the 1-year storm storage requirement, from design STEP 3, and the water quality volume, from design STEP 1, the engineer can do a preliminary design for the 1-year release opening in the multi-stage riser. To complete the design, some iterations may be required to meet the allowable release rate performance criteria.

This procedure is very similar to the water quality orifice sizing calculations:

1. Approximate the 1-year maximum head, $h_{2max}$.

   Establish the approximate elevation of the 1-year maximum water surface elevation using the stage-storage curve and the preliminary sizing calculations. Subtract the water quality volume elevation from the approximate 1-year maximum water surface elevation to find the 1-year maximum head, $h_{2max}$. If there are no water quality requirements, use the elevation of the basin bottom or invert.

2. Determine the maximum allowable 1-year discharge rate, Q1allowable, from STEP 2.
3. Calculate the size of the 1-year control release orifice using the Rearranged Orifice Equation, Equation A-36 and solve for the area, a, in square feet.

Note the minimum size for low flow orifices should be 3 inches in diameter or greater. When the calculations indicate a smaller orifice is required to achieve the desired discharge rate additional consideration is required to prevent clogging. Refer to Design Specifications P-SUP-02 Principal Spillway for more details.

The engineer may choose to use any one of a variety of orifice shapes or geometries. Regardless of the selection, the orifice will initially act as a weir until the top of the orifice is submerged. Therefore, the discharges for the first stages of flow are calculated using the weir equation:

*Equation A-37 Weir Evaluation*

$$Q_w = C_w L h^{1.5}$$

Where:

$Q_w$ = weir flow discharge, cfs.

$C_w$ = dimensionless weir flow coefficient, typically equal to 3.1 for sharp crested weirs. Refer to Table A-25.

L = length of weir crest, feet.

H = head, feet., measured from the water surface elevation to the crest of the weir

Flow through the rectangular opening will transition from weir flow to orifice flow once the water surface has risen above the top of the opening. This orifice flow is expressed by the orifice equation. The area, a, of a rectangular orifice is written as a = L x H.

Where:

L = length of opening, feet.

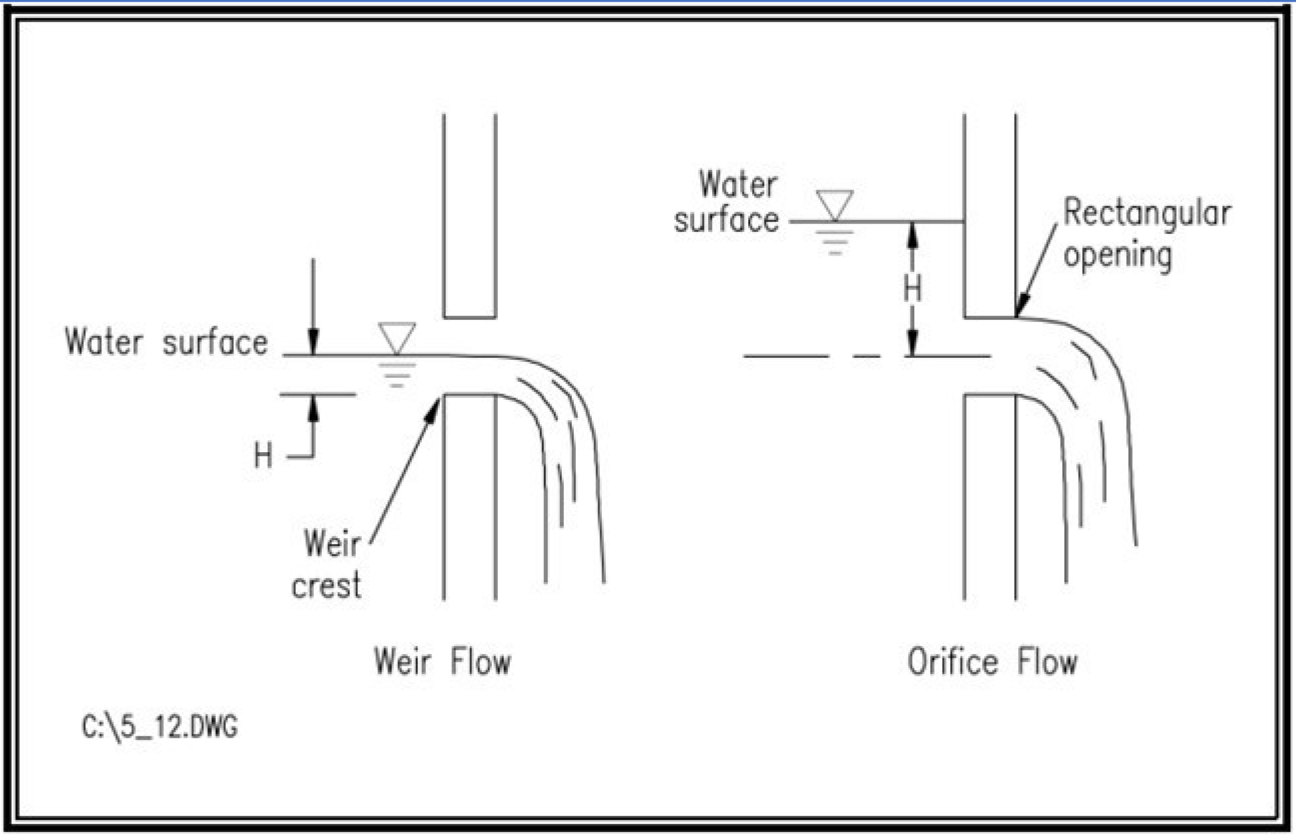
H = height of opening, feet.

Figure A-25 shows a rectangular orifice acting as a weir at the lower stages and as an orifice after the water surface rises to height H, the height of the opening.

4. Develop the stage-storage-discharge relationship for the 1-year storm.

   Calculate the discharge using the orifice equation and, if a rectangular opening is used, the weir equation as needed for each elevation specified on the stage-storage curve. Record the discharge on a Stage-Storage-Discharge Worksheet. Figure A-26 shows a completed Stage-Storage-Discharge Worksheet for Example 2.

**Figure A-25 Weir and Orifice Flow**




### Step 7 Check Performance of 1-Year Opening

(Note: This step may not be necessary if the design is to be completed using one of the shortcut routing procedures where the water surface elevations are established by the required storage volume and not by an actual routing.)

1. Check the performance of the 1-year control opening by a) reservoir routing the 1-year storm through the basin using an acceptable reservoir routing computer program or by b) doing the long hand calculations. Verify that the 1-year release rate is less than or equal to the allowable release rate. If not, reduce the size of the opening or provide additional storage and repeat STEP 6.

This procedure presents just one of many riser configurations. The engineer may choose to use any type of opening geometry for controlling the design storms and, with experience, may come to recognize the most efficient way to configure the riser. Note that if a weir is chosen for the 1-year storm control, the procedures outlined here for the 10-year storm may be used by substituting with the appropriate values for the 1-year storm. Refer to Design Specification P-SUP-02 for several different riser shapes.

### Step 8 Size 10-Year Control Opening

The design of the 10-year storm control opening is similar to the procedure used in sizing the 1-year control opening:

1. From the routing results, identify the exact 1-year water surface elevation.

2. Set the invert of the 10-year control just above the 1-year design water surface elevation and determine the corresponding storage volume from the stage-storage curve. Add this elevation, storage, and 1-year discharge to the stage-storage-discharge worksheet, Figure A-26.

   The 10-year control invert may be set at a small distance, such as 0.1 foot minimum, above the 1-year maximum water surface elevation. If the 1-year orifice is also to be used for the 10-year control, the head is measured from the maximum water surface elevation to the centerline of the 1-year orifice. See Figure A-27.

3. Establish the approximate 10-year maximum water surface elevation using the stage-storage curve and the preliminary sizing calculations. Subtract the invert elevation of the 10-year control (from Step 2 above) from the approximate 10-year maximum water surface elevation to find the 10-year maximum head, $h_{10max}$.
4. Determine the maximum allowable 10-year discharge rate, $Q1_{0allowable}$, from STEP 2.
5. Calculate the required size of the 10-year release opening. The engineer may choose between a circular and rectangular orifice, or a weir. If a weir is chosen, the weir flow equation can be rearranged to solve for L as follows.

| *Equation A-38 Weir Equation* | *Equation A-39 Rearranged Weir Equation* |
|---|---|
| $Q_W = C_W\ L\ h^{1.5}$ | $L = Q_{10allowable} / C_W\ h^{1.5}$ |

Where:

L = length of weir required, feet.

CW = dimensionless weir flow coefficient, see Table A-25.

$Q_{10allowable}$ = 10-year allowable riser weir discharge, cfs.

h = hydraulic head; water surface elevation minus the weir crest elevation.

6. Develop the stage-storage-discharge relationship for the 10-year storm. Calculate the discharge for each elevation specified on the stage-storage curve, and record the discharge on a Stage-Storage-Discharge Worksheet, as shown in Figure A-26.

   Any weir length lost to the trash rack or debris catcher must be accounted for. See Chapter 8 for Trash Rack Specifications and example riser configurations.

**Table A-25 Weir Flow Coefficients, C**

| Measured Head, h (feet) | Breadth of Weir Crest: 0.50 (feet) | Breadth of Weir Crest: 0.75 (feet) | Breadth of Weir Crest: 1.00 (feet) |
|---|---|---|---|
| 0.2 | 2.80 | 2.75 | 2.69 |
| 0.4 | 2.92 | 2.80 | 2.72 |
| 0.6 | 3.08 | 2.89 | 2.75 |
| 0.8 | 3.30 | 3.04 | 2.85 |
| 1.0 | 3.32 | 3.14 | 2.98 |
| 1.2 | 3.32 | 3.20 | 3.08 |
| 1.4 | 3.32 | 3.26 | 3.20 |
| 1.6 | 3.32 | 3.29 | 3.28 |

| Table A-25 Weir Flow Coefficients, C | | | |
|---|---|---|---|
| Measured Head, h (feet) | Breadth of Weir Crest: 0.50 (feet) | Breadth of Weir Crest: 0.75 (feet) | Breadth of Weir Crest: 1.00 (feet) |
| 1.8 | 3.32 | 3.32 | 3.31 |
| 2.0 | 3.32 | 3.32 | 3.30 |
| 3.0 | 3.32 | 3.32 | 3.32 |
| 4.0 | 3.32 | 3.32 | 3.32 |
| 5.0 | 3.32 | 3.32 | 3.32 |
| Source: Kings Handbook of Hydraulics | | | |

### Step 9 Check Performance of 10-Year Opening

(Note: This step may not be necessary if the design is to be completed using one of the short-cut routing procedures where the water surface elevations are established by the required storage volume and not by an actual routing.)

Check the performance of the 10-year control opening by a) reservoir routing the 1-year and 10-year storms through the basin using an acceptable reservoir routing computer program or by b) doing the long hand calculations. Verify that the 10-year release rate is less than or equal to the allowable release rate. If not, reduce the size of the opening and/or provide additional storage and repeat STEP 8.

### Step 10 Perform Hydraulic Analysis

At this point, several iterations may be required to calibrate and optimize the hydraulics of the riser and the riser and barrel system. Drop inlet spillways should be designed so that full flow is established in the outlet conduit and riser at the lowest head over the riser crest as is practical. Also, the structure should operate without excessive surging, noise, vibration, or vortex action at any stage. This requires the riser to have a larger cross-sectional area than the outlet conduit.

As the water passes over the rim of the riser, the riser acts as a weir (Figure A-28a); this discharge is described as riser weir flow control. However, when the water surface reaches a certain height over the rim of the riser, the riser will begin to act as a submerged orifice (Figure A-28b); such discharge is called riser orifice flow control. The engineer must compute the elevation at which this transition from riser weir flow control to riser orifice flow control takes place. (This transition usually occurs during high hydraulic head conditions, such as between the 10-yr. and 100-yr. design high water elevations.)

Note in Figure A-28a and b that the riser crest controls the flow, not the barrel. Thus, either condition can be described as riser flow control. Figure A-28c and d illustrates barrel flow control. Barrel flow control occurs when the barrel controls the flow at the upstream entrance to the barrel (barrel inlet flow control, Figure A-28c), or along the barrel length (barrel pipe flow control, Figure A-28d).

Barrel flow control conditions illustrated in Figure A-28c and d are desirable because they reduce or even eliminate cavitation forces, or surging and vibration (as described above), in the riser and barrel system. Cavitation forces in the riser and barrel system can greatly reduce the design flow capacity of the system. Cavitation forces may also cause vibrations that can damage the riser (especially corrugated metal risers) and the connection between the riser and barrel. This connection may crack and lose its watertight seal. Additionally, if a concrete riser is excessively tall with a minimum amount of the riser secured in the embankment, the cavitation forces may cause the riser to rock on its foundation, risking possible structural failure.

The surging, vibrations, and other cavitation forces result when the riser is restricting flow to the barrel such that the riser is flowing full and the barrel is not flowing full. This condition occurs when the flow through the riser structure transitions from riser weir flow control to riser orifice flow control before the barrel controls. Therefore, the barrel and riser system should be designed so that as the storm continues and the hydraulic head on the riser increases, the barrel controls the flow before the riser transitions from riser weir flow control to riser orifice flow control. This can be accomplished by checking the flow rates for the riser weir, riser orifice, and barrel inlet and outlet flow control at each stage of discharge. The lowest discharge for any given stage will be the controlling flow.

The following procedures are for designing and checking riser and barrel system hydraulics.

Riser Flow Control:

During the design of the control orifices and riser weir, the geometry of the riser is established. Subsequently, the riser must be checked to determine at what stage it transitions from riser weir to riser orifice flow control. The riser weir controls the flow initially, and then as the water rises, the top of the riser acts as a submerged horizontal orifice. Thus, the flow transitions from riser weir flow control to riser orifice flow control as the water in the basin rises. The flow capacity of the riser weir is determined using the Weir Equation and the flow capacity of the riser orifice is determined using the Orifice Equation for each elevation. The smaller of the two flows for any given elevation is the controlling flow.

1. Calculate the flow, in cfs, over the riser weir using the standard Weir Equation for each elevation specified on the Stage-Storage-Discharge Worksheet, Figure A-26. Record the flows on the worksheet.

   The weir length, L, is the circumference or length of the riser structure, measured at the crest, less any support posts or trash rack. The head is measured from the water surface elevation to the crest of the riser structure (refer to Figure A-27).

2. Calculate the flow, in cfs, through the riser structure using the standard Orifice Equation for each elevation specified on the Stage-Storage-Discharge Worksheet, Figure A-26. Record the flows on the worksheet.

   The Orifice flow area, a, is measured from the inside dimensions of the riser structure. The head is measured from the water surface elevation to the elevation of the orifice centerline, or, since the orifice is horizontal, to the elevation of the riser crest.

3. Compare the riser weir flow discharges to the riser orifice flow discharges. The smaller of the two discharges is the controlling flow for any given stage.

Barrel Flow Control:

Two types of barrel flow exist: 1) barrel flow with inlet control, as shown in Figure A-28c, and 2) barrel flow with outlet, or pipe flow control, as shown in Figure A-28d. For both types, different factors and formulas are used to compute the hydraulic capacity of the barrel. During barrel inlet flow control, the diameter of the barrel, amount of head acting on the barrel, and the barrel entrance shape play a part in controlling the flow. For barrel outlet, or pipe flow, control, consideration is given to the length, slope, and roughness of the barrel, and the elevation of the tailwater, if any, in the outlet channel.

1. Barrel Inlet Flow Control

Barrel inlet flow control means that the capacity of the barrel is controlled at the barrel entrance by the depth of headwater and the barrel entrance, which is acting as a submerged orifice. The flow through the barrel entrance can be calculated using the Orifice Equation or by simply using the Pipe Flow Nomograph shown in Figure A-29. This nomograph provides stage-discharge relationships for concrete culverts of various sizes. [Additional nomographs for other pipe materials and geometrics are available; refer to the U.S. Bureau of Public Roads (BPR) Hydraulic Engineering Circular (H.E.C.) 5.] The headwater, or depth of ponding, is the vertical distance measured from the water surface elevation to the invert at the entrance to the barrel. Refer to Figure A-29 for ratios of headwater to pipe diameter, or HW/D. This nomograph, based on the orifice equation, provides flow rates for three possible hydraulic entrance shapes, as shown in Figure A-30. During barrel inlet flow control, neither the barrel's length nor its outlet conditions are factors in determining the barrel's capacity. Note that when the HW/D design values exceed the chart values, the designer may use the orifice equation to solve for the flow rate.

The inlet control nomographs are not truly representative of barrel inlet flow. These nomographs should be used carefully and with the understanding that they were developed to predict flow through highway culverts operating under inlet control. However, depending on the size relationship between the riser and outlet conduit, the inlet control nomograph may provide a reasonable estimate.

The following procedure outlines the steps to calculate the discharge during barrel inlet flow control conditions:

1. Determine the entrance condition of the barrel (see Figure A-30).
2. Determine the headwater to pipe diameter ratio (HW/D) for each elevation specified on the stage-storage-discharge worksheet. Headwater is measured from the water surface elevation to the upstream invert of the barrel.
3. Determine the discharge, Q, in cfs, using the inlet control nomograph for circular concrete pipe presented in Figure A-29 (or the BPR H.E.C. 5 pipe flow nomographs for other pipe materials), or the Orifice Equation (for HW/D values which exceed the range of the nomographs) for each elevation specified on the Stage-Storage-Discharge Worksheet. Enter the values on the worksheet.

<u>Barrel Outlet Flow Control</u>:

Barrels flowing under outlet or pipe flow control experience full flow for all or part of the barrel length, as shown in Figure A-28d.

The general pipe flow equation is derived by using the Bernouli and Continuity Principles and is simplified to:

*Equation A-40 Pipe Flow Control Equation*

$$Q = a\sqrt{\frac{2gh}{1 + K_m + K_p L}}$$

Where:

Q = discharge, cfs.

a = flow area of the barrel, square feet.

g = acceleration due to gravity, feet/square foot per second.

h = elevation head differential, feet, see Figure A-31.

$K_m$ = coefficient of minor losses: $K_e + K_b$.

$K_e$ = entrance loss coefficient, see Table A-26.

$K_b$ = bend loss coefficient, typically = 0.5 for riser and barrel system.

$K_p$ = coefficient of pipe friction, see Table A-27.

l = length of the barrel, feet.

This equation is derived and further explained in the SCS's Engineering Field Manual, Chapter 3. The following procedure outlines the steps to check for barrel outlet control:

1. Determine the discharge for each elevation specified in the stage-storage-discharge table using the general Pipe Flow Equation.
2. Record the discharge on the stage-storage-discharge worksheet, Figure A-26
3. Compare the barrel inlet flow control discharges with the barrel outlet flow control discharges. The smaller of the two discharges is the controlling flow for any given stage.

## Step 11 Size 100-Year Release Opening or Emergency Spillway

It is recommended that all stormwater impoundment structures have a vegetated emergency spillway, if possible. This provides a degree of safety to prevent overtopping of the embankment if the principal spillway should become clogged, or otherwise inoperative. If an emergency spillway is not practical due to site constraints, the 100-year storm must be routed through the riser and barrel system.

**100-Year Release Opening**

The design procedure for sizing the 100-year release opening is the same as that of the 10-year design, except that the 100-year storm values are used instead of the 10-year values.

**Emergency Spillway**

Refer to Design Specification P-SUP-03, Vegetated Emergency Spillway for location and design requirements of an emergency spillway. An emergency spillway is a broad crested weir. It can act as a control structure by restricting the release of flow, or it can be used to safely pass the 100-year storm flow with a minimum of storage. The impact of the 100-year storm on the required storage is lessened by using an emergency spillway due to the spillway's ability to pass significant volumes of flow with little head. If an emergency spillway is not used, additional storage may be needed since the riser and barrel will usually pass only a small portion of the 100-year inflow. This remains true unless the riser and barrel are sized for the 100-year storm, in which case they will be oversized for the 2- and 10-year storms.

The following procedure can be used to design an emergency spillway that will safely pass, or control, the rate of discharge from the 100-year storm.

1. Identify the 10-year maximum water surface elevation based on the routing from STEP 9. This elevation will be used to establish the elevation of the 100-year release structure.
2. Determine the storage volume that corresponds to the 100-year control elevation from the stage-storage curve. Add this elevation, storage, and appropriate storm discharges to the Stage-Storage-Discharge Worksheet.
3. Set the invert of the emergency spillway at the 10-year high water elevation.
4. Determine the 100-year developed inflow from the hydrology.

   *A distance of 0.1 foot, minimum, is recommended between the 10-year high water mark and the invert of the emergency spillway.*

5. Using the design procedure provided in the "Emergency Spillway Design" section of this Appendix, determine the required bottom width of the spillway, the length of the spillway level section, and the depth of flow through the spillway that adequately passes the 100-year storm within the available free board. The minimum free board required is 1 foot from the 100-year water surface elevation to the settled top of embankment.

6. Develop the stage-storage-discharge relationship for the 100-year storm. Calculate the discharge for each elevation specified on the stage-storage curve. If a release rate is specified, then the TR-55 shortcut method can be used to calculate the approximate storage volume requirement. If a fixed storage volume is available, the same shortcut method can be used to decide what the discharge must be to ensure that the available storage is not exceeded. Refer to TR-55.

### Step 12 Calculate Total Discharge and Check Performance of 100-Year Control Opening

1. Calculate total discharge.

   The stage-storage-discharge table is now complete and the total discharge from the riser and barrel system and emergency spillway can be determined. The designer should verify that the barrel flow controls before the riser transitions from riser weir flow control to riser orifice flow control.

   The combined flows from the water quality orifice, the 1-year opening, the 10-year opening, and the riser will, at some point, exceed the capacity of the barrel. At this water surface elevation and discharge, the system transitions from riser flow control to barrel flow control. The total discharge for each elevation is simply the sum of the flows through the control orifices of the riser, or the controlling flow through the barrel and riser, whichever is less.

2. Check the performance of the 100-year control by a) reservoir routing the 1-year, 10-year, and 100-year storms through the basin using an acceptable reservoir routing computer program or by b) doing the long hand calculations. Verify that the design storm release rates are less than or equal to the allowable release rates, and that the 100-year design high water is:

   a. at least 2 feet lower than the settled top of embankment elevation if an emergency spillway is NOT used, or

   b. at least 1 feet lower than the settled top of embankment if an emergency spillway is used.

Also, the designer should verify that the release rates for each design storm are not too low, which would result in more storage being provided than is required.

## *Figure A-26 Stage-Storage – Discharge Worksheet, Example 1*

| ELEV (MSL) | STORAGE (ac-ft.) | 1-yr ext det ~~WATER QUALITY~~ ORIFICE(1) | | TRIAL 2 10-YEAR CONTROL WEIR (4) | | ORIFICE (5) | | RISER STRUCTURE WEIR (6) | | ORIFICE (7) | | BARREL INLET (8) | | OUTLET (9) | | EMERGENCY SPILLWAY (10) | | TOTAL Q (cfs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | h | Q | h | Q | h | Q | h | Q | h | Q | HW/D | Q | h | Q | h | Q | |
| 81 | 0 | 0 | 0 | | | | | | | | | | | | | | | 0 |
| 82 | .02 | 1 | 0.3 | | | | | | | | | | | | | | | 0.3 |
| 84 | .14 | 3 | 0.6 | | | | | | | | | | | | | | | 0.6 |
| 86 | .33 | 5 | 0.7 | | | | | | | | | | | | | | | 0.7 |
| 88 | .68 | 7 | 0.9 | | | | | | | | | | | | | | | 0.9 |
| 88.8 | .90 | 7.8 | 0.98 | 0 | 0 | | | | 0/0 | 0 | 0 | | | | | | | 1.0 |
| 89 | .95 | 8 | 1.0 | 0.2 | 0.4 | | | | 0/0.4 | 0.2 | ~~34.4~~ | 5.5 | ~~24~~ | 8.3 | ~~22.0~~ | | | 1.4 |
| 90 | 1.28 | 9 | 1.1 | 1.2 | 5.8 | | | | 0/5.8 | 1.2 | 84.4 | 6.2 | ~~26~~ | 9.3 | ~~23.3~~ | | | 6.9 |
| 91 | 1.75 | 10 | 1.1 | 2.2 | 14.3 | | | | 0/14.3 | 2.2 | ~~114.3~~ | 6.8 | ~~27~~ | 10.3 | ~~24.5~~ | | | 15.4 |
| 92 | 2.23 | 11 | ~~1.1~~ | 3.2 | ~~25.1~~ | | | | 0/25.1 | 3.2 | ~~137.8~~ | 7.5 | ~~28~~ | 11.3 | 25.7 | | | 25.7 |
| 92.2 | 2.40 | 11.2 | ~~1.1~~ | 3.4 | ~~27.5~~ | | | 0 | 0/27.5 | 3.4 | ~~142.0~~ | 7.6 | ~~29~~ | 11.5 | 25.9 | 0 | 0 | 25.9 |
| 93 | 2.94 | 12.0 | ~~1.1~~ | 4.2 | ~~37.8~~ | | | 0.8 | 17.0/54.8 | 4.2 | 157.9 | 8.1 | ~~30~~ | 12.3 | 26.8 | 0.8 | 54 | 80.8 |
| 94 | 3.81 | 13.0 | ~~1.2~~ | 5.2 | ~~52.0~~ | | | 1.8 | 27.5/79.5 | 5.2 | ~~175.7~~ | 8.8 | ~~31~~ | 13.3 | 27.8 | 1.8 | 214 | 241.8 |

(6) Q for elevations 88.8 to 92.2 ft. represents 10-yr. weir flow (4)
Q for elevations 92.2 to 94 ft represents 10-yr weir flow plus the top of riser weir flow: $Q = 23.8 (h)^{1.5}$ where h = wse - 92.2 ft.

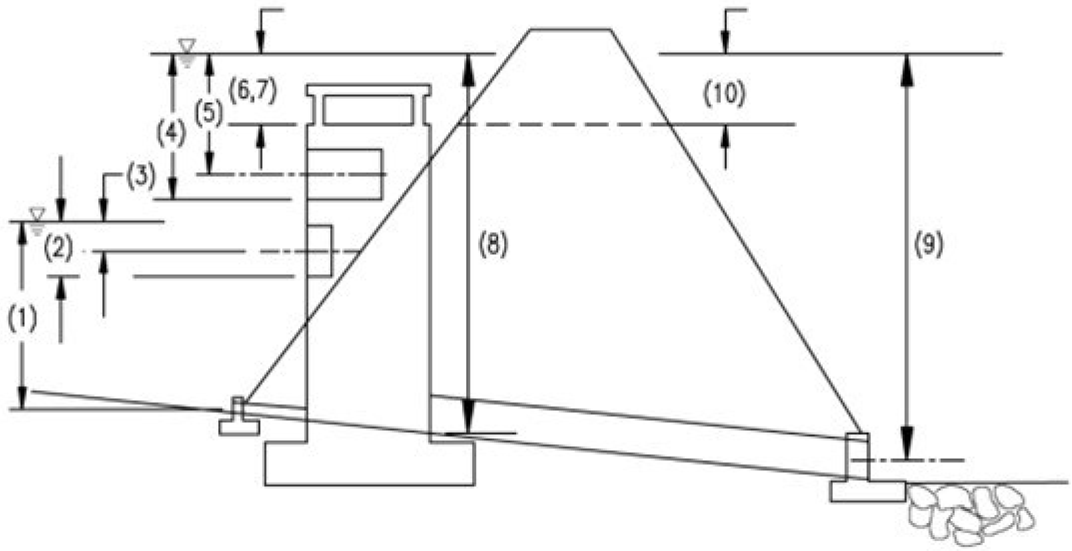
(7) $Q = 77.03 (h)^{1/2}$ where h = wse - 88.8 ft

(8) $Q = 8.5 (h)^{1/2}$ where h = wse - 80.75 ft

(9) $Q = 7.64 (h)^{1/2}$ where h = wse - 80.75 ft

(10) Figure 5-23: Design Data for Earth Spillways.

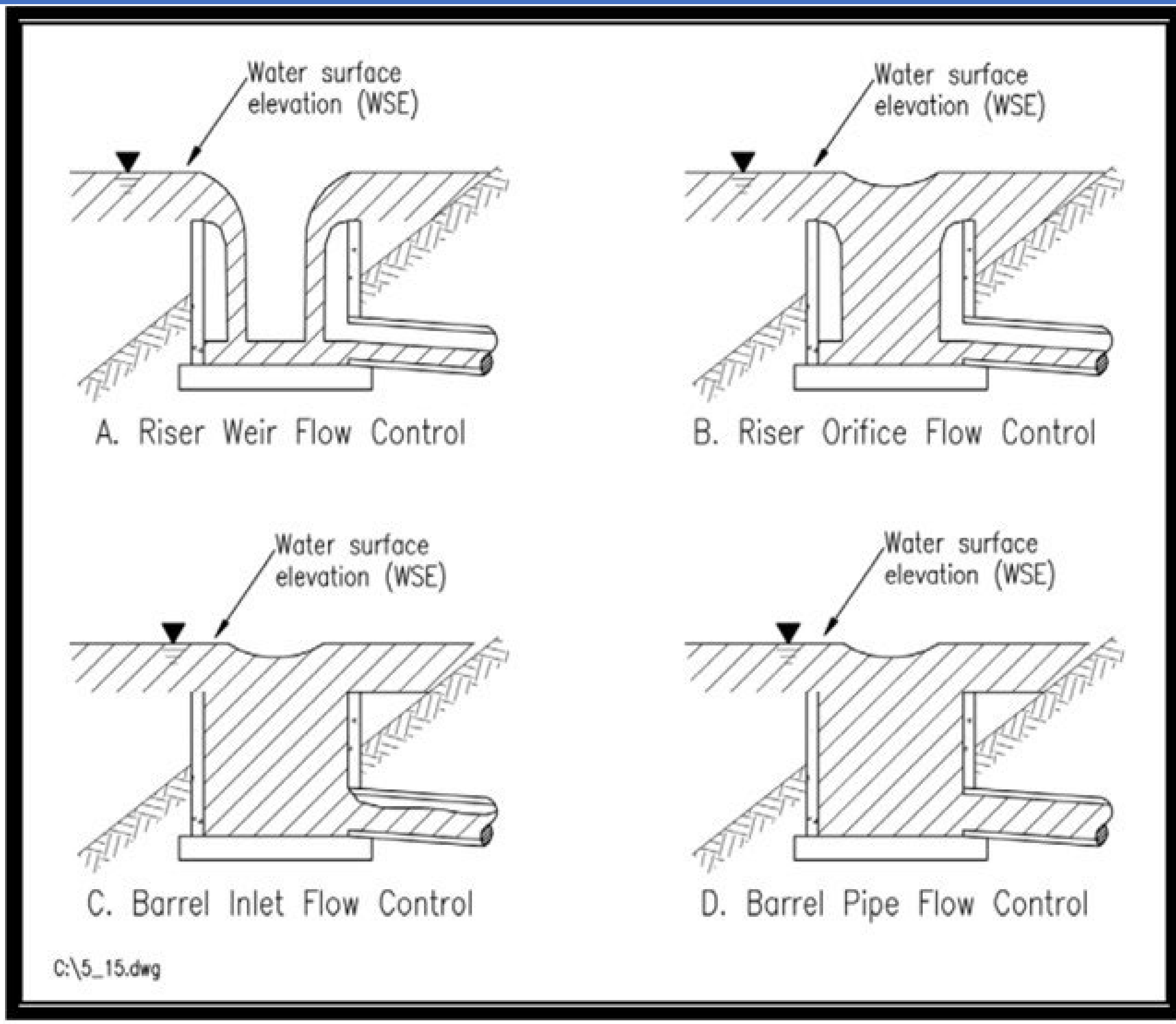
## *Figure A-27 Typical Hydraulic Head Values – Multi-Stage Riser*




1. WQ Orifice: H measured from water surface elevation (WSE) to centerline of pipe, or orifice. (orifice flow)
2. 2–year Control: Weir flow – H measured from WSE to invert of 2–year control weir.
3. 2–year Control: Orifice flow – H measured from WSE to centerline of opening (submerged).
4. 10–year Control: Weir flow – H measured from WSE to crest of opening.
5. 10–year Control: Orifice flow – H measured from WSE to centerline of opening.
6. Riser Structure: Weir flow – H measured from WSE to crest of riser top (if open).
7. Riser Structure: Orifice flow – H measured from WSE to crest of riser top, acting as horizontal orifice.
8. Barrel flow: Inlet control – H measured from WSE to upstream invert of outlet barrel.
9. Barrel flow: Outlet control – H measured from WSE to centerline of outlet of barrel or tailwater – whichever is higher.
10. Emergency Spillway: H measured from WSE to crest of Emergency Spillway.

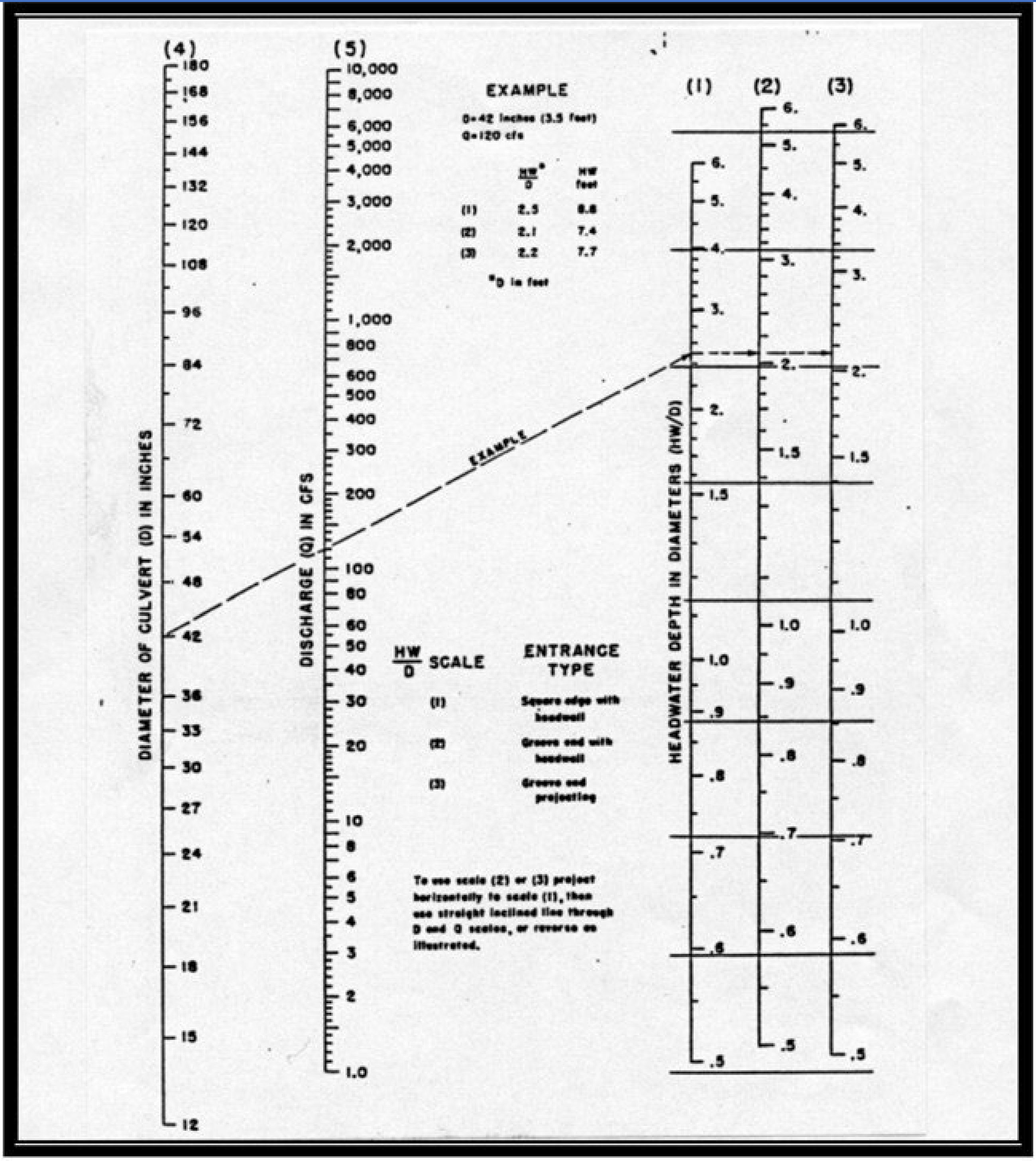
c:\5_14.dwg

## *Figure A-28 Riser Flow Diagrams*



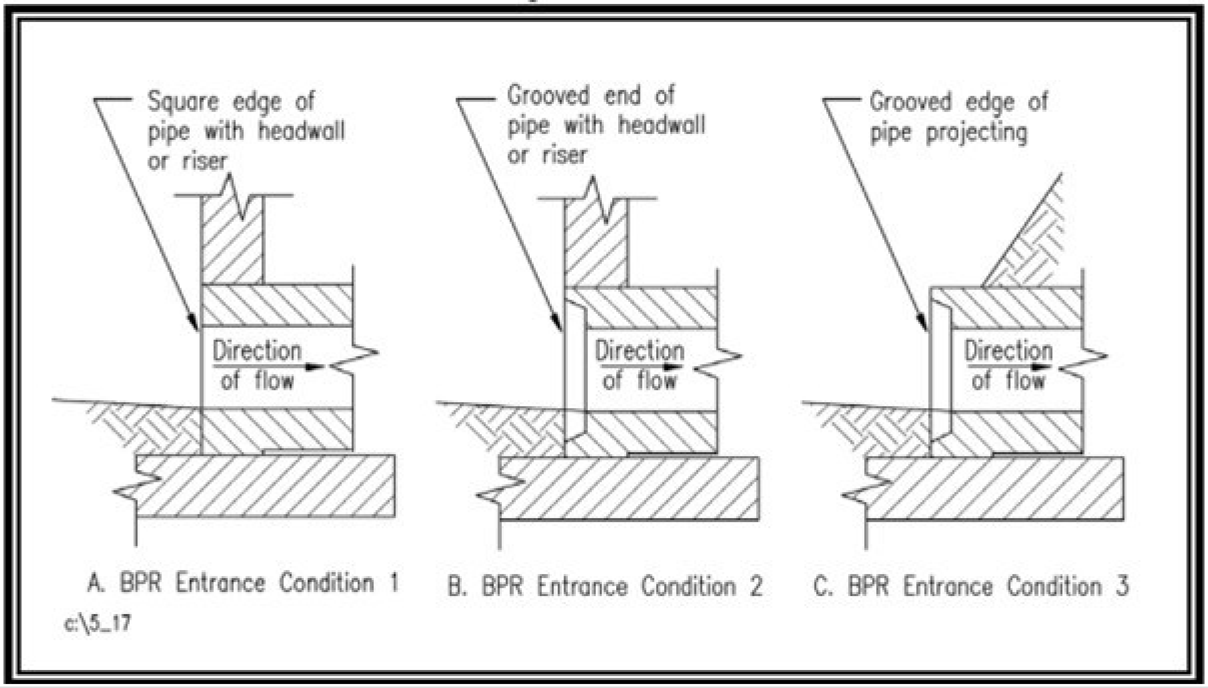

*Source: SCS Engineering Field Manual - Chapter 6*

## *Figure A-29 Headwater Depth for Concrete Pipe Culverts with Inlet Control*




*Source: Bureau of Public Roads*

## *Figure A-30 Headwater Depth Entrance Conditions*




## *Figure A-31 Hydraulic Head Values – Barrel Flow*

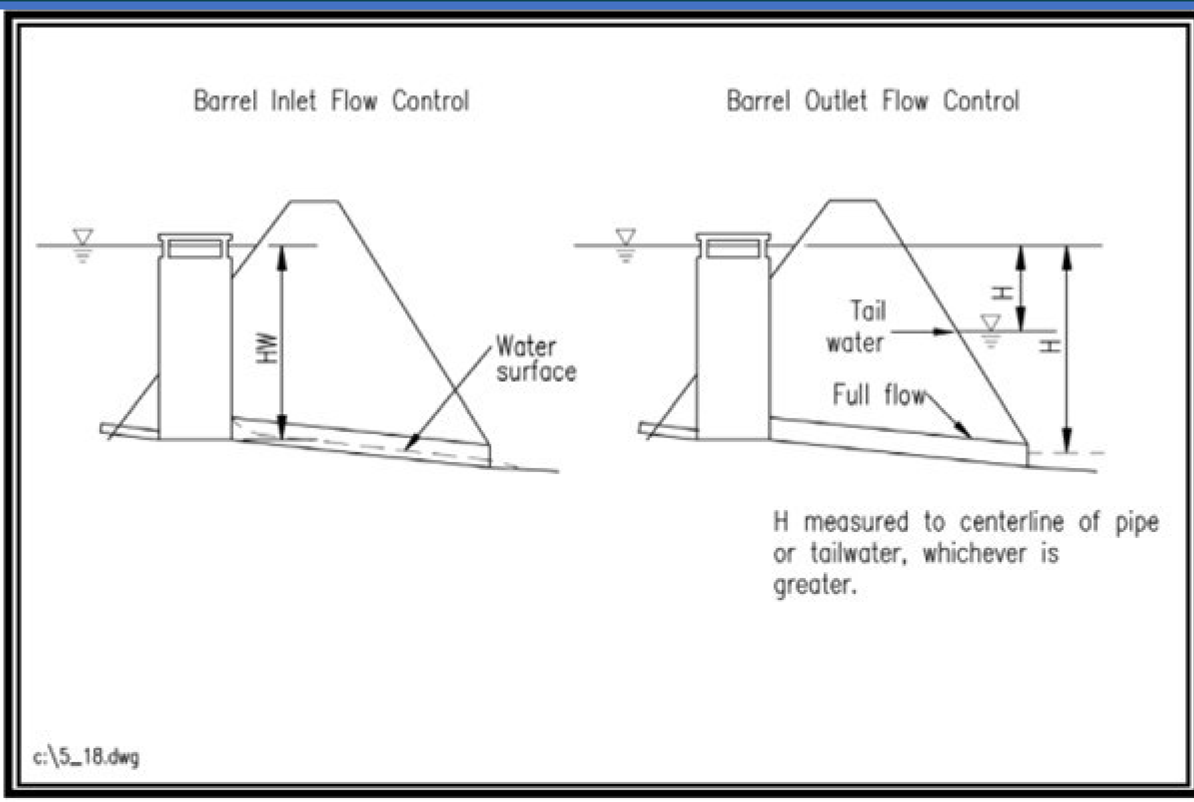


**Table A-26 Pipe Entrance Loss Coefficients – $K_e$**

| Type of Structure and Design of Entrance | Coefficient, Ke |
|---|---|
| **Pipe, Concrete** | |
| Projecting from fill, socket end (groove end) | 0.2 |
| Projecting from fill, square end cut | 0.5 |
| Headwall or headwall and wingwalls, socket end of pipe (groove end) | 0.2 |
| Headwall or headwall and wingwalls, square end | 0.5 |
| Headwall or headwall and wingwalls, rounded (radius = 1/12D) | 0.2 |
| Mitered to conform to fill slope | 0.7 |
| *End-section conforming to fill slope | 0.5 |
| **Pipe, or Pipe Arch, Corrugated Metal** | |
| Projecting from fill (no headwall) | 0.9 |
| Headwall or headwall and wingwalls, square end | 0.5 |
| Mitered to conform to fill slope | 0.7 |
| *End-section conforming to fill slope | 0.5 |

**Notes:**

Source: Federal Highway Administration, Bureau of Public Records

* "End-section conforming to fill slope" made of either metal or concrete, is the section commonly available from manufacturers. Based on limited hydraulic tests, it appears to be equivalent in operation to a headwall in either inlet or outlet control.

# Table A-27 Head Loss Coefficients, Kp, for Circular and Square Conduits Flowing Full

C(a). Head Loss Coefficient $K_p$ for Circular Pipe Flowing Full

$$K_p = \frac{5{,}087\,n^2}{(d_i)^{4/3}}$$

Head loss coefficient, $K_p$, for circular pipe flowing full

| Pipe diam, in | Flow area, ft$^2$ | Manning's coefficient of roughness, n | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.009 | 0.01 | 0.011 | 0.012 | 0.013 | 0.014 | 0.015 | 0.016 |
| 6 | 0.196 | 0.0378 | 0.0467 | 0.0565 | 0.0672 | 0.0789 | 0.0914 | 0.1050 | 0.1194 |
| 8 | 0.349 | 0.0258 | 0.0318 | 0.0385 | 0.0458 | 0.0537 | 0.0623 | 0.0715 | 0.0814 |
| 10 | 0.545 | 0.0191 | 0.0236 | 0.0286 | 0.0340 | 0.0399 | 0.0463 | 0.0531 | 0.0604 |
| 12 | 0.785 | 0.0150 | 0.0185 | 0.0224 | 0.0267 | 0.0313 | 0.0363 | 0.0417 | 0.0474 |
| 15 | 1.23 | 0.0111 | 0.0138 | 0.0166 | 0.0198 | 0.0232 | 0.0270 | 0.0309 | 0.0352 |
| 18 | 1.77 | 0.00873 | 0.0108 | 0.0130 | 0.0155 | 0.0182 | 0.0211 | 0.0243 | 0.0276 |
| 21 | 2.41 | 0.00711 | 0.00878 | 0.0106 | 0.0126 | 0.0148 | 0.0172 | 0.0198 | 0.0225 |
| 24 | 3.14 | 0.00595 | 0.00735 | 0.00889 | 0.0106 | 0.0124 | 0.0144 | 0.0165 | 0.0188 |
| 30 | 4.91 | 0.00442 | 0.00546 | 0.00660 | 0.00786 | 0.00922 | 0.0107 | 0.0123 | 0.0140 |
| 36 | 7.07 | 0.00347 | 0.00428 | 0.00518 | 0.00616 | 0.00723 | 0.00839 | 0.00963 | 0.0110 |
| 42 | 9.62 | 0.00282 | 0.00348 | 0.00422 | 0.00502 | 0.00589 | 0.00683 | 0.00784 | 0.00892 |
| 48 | 12.6 | 0.00236 | 0.00292 | 0.00353 | 0.00420 | 0.00493 | 0.00572 | 0.00656 | 0.00747 |
| 54 | 15.9 | 0.00202 | 0.00249 | 0.00302 | 0.00359 | 0.00421 | 0.00488 | 0.00561 | 0.00638 |
| 60 | 19.6 | 0.00175 | 0.00217 | 0.00262 | 0.00312 | 0.00366 | 0.00424 | 0.00487 | 0.00554 |
| 72 | 28.3 | 0.00138 | 0.00170 | 0.00205 | 0.00245 | 0.00287 | 0.00333 | 0.00382 | 0.00435 |
| 84 | 38.5 | 0.00112 | 0.00138 | 0.00167 | 0.00199 | 0.00234 | 0.00271 | 0.00311 | 0.00354 |
| 96 | 50.3 | 0.00094 | 0.00116 | 0.00140 | 0.00167 | 0.00196 | 0.00227 | 0.00260 | 0.00296 |

$$H_l = K_p L \frac{v^2}{2g}$$

Example: Compute head loss in 300 ft of 24-in diameter pipe when the full flow is 30 ft$^3$/s and Manning's n is 0.015.

$$v = \frac{Q}{a} = \frac{30\ ft^3/s}{3.14\ ft^2} = 9.55\ ft/s$$

$$\frac{v^2}{2g} = \frac{\left(9.55\frac{ft}{s}\right)^2}{2 \times 32.2\ ft/s^2} = 1.42\ ft$$

$$H_l = K_p L \frac{v^2}{2g} = 0.0165 \times 300 \times 1.42 = 7.03\ ft$$

# Table A-27 Head Loss Coefficients, Kp, for Circular and Square Conduits Flowing Full

C(b). Head Loss Coefficient $K_p$ for Circular Pipe Flowing Full

$$K_p = \frac{5{,}087\, n^2}{(d_i)^{4/3}}$$

Head loss coefficient, $K_p$, for circular pipe flowing full

| Pipe diam, in | Flow area, ft$^2$ | Manning's coefficient of roughness, n | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.017 | 0.018 | 0.019 | 0.020 | 0.021 | 0.022 | 0.023 | 0.024 | 0.025 |
| 6 | 0.196 | 0.1348 | 0.1512 | 0.1684 | 0.1866 | 0.2058 | 0.2258 | 0.2468 | 0.2688 | 0.2916 |
| 8 | 0.349 | 0.0919 | 0.1030 | 0.1148 | 0.1272 | 0.1402 | 0.1539 | 0.1682 | 0.1831 | 0.1987 |
| 10 | 0.545 | 0.0682 | 0.0765 | 0.0852 | 0.0944 | 0.1041 | 0.1143 | 0.1249 | 0.1360 | 0.1476 |
| 12 | 0.785 | 0.0535 | 0.0600 | 0.0668 | 0.0741 | 0.0817 | 0.0896 | 0.0980 | 0.1067 | 0.1157 |
| 15 | 1.23 | 0.0397 | 0.0446 | 0.0496 | 0.0550 | 0.0606 | 0.0666 | 0.0727 | 0.0792 | 0.0859 |
| 18 | 1.77 | 0.0312 | 0.0349 | 0.0389 | 0.0431 | 0.0476 | 0.0522 | 0.0570 | 0.0621 | 0.0674 |
| 21 | 2.41 | 0.0254 | 0.0284 | 0.0317 | 0.0351 | 0.0387 | 0.0425 | 0.0464 | 0.0506 | 0.0549 |
| 24 | 3.14 | 0.0212 | 0.0238 | 0.0265 | 0.0294 | 0.0324 | 0.0356 | 0.0389 | 0.0423 | 0.0459 |
| 30 | 4.91 | 0.0158 | 0.0177 | 0.0197 | 0.0218 | 0.0241 | 0.0264 | 0.0289 | 0.0314 | 0.0341 |
| 36 | 7.07 | 0.0124 | 0.0139 | 0.0154 | 0.0171 | 0.0189 | 0.0207 | 0.0226 | 0.0246 | 0.0267 |
| 42 | 9.62 | 0.0101 | 0.0113 | 0.0126 | 0.0139 | 0.0154 | 0.0169 | 0.0184 | 0.0201 | 0.0218 |
| 48 | 12.6 | 0.00843 | 0.00945 | 0.0105 | 0.0117 | 0.0129 | 0.0141 | 0.0154 | 0.0168 | 0.0182 |
| 54 | 15.9 | 0.00720 | 0.00808 | 0.00900 | 0.00997 | 0.0110 | 0.0121 | 0.0132 | 0.0144 | 0.0156 |
| 60 | 19.6 | 0.00626 | 0.00702 | 0.00782 | 0.00866 | 0.00955 | 0.0105 | 0.0115 | 0.0125 | 0.0135 |
| 72 | 28.3 | 0.00491 | 0.00550 | 0.00613 | 0.00679 | 0.00749 | 0.00822 | 0.00898 | 0.00978 | 0.0106 |
| 84 | 38.5 | 0.00400 | 0.00448 | 0.00499 | 0.00553 | 0.00610 | 0.00669 | 0.00731 | 0.00796 | 0.00864 |
| 96 | 50.3 | 0.00334 | 0.00375 | 0.00418 | 0.00463 | 0.00510 | 0.00560 | 0.00612 | 0.00667 | 0.00723 |

$$H_l = K_p L \frac{v^2}{2g}$$

Example: Compute head loss in 300 ft of 24-in diameter pipe when the full flow is 30 ft$^3$/s and Manning's n is 0.015.

$$v = \frac{Q}{a} = \frac{30\ ft^3/s}{3.14\ ft^2} = 9.55\ ft/s$$

$$\frac{v^2}{2g} = \frac{\left(9.55\frac{ft}{s}\right)^2}{2\ \times 32.2\ ft/s^2} = 1.42\ ft$$

$$H_l = K_p L \frac{v^2}{2g} = 0.0165 \times 300 \times 1.42 = 7.03\ ft$$

## Table A-27 Head Loss Coefficients, Kp, for Circular and Square Conduits Flowing Full

D. Head Loss Coefficient $K_c$ for Square Conduit Flowing Full

$$K_c = \frac{29.16n^2}{(r)^{4/3}}$$

| Conduit width and height ft | Flow area ft² | Manning's coefficient of roughness | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.010 | 0.011 | 0.012 | 0.013 | 0.014 | 0.015 | 0.016 |
| 2 | 4 | 0.00735 | 0.00889 | 0.01058 | 0.01242 | 0.01440 | 0.01653 | 0.01881 |
| 2.5 | 6.25 | 0.00546 | 0.00660 | 0.00786 | 0.00922 | 0.01070 | 0.01228 | 0.01397 |
| 3 | 9 | 0.00428 | 0.00518 | 0.00616 | 0.00723 | 0.00839 | 0.00963 | 0.01096 |
| 3.5 | 12.25 | 0.00348 | 0.00422 | 0.00502 | 0.00589 | 0.00683 | 0.00784 | 0.00892 |
| 4 | 16 | 0.00292 | 0.00353 | 0.00420 | 0.00493 | 0.00572 | 0.00656 | 0.00746 |
| 5 | 25 | 0.00217 | 0.00262 | 0.00312 | 0.00366 | 0.00424 | 0.00487 | 0.00554 |
| 6 | 36 | 0.00170 | 0.00205 | 0.00245 | 0.00287 | 0.00333 | 0.00382 | 0.00435 |
| 7 | 49 | 0.00138 | 0.00167 | 0.00199 | 0.00234 | 0.00271 | 0.00311 | 0.00354 |
| 8 | 64 | 0.00116 | 0.00140 | 0.00167 | 0.00196 | 0.00227 | 0.00260 | 0.00296 |
| 9 | 81 | 0.00099 | 0.00120 | 0.00142 | 0.00167 | 0.00194 | 0.00223 | 0.00253 |
| 10 | 100 | 0.00086 | 0.00104 | 0.00124 | 0.00145 | 0.00168 | 0.00193 | 0.00220 |
| 12 | 144 | 0.00067 | 0.00082 | 0.00097 | 0.00114 | 0.00132 | 0.00152 | 0.00173 |

$$H_l = K_c L \frac{v^2}{2g}$$

Example: Compute discharge in 250 ft of 3-ft by 3-ft box conduit, when the head loss is 2.25 ft and Manning's n is 0.014.

$$H_l = K_c L \frac{v^2}{2g}$$

$$v = \sqrt{2 \times 32.2\ ft^3/s\ \times 1.073\ ft} = 8.31\ ft/s$$

$$\frac{v^2}{2g} = \frac{H_l}{K_c L} = \frac{2.25\ ft}{0.00839 \times 250\ ft} = 1.073\ ft$$

$$Q = va = 8.31\ ft/s \times 9\ ft^2 = 75\ ft^3/s$$

Source: National Engineering Handbook, 210-650-H, 2nd Ed., Feb 2021)

### Step 13 Design Outlet Protection

With the total discharge known for the full range of design storms, adequate outlet protection can now be designed. Protection is necessary to prevent scouring at the outlet and to help reduce the potential for downstream erosion by reducing the velocity and energy of the concentrated discharge. The most common form of outlet protection is a riprap-lined apron, constructed at zero grade for a specified distance, as determined by the outlet flow rate and tailwater elevation. The design procedure follows:

Note that this procedure is for riprap outlet protection at the downstream end of an embankment conduit. It does not apply to continuous rock linings of channels or stream. Refer to Figure A-32.

1. Determine the tailwater depth, for the appropriate design storm, immediately below the discharge pipe. Typically, the discharge pipe from a stormwater management facility is sized to carry the allowable discharge from the 10-year frequency design storm. Manning's equation can be used to find the water surface elevation in the receiving channel for the 10-year storm, which represents the tailwater elevation. If the tailwater depth is less than half the outlet pipe diameter, it is called a minimum tailwater condition. If the tailwater depth is greater than half the outlet pipe diameter, it is called a maximum tailwater condition. Stormwater basins that discharge onto flat areas with no defined channel may be assumed to have a minimum tailwater condition.

   Outflows from stormwater management facilities must be discharged to an adequate channel. Basins discharging onto a flat area with no defined channel will usually require a channel to be provided which can convey the design flows.

2. Determine the required riprap size, D50, and apron length, La.

   Enter the appropriate figure, either Figure A-33: Minimum Tailwater Condition, or Figure A-34: Maximum Tailwater Condition, with the design discharge of the pipe spillway to read the required apron length, Ls. (The apron length should not be less than 10 feet.)

3. Determine the required riprap apron width, W.

   When the pipe discharges directly into a well-defined channel, the apron shall extend across the channel bottom and up the channel banks to an elevation 1 foot above the maximum tailwater depth or the top of bank, whichever is less.

   If the pipe discharges onto a flat area with no defined channel, the width of the apron shall be determined as follows:

   a. The upstream end of the apron, next to the pipe, shall be 3 times wider than the diameter of the outlet pipe.
   b. For a minimum tailwater condition, the width of the apron's downstream end shall equal the pipe diameter plus the length of the apron.
   c. For a maximum tailwater condition, the width of the apron's downstream end shall equal the pipe diameter plus 0.4 times the length of the apron.

   Using the same figure as in Step 2, above, determine the D50 riprap size and select the appropriate class of riprap, as shown in Table A-28. Values falling between the table values should be rounded up to the next class size.

4. Determine the required depth of the rip rap blanket.

   The depth of the rip rap blanket is approximated as: 2.25 x D50.

Additional design considerations and specifications can be found in Minimum Standard 3.02, Principal Spillway and Std. and Spec. 3.18 and 3.19 of the Virginia Erosion and Sediment Control Handbook, 1992 edition.

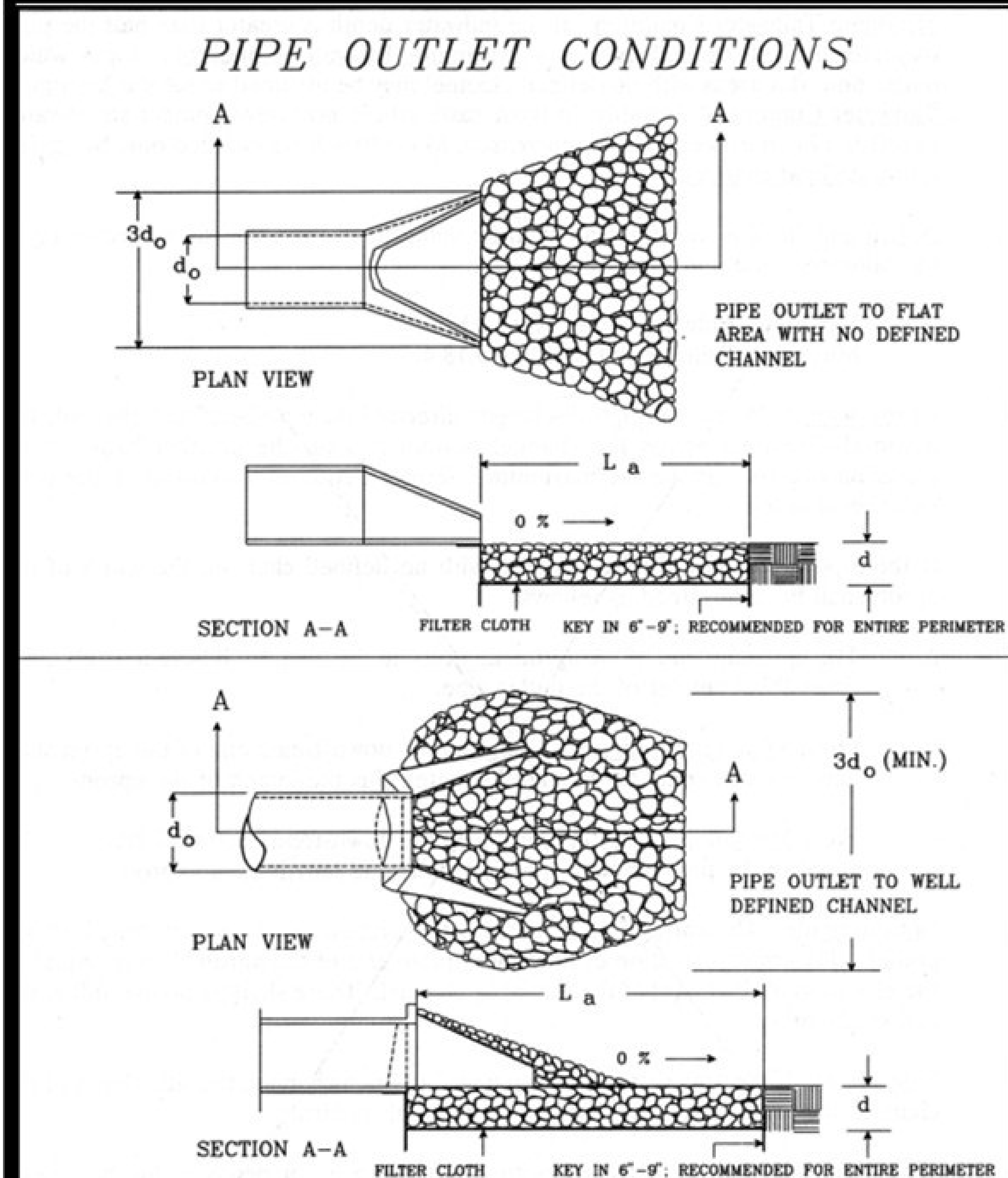
**Table A-28 Graded Riprap Design Values**

| Riprap Class | D15 Weight (pounds) | Mean D15 Spherical Diameter (feet) | Mean D50 Spherical Diameter (feet) |
|---|---|---|---|
| Class AI | 25 | 0.7 | 0.9 |
| Class I | 50 | 0.8 | 1.1 |
| Class II | 150 | 1.3 | 1.6 |
| Class III | 500 | 1.9 | 2.2 |

| Table A-28 Graded Riprap Design Values | | | |
|---|---|---|---|
| Riprap Class | D15 Weight (pounds) | Mean D15 Spherical Diameter (feet) | Mean D50 Spherical Diameter (feet) |
| Type I | 1,500 | 2.6 | 2.8 |
| Type I | 6,000 | 4.0 | 4.5 |

Source: Virginia Department of Transportation Draining Manual

## Figure A-32 Outlet Protection Detail




NOTES:
1. APRON LINING MAY BE RIPRAP, GROUTED RIPRAP, GABION BASKET, OR CONCRETE.
2. La IS THE LENGTH OF THE RIPRAP APRON AS CALCULATED USING FIG 5-20 AND FIG 5-21.
3. d = 1.5 TIMES THE MAXIMUM STONE DIAMETER, BUT NOT LESS THAN 6 INCHES.

## Figure A-33 Minimum Tailwater Condition

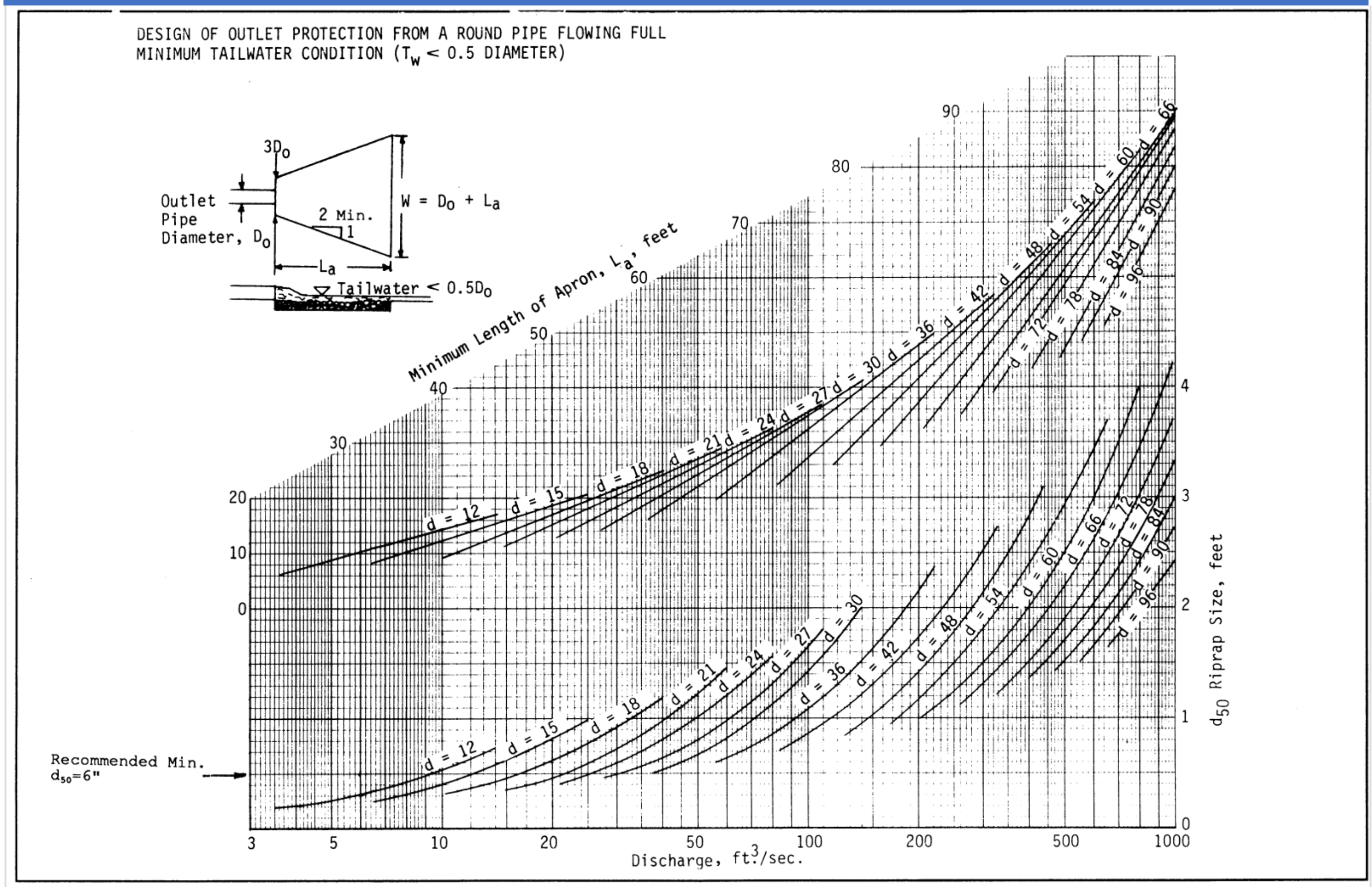
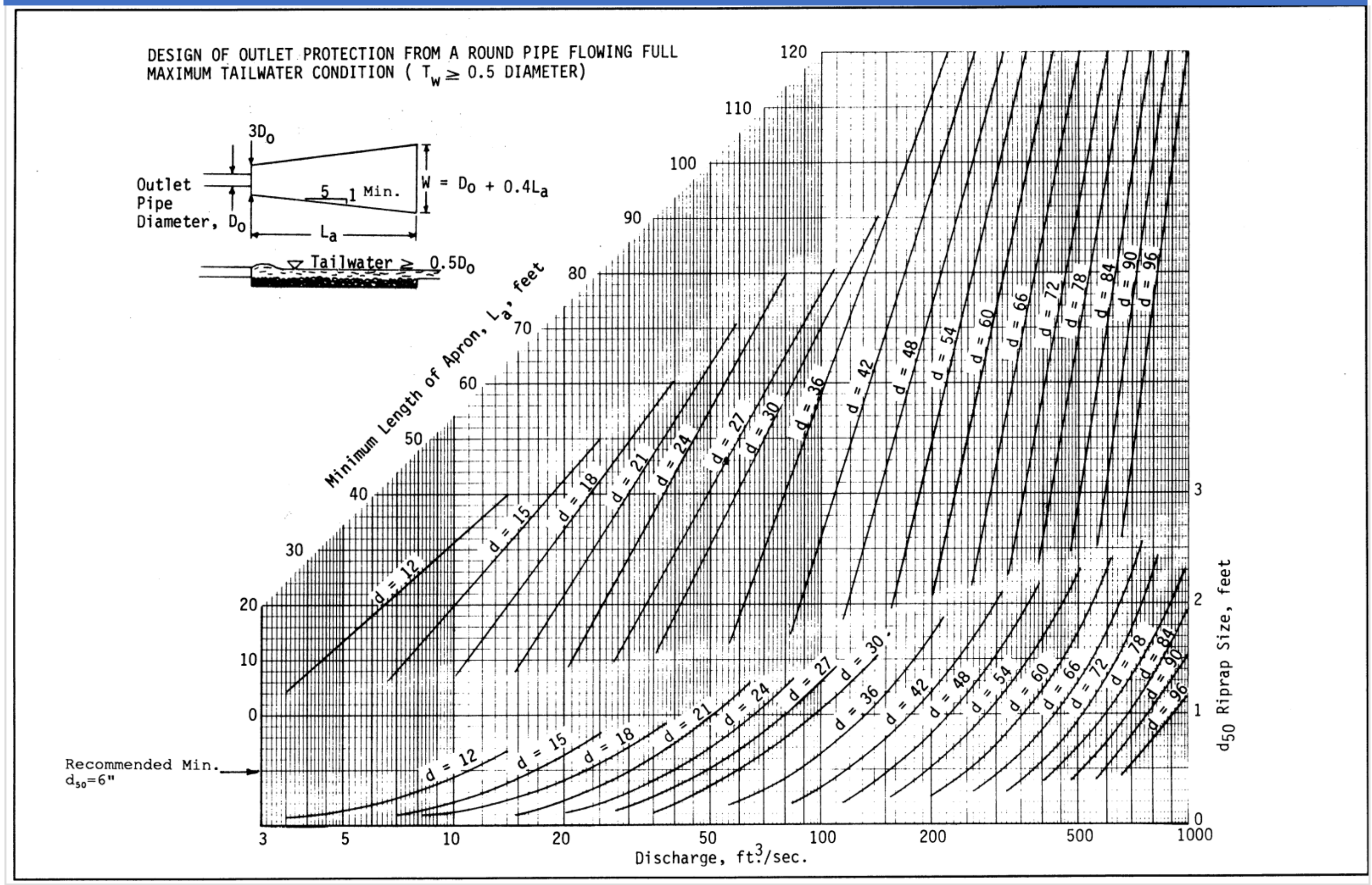


**Figure A-34 Maximum Tailwater Condition**




## Step 14 Perform Buoyancy Calculation

The design of a multi-stage riser structure must include a buoyancy analysis for the riser and footing. When the ground is saturated and ponded runoff is at an elevation higher than the footing of the riser structure, the riser structure acts like a vessel. During this time, the riser is subject to uplifting, buoyant forces that are relative in strength to the volume of water displaced. Flotation will occur when the weight of the structure is less than or equal to the buoyant force exerted by the water. Flotation forces on the riser can lead to failure of the connection between the riser structure and barrel, and any other rigid connections. Eventually, this can also lead to the failure of the embankment.

A buoyancy calculation is the summation of all forces acting on the riser. The upward force is the weight of the water, or 62.4 lb/cubic feet. The downward force includes the weight of the riser structure, any components, such as trash racks, and the weight of the soil above the footing. Note that conventional reinforced concrete weighs about 150 lb/cubic feet and the unit weight of soil is approximately 120 lb/cubic feet. The weight of components such as trash racks, anti-vortex devices, hoods, etc. is very specific to each structure and, depending upon the design, may or may not be significant in comparison to the other forces. If an extended base footing is used below the ground surface to support the control structure, then the weight of the soil above the footing may also be a significant force.

The outlet pipe is excluded from the buoyancy analysis for the control structure. However, the barrel should be analyzed separately to insure that it is not subject to flotation. The method used to attach the control structure to the outlet pipe is considered to have no bearing on the potential for these components to float.

The following procedure compares the upward force (buoyant force) to the downward force (structure weight). To maintain adequate stability, the downward force should be a minimum of 1.25 times the upward force.

1. Determine the buoyant force.

   The buoyant force is the total volume of the riser structure and base, using outside dimensions (i.e., the total volume displacement of the riser structure) multiplied by the unit weight of water (62.4 lb/cubic feet).

2. Determine the downward or resisting force.

   The downward force is the total volume of the riser walls below the crest, including any top slab, footing, etc., less the openings for any pipe connections, multiplied by the unit weight of reinforced concrete (150 lb/cubic feet). Additional downward forces from any components may also be added, including the weight of the soil above the extended footing.

3. Decide if the downward force is greater than the buoyant force by a factor of 1.25 or more.

   If the downward force is not greater than the buoyant force by a factor of 1.25 or more, then additional weight must be added to the structure. This can be done by sinking the riser footing deeper into the ground and adding concrete to the base. Note that this will also increase the buoyant force, but since the unit weight of concrete is more than twice that of water, the net result will be an increase in the downward force. The downward and buoyant forces should be adjusted accordingly, and step 3 repeated.

### Step 15 Provide Seepage Control

Seepage control should be provided for the pipe through the embankment. The two most common devices for controlling seepage are 1) filter and drainage diaphragms and 2) anti-seep collars. The use of these devices is discussed in detail in Minimum Standard 3.02, Principal Spillway. Note that filter and drainage diaphragms are preferred over anti-seep collars for controlling seepage along pipe conduits.

Filter and Drainage Diaphragms:

The design of filter and drainage diaphragms depends on the foundation and embankment soils and is outside the scope of this manual. When filter and drainage diaphragms are warranted, their design and construction should be supervised by a registered professional engineer. Design criteria and construction procedures for filter and drainage diaphragms can be found in the following references:

- USDA SCS TR-60
- USDA SCS Soil Mechanics Note No. 1: Guide for Determining the Gradation of Sand and Gravel Filters*
- USDA SCS Soil Mechanics Note No. 3: Soil Mechanics Consideration for Embankment Drains*
- U.S. Department of the Interior ACER Technical Memorandum No. 9: Guidelines for Controlling Seepage Along Conduits Through Embankments

* These publications include design procedures and examples.

Anti-Seep Collars:

The Bureau of Reclamation, the U.S. Army Corps of Engineers and the Soil Conservation Service no longer recommend the use of anti-seep collars. In 1987, the Bureau of Reclamation issued Technical Memorandum No. 9 that states:

“When a conduit is selected for a waterway through an earth or rockfill embankment, cutoff [anti-seep] collars will not be selected as the seepage control measure.”

Alternative measures to anti-seep collars include graded filters (or filter diaphragms) and drainage blankets. These devices are not only less complicated and more cost-effective to construct than cutoff collars, but also allow for easier placement of the embankment fill. Despite this information, anti-seep collars may be appropriate for certain situations. A design procedure is provided below. Criteria for the use and placement of anti-seep collars are presented in Minimum Standard 3.02, Principal Spillway.

1. Determine the length of the barrel within the saturated zone using the following equation:

*Equation A-41 Barrel Length in Saturated Zone*

$$L_s = Y(Z+4)\left[1 + \frac{S}{0.25 - S}\right]$$

Where:

$L_s$ = length of the barrel in the saturated zone, feet.

Y = the depth of water at the principal spillway crest (10-year frequency storm water surface elevation), feet.

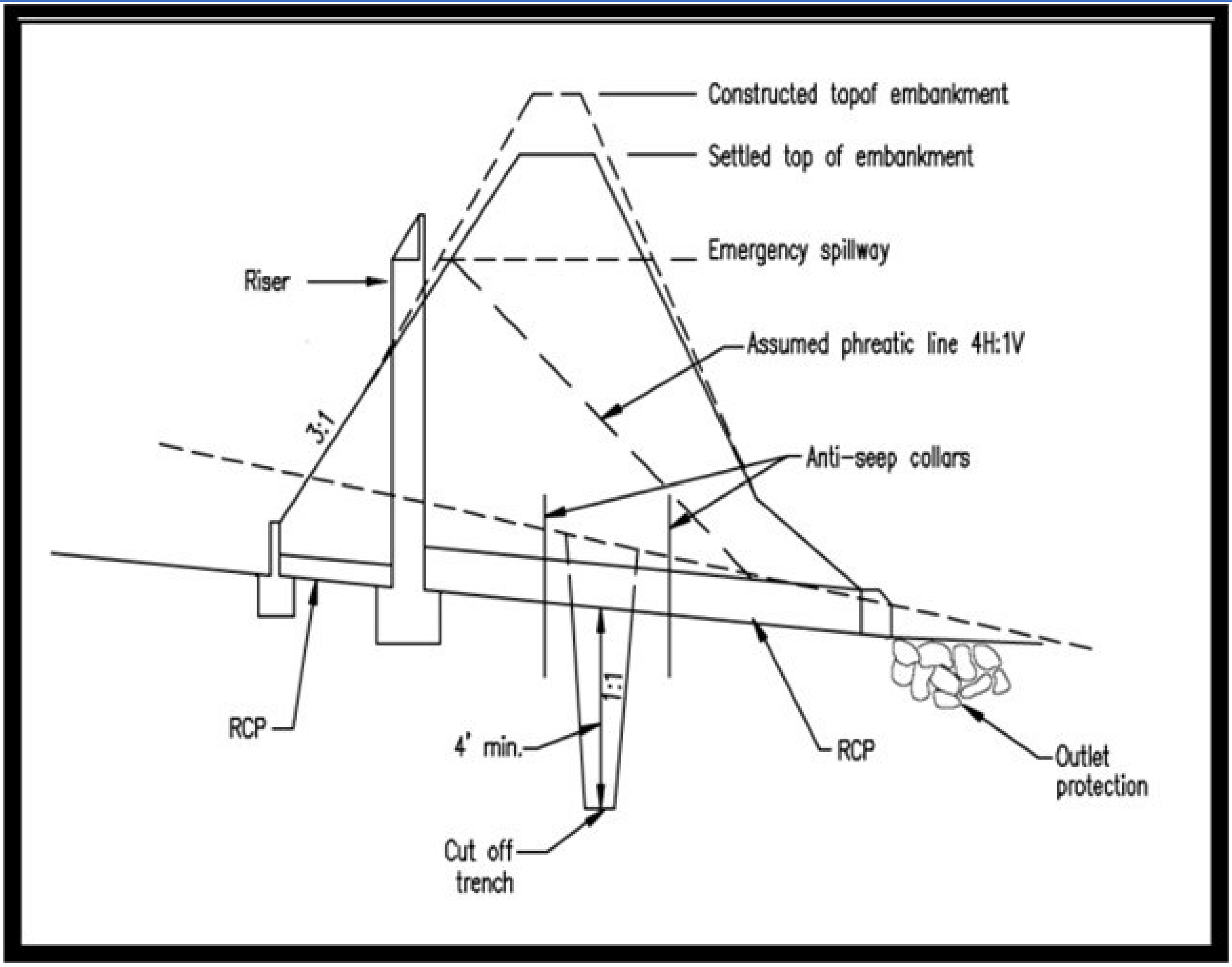
Z = slope of the upstream face of the embankment, in Z feet horizontal to 1 feet vertical (Z feet H:1V).

S = slope of the barrel, in feet per foot.

The length of pipe within the saturated zone can also be determined graphically on a scale profile of the embankment and barrel. The saturated zone of the embankment can be approximated as follows: starting at a point where the 10-year storm water surface elevation intersects the embankment slope, extend a line at a 4H:1V slope downward until it intersects the barrel. The area under this line represents the theoretical zone of saturation (refer to Figure A-35).

2. Determine the length required by multiplying 15% times the seepage length: 0.15 Ls. The increase in seepage length represents the total collar projection. This can be provided for by one or multiple collars.
3. Choose a collar size that is at least 4 feet larger than the barrel diameter (2 feet above and 2 feet below the barrel). For example, a 7-feet square collar would be selected for a 36-inch diameter barrel.
4. Determine the collar projection by subtracting the pipe diameter from the collar size.
5. Determine the number of collars required. The number of collars is found by dividing the seepage length increase, found in Step 2, by the collar projection from Step 4. To reduce the number of collars required, the collar size can be increased. Alternatively, the collar size can be decreased by providing more collars.

**Figure A-35 Phreatic Line Graphical Determination**




## A.8.5 Emergency Spillway Design

A vegetated emergency spillway is designed to convey a predetermined design flood volume without excessive velocities and without overtopping the embankment.

Two design methods are presented here. The first (Procedure 1) is a conservative design procedure which is also found in Sediment Basin specifications in Chapter 7 of this handbook. This procedure is typically acceptable for stormwater management basins. The second method (Procedure 2) utilizes the roughness, or retardance, and durability of the vegetation and soils within the vegetated spillway. This second design is appropriate for larger or regional stormwater facilities where construction inspection and permanent maintenance are more readily enforced. These larger facilities typically control relatively large watersheds and are located such that the stability of the emergency spillway is essential to safeguard downstream features.

The following design procedures establish a stage-discharge relationship (Hp versus Q) for a vegetated emergency spillway serving a stormwater management basin (refer to Figure A-36).

The information required for these designs includes the determination of the hydrology for the watershed draining to the basin. The design should include calculations for the allowable release rate from the basin if the spillway is to be used to control a design frequency storm. Otherwise, the design peak flow rate should be calculated based on the spillway design flood, or downstream conditions.

(In general, a vegetated emergency spillway should not be used as an outlet for any storm less than the 100-year frequency storm, unless it is armored with a non-erodible material. The designer must consider the depth of the riprap blanket when riprap is used to armor the spillway. As noted previously, Class I riprap would require a blanket thickness or stone depth of 30" which may add considerable height to the embankment.)

The design maximum water surface elevations for the emergency spillway should be at least 1 foot lower than the settled top of the embankment. Refer to P-SUP-03, Vegetated Emergency Spillways.

### A.8.5.1 Procedure 1

1. Determine the design peak rate of inflow from the spillway design flood into the basin using the developed condition hydrology or determine the allowable design peak release rate, Q, from the basin based on downstream conditions or watershed requirements.
2. Estimate the maximum water surface elevation and calculate the maximum flow through the riser and barrel system at this elevation (refer to the stage-storage-discharge table). Subtract this flow volume from the design peak rate of inflow to determine the desired maximum spillway design discharge.
3. Determine the crest elevation of the emergency spillway. This is usually a small increment (0.1 feet) above the design high water elevation of the next smaller storm, typically the 10-year frequency storm.
4. Enter Table A-29 with the maximum Hp value (maximum design water surface elevation from Step 2, less the crest elevation of the emergency spillway), and read across for the desired maximum spillway design discharge (from Step 2 above). Read the design bottom width of the emergency spillway (in feet) at the top of the table, and verify the minimum exit slope (s) and length (x), or;

   If a maximum bottom width (b) is known due to grading or topographic constraints, enter Table A-29 at the top with the desired bottom width and read down to find the desired discharge, Q, and then read across to the left to determine the required flow depth, Hp.

5. Add the appropriate Hp and discharge Q values to the stage-storage-discharge table.

**Example Procedure 1:**

Given:

Q = 250 cfs (determined from post-developed condition hydrology).

$s_o$ = 4% (slope of exit channel).

L = 50 feet (length of level section).

Find: Width of spillway, b, velocity, v, and depth of water above the spillway crest, Hp.

Solution: Complete Steps 1 through 5 of design Procedure 1 for vegetated emergency spillways by using the given information as follows:

1. Peak rate of inflow: given Q = 250 cfs.
2. The flow through the riser and barrel at the estimated maximum water surface elevation is calculated to be 163 cfs. The desired maximum spillway design discharge is 250 cfs – 163 cfs = 87 cfs, at a Hp value of 1.3 feet.
3. Emergency spillway excavated into undisturbed material. The slope of the exit channel and length and elevation of level section: given, so = 4%, L = 50 feet, elevation = 100.0 feet (given).

4. Enter Table A-29 with the desired Hp value of 1.3 ft. And read across to 86 cfs, and read up to a bottom width of 24 feet at the top of the table. The minimum exit channel slope is 2.7% which is less than 4% provided, and the length of exit channel is required to be 63 feet. The velocity within the exit channel is 4.7 feet/second at an exit channel slope of 2.7%. Since the provided exit channel slope is 4.0%, erosive velocities may warrant special treatment of the exit channel.
5. Add the elevation corresponding to 1.3 feet above the crest of the emergency spillway to the Stage-Storage-Discharge Worksheet.

### A.8.5.2 Procedure 2

1. Determine the design peak rate of inflow from the spillway design flood into the basin, using the developed condition hydrology, or determine the allowable design peak release rate, Q, from the basin based on downstream conditions or watershed requirements.
2. Estimate the maximum water surface elevation and calculate the associated flow through the riser and barrel system for this elevation. Subtract this flow value from the design peak rate of inflow to determine the desired maximum spillway design discharge.
3. Position the emergency spillway on the basin grading plan at an embankment abutment.
4. Determine the slope, so, of the proposed exit channel, and the length, L, and elevation of the proposed level section from the basin grading plan.
5. Classify the natural soils around the spillway as erosion resistant or easily erodible soils.
6. Determine the type and height of vegetative cover to be used to stabilize the spillway.
7. Determine the permissible velocity, v, from Table A-5b Permissible Velocity for Vegetated Spillways, based on the vegetative cover, soil classification, and the slope of the exit channel, so.
8. Determine the retardance classification of the spillway based on the type and height of vegetative cover from Table A-5c.
9. Determine the unit discharge of the spillway, q, in cubic feet per second per foot (cfs/ft), from Table A-30 (a-d) for the selected retardance, the maximum permissible velocity, v, and the slope of the exit channel, so.
10. Determine the required bottom width of the spillway, in feet, by dividing the allowable or design discharge, Q, by the spillway unit discharge, q:

*Equation A-42 Spillway Bottom Width Calculation*

$$\frac{Q(cfs)}{q(cfs/ft)} \cdot ft.$$

11. the level section, L.
12. Enter the stage-discharge information into the stage-storage-discharge table.

The following examples use Table A-5b and Table A-5c to find the capacity of a vegetated emergency spillway.

**Example Procedure 2:**

Given:

Q = 250 cfs (determined from post-developed condition hydrology).

$s_o$ = 4% (slope of exit channel).

L = 50 feet(length of level section).

Erosion resistant soils.

Sod forming grass-legume mixture cover, 6 to 10-inch height.

Find: Permissible velocity, v, width of spillway, b, depth of water above the spillway crest, Hp.

Solution: Complete Steps 1 through 12 of design Procedure 2 for vegetated emergency spillways by using the given information as follows:

1. Peak rate of inflow: given Q = 250 cfs.
2. The flow through the riser and barrel at the estimated maximum water surface elevation is calculated to be 163 cfs. The desired maximum spillway design discharge is 250 cfs – 163 cfs = 87 cfs.
3. Emergency spillway excavated into undisturbed material.
4. Slope of exit channel, and length and elevation of level section: given, so = 4%, L = 50 feet, elevation = 100.0 feet (given).
5. Soil classification: given, erosion resistant soils.
6. Vegetative cover: given, sod-forming grass-legume mixture.
7. Permissible velocity v = 5 ft./sec. from Table A-5b for sod-forming grass-legume mixtures, erosion resistant soils, and exit channel slope so = 4%.
8. Retardance classification, C, from Table A-5c for sod-forming grass-legume mixtures, expected height = 6 to 10 inches.
9. The unit discharge of the spillway q = 3 cfs/ft from Table A-30c for Retardance C, maximum permissible velocity v = 5 ft./sec., and exit channel slope so = 4%.
10. The required bottom width b = Q' q = 87 cfs/ 3 cfs/ft = 29 feet.
11. The depth of flow, Hp, from Table A-30c for Retardance C ; enter at q = 3 cfs/ft, find Hp = 1.4 feet for level section L = 50 feet.
12. The stage-discharge relationship: at stage elevation 1.4 feet above the spillway crest (101.4 feet), the discharge is 87 cfs.

**Example Procedure 2:**

Given:

Q = 175 cfs (determined from post-developed hydrology).

$s_o$ = 8 % (slope of exit channel).

L = 25 feet (length of level section).

Easily erodible soil.

Bahiagrass, good stand, 11 to 24 inches expected.

Find: Permissible velocity, v, width of spillway, b, depth of water above the spillway crest, Hp.

Analyze the spillway for stability during the vegetation establishment period, and capacity once adequate vegetation is achieved.

Solution: Complete Steps 1 through 12 of the design Procedure 2 for vegetated emergency spillways by using the given information as follows:

1. Q = 175 cfs.
2. The flow through the riser and barrel at the estimated maximum water surface elevation is calculated to be 75 cfs. The desired maximum spillway design discharge is 175 cfs – 75 cfs = 100 cfs.
3. Emergency spillway in undisturbed ground.
4. $s_o$ = 8 %; L = 25 feet, elevation = 418.0 feet (given)
5. Easily erodible soils.
6. Bahiagrass, good stand, 11 to 24 inches expected.
7. Permissible velocity, v = 5 ft./sec., from Table A-5b

Retardance used for stability during the establishment period – good stand of vegetation 2 to 6 inches; Retardance D.

8. Retardance used for capacity – good stand of vegetation 11 to 24 inches; Retardance B.
9. Unit discharge q = 2 cfs/ft for stability. From Table A-30d for Retardance D, permissible velocity, v = 5 ft./sec., and so = 8%
10. Bottom width b = Q/ q = 100 cfs/ 2 cfs/ ft = 50 feet (stability)
11. The depth of flow, Hp, for capacity. From Table A-30b for Retardance B, enter at q = 2 cfs/ft, find Hp = 1.4 feet for L = 25 feet.
12. The stage-discharge relationship: at stage (elevation) 1.4 feet above the spillway crest (419.4'), the discharge, Q, is 100 cfs.

**Table A-5b Permissible Velocity for Vegetated Spillways[1]**

| Vegetative Cover | Permissible Velocity[2] (feet per second) | | | |
|---|---|---|---|---|
| | Erosion Resistant Soils[3] | | Easily Erodible Soils[4] | |
| | Slope of Exit Channel | | Slope of Exist Channel | |
| | 0-5% | 5-10% | 0-5% | 5-10% |
| Bermuda grass | 8 | 7 | 6 | 5 |
| Buffalograss<br>Kentucky Bluegrass<br>Smooth Bromegrass<br>Tall Fescue | 7 | 6 | 5 | 4 |
| Sod Forming Grass-legume mixture | 5 | 4 | 4 | 3 |
| Lespedeza<br>Weeping Lovegrass<br>Yellow Bluestem<br>Native Grass Mixtures | 3.5 | 3.5 | 2.5 | 2.5 |

**Notes:**

1 Source: NRCS National Engineering Handbook, Part 654, Chapter 8, Table 8-6 (2007).

2 Greatest mean velocity that will not cause the channel boundary to erode.

3 Those with a high clay content and high plasticity. Typical soil textures are silty clay, sandy clay, and clay.

4 Those with a high content of fine sand or silty and lower plasticity or non-plastic. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

| Table A-5c Retardance Classifications for Vegetated Channel Linings | | | |
|---|---|---|---|
| **Retardance** | **Vegetative Cover** | **Stand** | **Condition** |
| B | Tall Fescue | Good | Unmowed - 18" |
| | Grass-Legume Mixture | Good | Unmowed - 20" |
| | Small Grains, Mature | Good | Uncut - 19" |
| | Bermuda Grass Reed | Good | Tall - 12" |
| | Canary Grass | Good | Mowed - 14" |
| C | Bermuda Grass | Good | Mowed - 6" |
| | Redtop | Good | Headed - 18" |
| | Grass-Legume Mixture - Summer | Good | Unmowed - 7" |
| | Kentucky Bluegrass | Good | Headed - 9" |
| | Small Grains, Mature | Poor | Uncut - 19" |
| | Tall Fescue | Good | Mowed - 6" |
| D | Bermuda Grass | Good | Mowed - 2.5" |
| | Red Fescue | Good | Headed - 15" |
| | Grass-Legume Mixture - spring and fall | Good | Unmowed - 5" |

Source: NRCS National Engineering Handbook, Part 654, Chapter 8, Table 8-7 (2007).

# Table A-29 Design Data for Earth Spillways

| STAGE (Hp) IN FEET | SPILLWAY VARIABLES | BOTTOM WIDTH (b) IN FEET | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
| 0.5 | Q | 6 | 7 | 8 | 10 | 11 | 13 | 14 | 15 | 17 | 18 | 20 | 21 | 22 | 24 | 25 | 27 | 28 |
| | V | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| | S | 3.9 | 3.9 | 3.9 | 3.9 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 |
| | X | 32 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 |
| 0.6 | Q | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 35 | 37 | 39 |
| | V | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | S | 3.7 | 3.7 | 3.7 | 3.7 | 3.6 | 3.7 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | X | 36 | 36 | 36 | 36 | 36 | 36 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 |
| 0.7 | Q | 11 | 13 | 16 | 18 | 20 | 23 | 25 | 28 | 30 | 33 | 35 | 38 | 41 | 43 | 44 | 46 | 48 |
| | V | 3.2 | 3.2 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| | S | 3.5 | 3.5 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |
| | X | 39 | 40 | 40 | 40 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 |
| 0.8 | Q | 13 | 16 | 19 | 22 | 26 | 29 | 32 | 35 | 38 | 42 | 45 | 46 | 48 | 51 | 54 | 57 | 60 |
| | V | 3.5 | 3.5 | 3.5 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| | S | 3.3 | 3.3 | 3.3 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| | X | 44 | 44 | 44 | 44 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 | 45 |
| 0.9 | Q | 17 | 20 | 24 | 28 | 32 | 35 | 39 | 43 | 47 | 51 | 53 | 57 | 60 | 64 | 68 | 71 | 75 |
| | V | 3.7 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 |
| | S | 3.2 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| | X | 47 | 47 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 49 | 49 | 49 | 49 | 49 | 49 | 49 |
| 1.0 | Q | 20 | 24 | 29 | 33 | 38 | 42 | 47 | 51 | 56 | 61 | 63 | 68 | 72 | 77 | 81 | 86 | 90 |
| | V | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| | S | 3.1 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| | X | 51 | 51 | 51 | 51 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| 1.1 | Q | 23 | 28 | 34 | 39 | 44 | 49 | 54 | 60 | 65 | 70 | 74 | 79 | 84 | 89 | 95 | 100 | 105 |
| | V | 4.2 | 4.2 | 4.2 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 | 4.3 |
| | S | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| | X | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| 1.2 | Q | 28 | 33 | 40 | 45 | 51 | 58 | 64 | 69 | 76 | 80 | 86 | 92 | 98 | 104 | 110 | 116 | 122 |
| | V | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| | S | 2.9 | 2.9 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| | X | 58 | 58 | 59 | 59 | 59 | 59 | 59 | 59 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| 1.3 | Q | 32 | 38 | 46 | 53 | 58 | 65 | 73 | 80 | 86 | 91 | 99 | 106 | 112 | 119 | 125 | 133 | 140 |
| | V | 4.5 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 | 4.7 |
| | S | 2.8 | 2.8 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| | X | 62 | 62 | 62 | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 64 | 64 | 64 | 64 | 64 | 64 |
| 1.4 | Q | 37 | 44 | 51 | 59 | 66 | 74 | 82 | 90 | 96 | 103 | 111 | 119 | 127 | 134 | 142 | 150 | 158 |
| | V | 4.7 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.8 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 | 4.9 |
| | S | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| | X | 65 | 66 | 66 | 66 | 66 | 67 | 67 | 67 | 67 | 67 | 67 | 68 | 68 | 68 | 68 | 68 | 69 |
| 1.5 | Q | 41 | 50 | 58 | 66 | 75 | 85 | 92 | 101 | 108 | 116 | 125 | 133 | 142 | 150 | 160 | 169 | 178 |
| | V | 4.8 | 4.9 | 4.9 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.1 | 5.1 | 5.1 |
| | S | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 |
| | X | 69 | 69 | 70 | 70 | 71 | 71 | 71 | 71 | 71 | 71 | 71 | 72 | 72 | 72 | 72 | 72 | 72 |
| 1.6 | Q | 46 | 56 | 65 | 75 | 84 | 94 | 104 | 112 | 122 | 132 | 142 | 149 | 158 | 168 | 178 | 187 | 197 |
| | V | 5.0 | 5.1 | 5.1 | 5.1 | 5.1 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 |
| | S | 2.6 | 2.6 | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| | X | 72 | 74 | 74 | 75 | 75 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 | 76 |
| 1.7 | Q | 52 | 62 | 72 | 83 | 94 | 105 | 115 | 126 | 135 | 145 | 156 | 167 | 175 | 187 | 196 | 206 | 217 |
| | V | 5.2 | 5.2 | 5.2 | 5.3 | 5.3 | 5.3 | 5.3 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 |
| | S | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| | X | 76 | 78 | 79 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| 1.8 | Q | 58 | 69 | 81 | 93 | 104 | 116 | 127 | 138 | 150 | 160 | 171 | 182 | 194 | 204 | 214 | 226 | 233 |
| | V | 5.3 | 5.4 | 5.4 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.5 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 | 5.6 |
| | S | 2.5 | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| | X | 80 | 82 | 83 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 | 84 |
| 1.9 | Q | 64 | 76 | 88 | 102 | 114 | 127 | 140 | 152 | 164 | 175 | 188 | 201 | 213 | 225 | 235 | 248 | 260 |
| | V | 5.5 | 5.5 | 5.5 | 5.6 | 5.6 | 5.6 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 | 5.7 |
| | S | 2.5 | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| | X | 84 | 85 | 86 | 87 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 | 88 |
| 2.0 | Q | 71 | 83 | 97 | 111 | 125 | 138 | 153 | 164 | 178 | 193 | 204 | 218 | 232 | 245 | 256 | 269 | 283 |
| | V | 5.6 | 5.7 | 5.7 | 5.7 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 |
| | S | 2.5 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| | X | 88 | 90 | 91 | 91 | 91 | 91 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 | 92 |
| 2.1 | Q | 77 | 91 | 107 | 122 | 135 | 149 | 162 | 177 | 192 | 207 | 220 | 234 | 250 | 267 | 276 | 291 | 305 |
| | V | 5.7 | 5.8 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| | S | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| | X | 92 | 93 | 95 | 95 | 95 | 95 | 95 | 95 | 95 | 96 | 96 | 96 | 96 | 96 | 96 | 96 | 96 |
| 2.2 | Q | 84 | 100 | 116 | 131 | 146 | 163 | 177 | 194 | 210 | 224 | 238 | 253 | 269 | 288 | 301 | 314 | 330 |
| | V | 5.9 | 5.9 | 6.0 | 6.0 | 6.0 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.2 | 6.2 | 6.2 | 6.2 |
| | S | 2.4 | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 |
| | X | 96 | 98 | 99 | 99 | 99 | 99 | 99 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2.3 | Q | 90 | 108 | 124 | 140 | 158 | 175 | 193 | 208 | 226 | 243 | 258 | 275 | 292 | 306 | 323 | 341 | 354 |
| | V | 6.0 | 6.1 | 6.1 | 6.1 | 6.2 | 6.2 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 |
| | S | 2.4 | 2.4 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| | X | 100 | 102 | 102 | 103 | 103 | 103 | 104 | 104 | 104 | 105 | 105 | 105 | 105 | 105 | 105 | 105 | 105 |
| 2.4 | Q | 99 | 116 | 136 | 152 | 170 | 189 | 206 | 224 | 241 | 260 | 275 | 294 | 312 | 327 | 346 | 364 | 378 |
| | V | 6.1 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 | 6.4 |
| | S | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| | X | 105 | 105 | 106 | 107 | 107 | 108 | 108 | 108 | 108 | 109 | 109 | 109 | 109 | 109 | 109 | 109 | 109 |

*Source: USDA - SCS*

| Table A-30a Hp and Slope Range for Discharge, Velocity and Crest Length – Retardance A | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum Velocity, *v* (feet per second) | Unit Discharge, q (cubic feet per second) | 25-Foot-Long Level Section*, L (feet) | 50-Foot-Long Level Section*, L (feet) | 100-Foot-Long Level Section*, L (feet) | 200-Foot-Long Level Section*, L (feet) | Minimum Slope Range, So, (%) | Maximum Slope Range, So, (%) |
| 3 | 3 | 2.3 | 2.5 | 2.7 | 3.1 | 1 | 11 |
| 4 | 4 | 2.3 | 2.5 | 2.8 | 3.1 | 1 | 12 |
| 4 | 5 | 2.5 | 2.6 | 2.9 | 3.2 | 1 | 7 |
| 5 | 6 | 2.6 | 2.7 | 3.0 | 3.3 | 1 | 9 |
| 6 | 7 | 2.7 | 2.8 | 3.1 | 3.5 | 1 | 12 |
| 7 | 10 | 3.0 | 3.2 | 3.4 | 3.8 | 1 | 9 |
| 8 | 12.5 | 3.3 | 3.5 | 3.7 | 4.1 | 1 | 10 |

**Note:** Compute Depth of Water Above Spillway as Hp (feet). Source: Soil Conservation Service (SCS) Engineering Manual.

| Table A-30b Hp Slope Range for Discharge, Velocity, and Crest Length – Retardance B | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum Velocity, *v* (feet per second) | Unit Discharge, q (cubic feet per second) | 25-Foot-Long Level Section*, L (feet) | 50-Foot-Long Level Section*, L (feet) | 100-Foot-Long Level Section*, L (feet) | 200-Foot-Long Level Section*, L (feet) | Minimum Slope Range, So, (%) | Maximum Slope Range, So, (%) |
| 2 | 1 | 1.2 | 1.4 | 1.5 | 1.8 | 1 | 12 |
| 2 | 1.25 | 1.3 | 1.4 | 1.6 | 1.9 | 1 | 7 |
| 3 | 1.5 | 1.3 | 1.5 | 1.7 | 1.9 | 1 | 12 |
| 3 | 2 | 1.4 | 1.5 | 1.7 | 1.9 | 1 | 8 |
| 4 | 3 | 1.6 | 1.7 | 1.9 | 2.2 | 1 | 9 |
| 5 | 4 | 1.8 | 1.9 | 2.1 | 2.4 | 1 | 8 |
| 6 | 5 | 1.9 | 2.1 | 2.3 | 2.5 | 1 | 10 |
| 7 | 6 | 2.1 | 2.2 | 2.4 | 2.7 | 1 | 11 |
| 8 | 7 | 2.2 | 2.4 | 2.6 | 2.9 | 1 | 12 |

**Note:** Compute Depth of Water Above Spillway as *Hp* (feet). Source: Soil Conservation Service (SCS) Engineering Manual.

| Table A-30c Hp and Slop Range for Discharge, Velocity, and Crest Length – Retardance C | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum Velocity, *v* (feet per second) | Unit Discharge, q (cubic feet per second) | 25-Foot-Long Level Section*, L (feet) | 50-Foot-Long Level Section*, L (feet) | 100-Foot-Long Level Section*, L (feet) | 200-Foot-Long Level Section*, L (feet) | Minimum Slope Range, So, (%) | Maximum Slope Range, So, (%) |
| 2 | 0.5 | 0.7 | 0.8 | 0.9 | 1.1 | 1 | 6 |
| 2 | 1 | 0.9 | 1.0 | 1.2 | 1.3 | 1 | 3 |
| 3 | 1.25 | 0.9 | 1.0 | 1.2 | 1.3 | 1 | 6 |
| 4 | 1.5 | 1.0 | 1.1 | 1.2 | 1.4 | 1 | 12 |
| 4 | 2 | 1.1 | 1.2 | 1.4 | 1.6 | 1 | 7 |
| 5 | 3 | 1.3 | 1.4 | 1.6 | 1.8 | 1 | 6 |
| 6 | 4 | 1.5 | 1.6 | 1.8 | 2.0 | 1 | 12 |
| 8 | 5 | 1.7 | 1.8 | 2.0 | 2.2 | 1 | 12 |
| 9 | 6 | 1.8 | 2.0 | 2.1 | 2.4 | 1 | 12 |
| 9 | 7 | 2.0 | 2.1 | 2.3 | 2.5 | 1 | 10 |
| 10 | 7.5 | 2.1 | 2.2 | 2.4 | 2.6 | 1 | 12 |

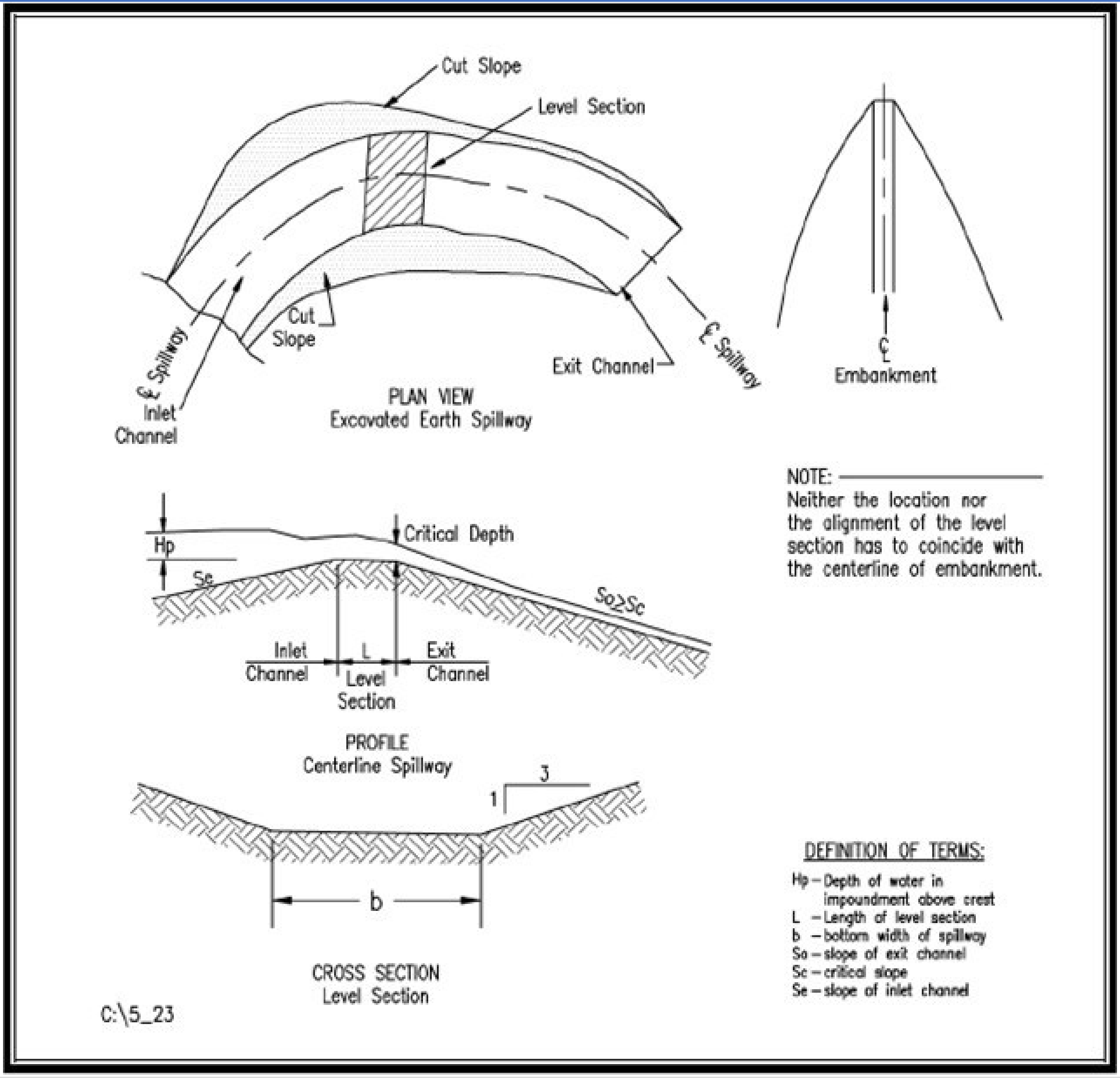
**Note:** Compute Depth of W5ater Above Spillway as *Hp* (feet). Source: Soil Conservation Service (SCS) Engineering Manual.

| Table A-30d Hp Slope Range of Discharge, Velocity, and Crest Length – Retardance D | | | | | | | |
|---|---|---|---|---|---|---|---|
| Maximum Velocity, *v* (feet per second) | Unit Discharge, q (cubic feet per second) | 25-Foot-Long Level Section*, L (feet) | 50-Foot-Long Level Section*, L (feet) | 100-Foot-Long Level Section*, L (feet) | 200-Foot-Long Level Section*, L (feet) | Minimum Slope Range, So, (%) | Maximum Slope Range, So, (%) |
| 2 | 0.5 | 0.6 | 0.6 | 0.8 | 0.9 | 1 | 6 |
| 3 | 1 | 0.8 | 0.8 | 1.0 | 1.1 | 1 | 6 |
| 3 | 1.25 | 0.8 | 0.8 | 1.0 | 1.2 | 1 | 4 |
| 4 | 1.5 | 0.8 | 0.8 | 1.0 | 1.2 | 1 | 10 |
| 4 | 2 | 1.0 | 1.0 | 1.3 | 1.4 | 1 | 4 |
| 5 | 1.5 | 0.9 | 0.9 | 1.2 | 1.3 | 1 | 12 |
| 5 | 2 | 1.0 | 1.0 | 1.3 | 1.4 | 1 | 9 |
| 5 | 3 | 1.2 | 1.1 | 1.5 | 1.7 | 1 | 4 |
| 6 | 2.5 | 1.1 | 1.2 | 1.4 | 1.5 | 1 | 11 |

| Table A-30d Hp Slope Range of Discharge, Velocity, and Crest Length – Retardance D | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Maximum Velocity, *v* (feet per second)** | **Unit Discharge, q (cubic feet per second)** | **25-Foot-Long Level Section*, L (feet)** | **50-Foot-Long Level Section*, L (feet)** | **100-Foot-Long Level Section*, L (feet)** | **200-Foot-Long Level Section*, L (feet)** | **Minimum Slope Range, So, (%)** | **Maximum Slope Range, So, (%)** |
| 6 | 3 | 1.2 | 1.3 | 1.5 | 1.7 | 1 | 7 |
| 7 | 3 | 1.2 | 1.2 | 1.5 | 1.7 | 1 | 12 |
| 7 | 4 | 1.4 | 1.5 | 1.7 | 1.9 | 1 | 7 |
| 8 | 4 | 1.4 | 1.5 | 1.7 | 1.9 | 1 | 12 |
| 8 | 5 | 1.6 | 1.7 | 1.9 | 2.0 | 1 | 8 |
| 10 | 6 | 1.8 | 1.9 | 2.0 | 2.2 | 1 | 12 |

**Note:** Compute Depth of W5ater Above Spillway as *Hp* (feet). Source: Soil Conservation Service (SCS) Engineering Manual.

**Figure A-36 Vegetated Emergency Spillways: Typical Plan and Section**




## A.8.6 Water Balance Analysis

This is applicable to wet ponds, wet swales, wetlands, and enhanced (Level 2) extended detention. The design specifications reference the use of water balance for determining the depth of the pools. The water balance analysis here provides feasibility of the practice. The water balance analysis also helps determine if a drainage area is large enough to support a permanent pool during normal conditions. The maximum draw down due to evaporation and infiltration is checked against the anticipated inflows during that same period. The anticipated drawdown during an extended period of no appreciable rainfall is checked as well. This will also help establish a planting zone for vegetation which can tolerate the dry conditions of a periodic draw down of the permanent pool.

The water balance is defined as the change in volume of the permanent pool resulting from the potential total inflow less the potential total outflow.

Change volume = inflows – outflows

Where:

inflows = runoff, baseflow, and rainfall.

Outflows = infiltration, surface overflow, evaporation, and evapotranspiration.

This procedure will assume no inflow from baseflow, and because only the permanent pool volume is being evaluated, no losses for surface overflows. In addition, infiltration should be addressed by a geotechnical report. A clay liner should be specified in accordance with P-SUP-01 if the analysis of the existing soils indicates excessive infiltration. In many cases, the permeability of clayey soils will be reduced to minimal levels due to the clogging of the soil pores by the fines which eventually settle out of the water column. This may be considered in the water balance equation by assuming the permeability of a clay liner: 1 x 10-6 cm/s (3.94 x 10-7 in/sec.) per specifications. Therefore, the change in storage = runoff – evaporation – infiltration.

Example

Given:

| | |
|---|---|
| Permanent Pool Volume: | Level 1 Wet Pond: Total BMP Treatment Volume = 400,000 $ft^3$ = 9.18 ac-ft |
| Permanent Pool Surface area: | 2.4 ac. |
| Infiltration (clay liner per specs.): | 1 x $10^{-6}$ cm/s (3.94 x 10-7 in./sec.) |

Find:

a. Draw down during highest period of evaporation.

b. Draw down during extended period of no appreciable rainfall.

Solution:

a. Draw down during highest period of evaporation: July

Inflow = Monthly Runoff = P x E

Where:

P = precipitation

E = efficiency of runoff (assumed to be ratio of SCS runoff depth to rainfall depth for 2 year storm)

= 1.1 in./ 3.1” = 0.35

(From Table A-32 and A-33)

Inflow: Runoff = 5.03 in. × 0.35 = 1.76 in. = 1.76 in. × 85 ac. ÷ 12 in./ft. = 12.5 acre-feet Outflow: Evaporation = 2.4 ac. × 6.23 in. ÷ 12 in./ft. = 1.24 acre-feet

Infiltration (w/ liner) = 2.4 ac. × (3.94 × 10G7 in./sec.) (3600 sec./hr.) (24 hour/day) (31 days) ÷ (12 in./ft.) = 0.21 acre-feet.

**Water balance** (w/ liner) = (inflow) – (outflow) = (12.5 acre-feet) – (1.24 + 0.21) acre-feet = + 11.05 acre- feet

Infiltration (w/o liner); assume infiltration rate of 0.02 in./hr. (clay/silty clay) =

A.4438 ac. × 0.02 in./hr. × (24 hour/day) (31 days) ÷ 12 in./ft. = 2.97 acre-feet

**Water balance** (w/o liner) = (12.5 acre-feet) – (2.97 + 0.21) acre-feet = + 9.32 acre-feet

| Table A-31 Example Water Balance Precipitation and Evaporation | | | | | |
|---|---|---|---|---|---|
| | April | May | June | July | August |
| Precipitation (inches) | 2.96 | 3.84 | 3.62 | 5.03 | 4.40 |
| Evaporation (inches) | 2.28 | 3.89 | 5.31 | 6.23 | 5.64 |

b. Drawdown during periods of no appreciable rainfall. Assume a 45-day period during July and August with no rainfall.

Inflow: unoff = 0”

Outflow: Evaporation = Avg. evaporation (July-Aug.) = 6.23 in. + 5.64 in. ÷ 2 = 5.93 in.

Avg. daily evaporation = 5.93 in. ÷ 31 days = 0.191 in./day Evaporation for 45 days = 45 days × 0.191 in./day = 8.61 in.

Total evaporation = 2.4 ac. × 8.61 in. ÷ 12 in./ft. = 1.7 acre-feet

Infiltration (w/ liner): 2.4 ac. × (3.94 x 10-7 in./sec.) (3600 sec./hr.) (24 hour/day) (45 days) ÷12 in./ft. = 0.30 acre-feet

**Water balance** ( w/ liner): ( 0 ) – (1.7 + 0.30) acre-feet = –2.0 acre-feet

Specify drawdown tolerant plants in areas corresponding to a depth of 2.0 acre-feet (use stage storage curve).

Infiltration (w/o liner): 2.4 ac.× (.02 in./hr.) (24 hour/day) (45 day) ÷ 12 in./ft. = 4.32 acre-feet

**Water balance** ( w/o liner): ( 0 ) – (1.7 + 4.32) acre-feet = – 6.02 acre-feet

This basin (without a liner) will experience a significant draw down during drought conditions. Over time, the rate of infiltration may decrease due to the clogging of the soil pores. However, the aquatic and wetland plants may not survive the potential drought conditions and subsequent draw down during the first few years, and eventually give way to invasive species.

Note: A permanent pool volume of 9.18 acre-feet = 1.29 watershed inches. A rainfall event yielding 1.29” or more of runoff will fill the pool volume.

| Table A-32 Typical Monthly Precipitation (inches) | | | | | | |
|---|---|---|---|---|---|---|
| Station | April | May | June | July | August | September |
| Charlottesville | 3.34 | 4.88 | 3.74 | 4.75 | 4.71 | 4.10 |
| Danville | 3.24 | 3.85 | 3.65 | 4.42 | 3.80 | 3.39 |
| Farmville | 3.03 | 4.05 | 3.41 | 4.34 | 3.99 | 3.18 |
| Fredericksburg | 3.05 | 3.85 | 3.35 | 3.65 | 3.61 | 3.49 |
| Hot Springs | 3.43 | 4.15 | 3.36 | 4.49 | 3.70 | 3.39 |
| Lynchburg | 3.09 | 3.91 | 3.45 | 4.16 | 3.59 | 3.24 |
| Norfolk | 3.06 | 3.81 | 3.82 | 5.06 | 4.81 | 3.90 |
| Page County | 3.84 | 4.77 | 4.41 | 4.50 | 4.34 | 4.81 |
| Pennington Gap | 4.25 | 4.83 | 4.09 | 4.77 | 3.76 | 3.67 |
| Richmond | 2.98 | 3.84 | 3.62 | 5.03 | 4.40 | 3.34 |

| Table A-32 Typical Monthly Precipitation (inches) | | | | | | |
|---|---|---|---|---|---|---|
| Station | April | May | June | July | August | September |
| Roanoke | 3.25 | 3.98 | 3.19 | 3.91 | 4.15 | 3.50 |
| Staunton | 2.82 | 3.60 | 2.95 | 3.49 | 3.67 | 3.46 |
| Washington National Airport | 2.31 | 3.66 | 3.38 | 3.80 | 3.91 | 3.31 |
| Williamsburg | 3.01 | 4.52 | 4.03 | 4.96 | 4.72 | 4.25 |
| Winchester | 3.08 | 3.74 | 3.87 | 3.89 | 3.46 | 3.11 |
| Wytheville | 3.09 | 3.95 | 3.03 | 4.20 | 3.44 | 3.09 |

Source: Virginia Department of Environmental Services, Virginia State Climatology Office, Charlottesville, Virginia

| Table A-33 Potential Evapotranspiration (Inches), Calculated by the Thornthwaite Method | | | | | | |
|---|---|---|---|---|---|---|
| Station | April | May | June | July | August | September |
| Charlottesville | 2.24 | 3.84 | 5.16 | 6.04 | 5.45 | 3.87 |
| Danville | 2.35 | 3.96 | 5.31 | 6.23 | 5.69 | 3.91 |
| Farmville | 2.34 | 3.81 | 5.13 | 6.00 | 5.41 | 3.71 |
| Fredericksburg | 2.11 | 3.80 | 5.23 | 6.11 | 5.46 | 3.83 |
| Hot Springs | 1.94 | 3.41 | 4.50 | 5.14 | 4.69 | 3.33 |
| Lynchburg | 2.21 | 3.72 | 4.99 | 5.85 | 5.31 | 3.70 |
| Norfolk | 2.20 | 3.80 | 5.37 | 6.34 | 5.79 | 4.14 |
| Page County | 1.68 | 3.06 | 4.09 | 4.71 | 4.26 | 3.05 |
| Pennington Gap | 2.14 | 3.59 | 4.72 | 5.45 | 4.97 | 3.60 |
| Richmond | 2.28 | 3.89 | 5.31 | 6.23 | 5.64 | 3.92 |
| Roanoke | 2.20 | 3.75 | 4.99 | 5.85 | 5.30 | 3.67 |
| Staunton | 2.00 | 3.52 | 4.77 | 5.52 | 4.95 | 3.47 |
| Washington National Airport | 2.13 | 3.87 | 5.50 | 6.51 | 5.84 | 4.06 |
| Williamsburg | 2.27 | 3.86 | 5.23 | 6.14 | 5.61 | 3.97 |
| Winchester | 2.07 | 3.68 | 4.99 | 5.82 | 5.26 | 3.67 |
| Wytheville | 2.01 | 3.43 | 4.46 | 5.17 | 4.71 | 3.39 |

Source: Virginia Department of Environmental Services, Virginia State Climatology Office, Charlottesville, Virginia

## A.8.7 Open Channel Flow Computations

Refer to the VDOT Drainage Manual for open channel flow computations. Specifically, Chapters 7 for ditches and channel.

VDOT Drainage Manual: https://www.virginiadot.org/business/locdes/hydra-drainage-manual.asp

Chapter 8 Ditches and Channels: https://www.virginiadot.org/business/resources/LocDes/DrainageManual/chapter7.pdf

### A.8.8 Storm Drains and Culvert Computations

Refer to the VDOT Drainage Manual for storm drain and culvert computations. Specifically, Chapters 8 and 9 for culverts and storm drains, respectively.

VDOT Drainage Manual: https://www.virginiadot.org/business/locdes/hydra-drainage-manual.asp

Chapter 8 Culverts: https://www.virginiadot.org/business/resources/LocDes/DrainageManual/chapter8.pdf

Chapter 9 Storm Drains: https://www.virginiadot.org/business/resources/LocDes/DrainageManual/chapter9.pdf

When confirming manmade stormwater conveyance systems confine the post-development peak flow rate from the 10-year 24-hour storm within the system (Flood Protection Criteria or MS-19 part 2.b.c), designers should also consider the impacts that headwater conditions have on the surrounding areas. Headwater can affect the capacity of upstream adjoining channels. Erosion and Sediment Control measures should be implemented to protect against scour from headwater damage.

## A.9 Stormwater Computer Models

In urban stormwater management there are typically three types of models used commonly: hydrologic, hydraulic and water quality models. There are also a number of other specialty models to simulate ancillary issues (some of which are sub-sets of the three main categories) such as sediment transport, channel stability, lake quality, dissolved oxygen and evapotranspiration. This appendix includes information about a number of useful models, some in the public domain and available for free, and others that are proprietary, for which prices can vary dramatically. The models described in this appendix are some of the most popular models in current use, but inclusion of their descriptions does not constitute any endorsement of their use by VDEQ or the Commonwealth of Virginia.

Hydrologic Models attempt to simulate the rainfall-runoff process to tell us “how much runoff, how often.” They use rainfall information or simulations and land cover characteristics to provide runoff characteristics including peak flow rates, flood hydrographs and flow frequencies. Hydrologic models can be:

- Deterministic – giving one answer for a specific input set; OR
- Stochastic – involving random inputs giving any number of responses for a given set of parameters.
- Single Event – simulating one storm event.
- Continuous – simulating many storm events over a period of time; OR
- Lumped – representing a large watershed by a single set of parameters; OR
- Distributed – watersheds are broken into many small homogeneous subwatersheds, each of which has a complete hydrologic calculation made on it.

Hydraulic Models take a known flow amount (typically the output of a hydrologic model) and provide information about flow height, location, velocity, direction and pressure. Hydraulic models share some of the differing characteristics of hydrologic models (continuous vs. single event) and add:

- One-dimensional – calculating flow information in one direction (e.g., downstream) only; OR

- Multi-dimensional – calculating flow information in several dimensions (e.g., in and out of the channel and downstream). Two-dimensional models are particularly useful when the overall channel pattern changes and bank erosion are concerns.
- Steady – having a single unchanging flow velocity value at a point in the system; OR
- Unsteady – having flow velocities that change with time at a point in the system.
- Uniform – a state of steady flow when the mean velocity and cross-sectional area remain constant over distance in all sections of a reach (assuming the channel slope and energy slope are equal); OR
- Non-uniform – a state of dynamic flow over distance (derived by solving a more complex formulation of the energy and momentum equations).

For most problems encountered in hydraulics, a simple one-dimensional, steady model will work well. But if the volume and time distribution of flow are important (for example, in a steeper stream with storage behind a series of high culvert embankments) or the behavior of a channel over a storm hydrograph is needed, then an unsteady model is called for. If there is a need to predict with accuracy the ebb and flow of floodwater out of a channel (for example in a wide, flat floodplain where there are relief openings under a road) or bank erosion potential, then a 2-dimensional model becomes necessary. If pressure flow and the accurate computation of a hydraulic grade line are important, then an unsteady, non-uniform model with pressure flow calculating capabilities is needed.

## A.9.1 Water Quality Models

The goal in water quality modeling is to adequately simulate the various processes and interactions of stormwater pollution. Water quality models have been developed with an ability to predict loadings of various types of stormwater pollutants.

Water quality models can become very complex if the complete cycle of buildup, wash-off and impact are determined. These models share the various features of hydrologic and hydraulic models in that it is the runoff flow that carries the pollutants. Therefore, a continuous hydrologic model with estimated pollution concentrations becomes a continuous water quality pollution model. Water quality models can reflect pollution from both point and nonpoint sources.

Water quality models tend to have applications that are targeted toward specific pollutants, source types or receiving waters. Some models involve biological processes as well as physical and chemical processes. Often great simplifications or gross assumptions are necessary to be able to model pollutant accumulations, transformations and eventual impacts. Such simplifications cannot be disregarded when interpreting model results.

Simple spreadsheet-based loading models involve an estimate of the runoff volume which, when multiplied by an event mean concentration, provide an estimate of the total pollution loading. Because of the lack of ability to calibrate such models for variable physical parameters, such simple models tend to be more accurate when they reflect a longer time period over which the pollution load is averaged. An annual pollutant load prediction may tend toward a central estimate, while any specific storm prediction may be grossly in error when compared to actual loadings because antecedent conditions vary widely from week to week. In reality, it is easy for one storm to discharge a lot of P and N that can then get masked by a lot of smaller storms. Unless each storm's loading is considered (which can also be done rather simply using spreadsheet programs), we may not be able to accurately identify the actual sources of these inputs, which must be addressed to effectively reduce stormwater pollution.

On the other hand, simulation models have the ability to adjust a number of loading parameters for calibration purposes and can simulate pollution accumulation over a long period. They can then more reliably predict loadings for any specific storm event.

Calibration data is always recommended in hydrologic or hydraulic models for an acceptably accurate answer. In water quality models the non-calibrated prediction is often off by orders of magnitude. Water quality predictions are not credible without adequate site-specific data for calibration and verification. However, even without specifically accurate loading values, the relative effects of pollution abatement controls can be tested using uncalibrated models. But actual site-specific data should be incorporated whenever possible. Sampling is at a point where a small amount of localized data can be easily collected and will significantly improve the model's results.

## A.9.2 Computer Model Applications

Stormwater computer models can also be categorized by their use or application:

- Screening-level models are typically equations or spreadsheet models that give a first estimate of the magnitude of urban runoff quality or quantity. Sometimes this is the only level that is necessary to provide answers, when the answer needs to be only approximate or because there is no data to justify a more refined procedure. The user should then consider efforts to collect more data in order to utilize more sophisticated models to achieve a more robust answer.
- Planning-level models are used to perform "what if" analyses, comparing design alternatives or control options in a general way. They are used to establish flow frequencies, floodplain boundaries, and general pollution loading values.
- Design-level models are oriented toward the detailed simulation of a single storm event for the purposes of urban stormwater design. They provide a more complete description of flow or pollution values anywhere in the system of concern and allow for adjustment of various input and output variables in some detail. They can be more exact in the impact of control options and tend to have a better ability to be calibrated to fit observed data.
- Operational models are used to produce actual control decisions during a storm event. They are often linked with SCADA systems. They are often developed from modified or strongly calibrated design models or can be developed on a site-specific basis to appropriately link with the system of concern and accurately model the important physical phenomena.

## A.9.3 The Modeling Process

The overall modeling process involves: (1) development of study or model objectives, (2) identification of resources and constraints, (3) selection and implementation of the model itself, and (4) identification of the data needed to run the model.

### A.9.3.1 Model Objectives

It is important to know specifically what answers are needed, to what accuracy, and in what format. Requiring a simple peak flow is far different from needing to know the timing of peaks from several different intersecting watersheds. Estimating future floodplain elevations along a reach is a fundamentally different problem than finding the probability of roadway overtopping.

A review of the problem begins the process of determining the model objectives. These objectives also establish a performance or design criteria for the model. Must the system handle the 25-year storm? Are future conditions important? Which ones? Are annual loadings of pollution adequate? Which pollutants?

Those aspects of the system to be modeled will dictate what models are appropriate for use. For example, if storm sewers are present then an open channel model can be ruled out as an appropriate model for the entire system. If a specific type of hydraulic structure is present that a standard model cannot handle, an alternate way to simulate that structure will be necessary. Model objectives also explain how the numbers generated from the model will relate to the needs of the study. For example, if a cost-benefit analysis is required, the model results must be interpreted in terms of overall life-cycle cost and not simply in terms of discharge rate.

### A.9.3.2 Model Constraints

Availability of data, funds, time and user ability can potentially constrain modeling solutions. The goal of any modeling effort is to develop an approach that stays within the constraints dictated while addressing the needs of the study identified in the previous step. Data collection/availability and cost are usually the chief constraints.

Sources of existing available data should be researched. Look for data that tends to "ground truth" model outputs. Even partial data can be useful if it helps to validate the model or modeling results. After existing data sources have been identified, the need to gather additional data is assessed. Automated processes and systems such as GPS can reduce both cost and human error. A consideration of the long-term use of data and its maintenance is necessary. For example, if the model is to eventually become an operational model, the ability to maintain the data in a cost-effective way becomes of paramount importance.

Accuracy and the corresponding necessary level of detail are of overriding importance. Accuracy depends on both the accuracy of the input data and the degree to which the model adequately represents the hydrologic, hydraulic or water quality processes being modeled. For example, if lumped hydrologic parameters are adequate, then the cost of the modeling effort can be reduced. However, the ability to determine information within the sub-basin represented by a single parameter is lost. Changing model needs from an average 500-acre sub-basin size to a 50-acre size can increase the cost of a model almost 10-fold. Is the additional information derived worth the additional cost?

Both risk and uncertainty affect the modeler's ability to predict results accurately. Risk is an estimated chance of an occurrence, such as flooding. Uncertainty is the error associated with measuring or estimating key parameters or functions. Uncertainty arises due to errors in sampling, measurement, estimation and forecasting, and modeling. For hydrologic and hydraulic analysis, stage and discharge are of prime importance. Uncertainty in discharge is due to short or non-existent flood records, inaccurate rainfall-runoff modeling, and inaccuracy in known flood flow regulation where it exists. Stage uncertainty comes from errors and unknowns in roughness, geometry, etc.

Accuracy developed in one area can be impacted by rough estimates in another, negating the technological gains. For example, the gains in accuracy from very precise field surveys of cross sections can be lost if the estimates of roughness coefficients or discharge rates are very approximate.

Sensitivity analysis involves holding all parameters constant except one and assessing the change in the output variable of concern based on a certain percent change in the input variable. Those variables that are amplified in the output should be estimated with higher accuracy and with a more detailed consideration of the potential range of values and the need for conservative design. The modeler must try to assess how accurate estimates are and account for risk and uncertainty through estimating the range of potential error and choosing values that balance conservative engineering with cost consciousness. The designer typically develops a "most likely" estimate of a certain design parameter (for example, 10-year storm rainfall or Manning's roughness coefficient) and then uses sensitivity analysis to test the impact of variability in the parameter estimate on the final solution.

### A.9.3.3 Selection and Implementation

Once the model objectives and constraints have been evaluated, the model (or models) is selected and the study or design is implemented. Typical steps in model implementation include validation, calibration, verification and production.

Validation involves a determination that the model is structured and coded as intended for the range of variables to be encountered in the study. Validation tests key algorithms for accuracy. For example, if a hydrologic model cannot handle short time steps or long time periods it cannot be used without modification. If a certain model begins to lose accuracy at high or low imperviousness or cannot accurately handle backwater situations, and these will be encountered in practice the model cannot be used. Often validation is a one-time effort, after which the modeler is comfortable with the model's "quirks" and knows how to deal with them. Validation often involves pushing parameters to the limit of reasonable extent to test an algorithm. For example, in a hydrologic model infiltration can be reduced to zero to test if the input and output hydrographs are equal. Or the model can be run with small rainfalls using porous soils to determine if no runoff is generated, or only runoff from directly connected impervious areas.

Calibration is the comparison of a model to field measurements, other known estimates of output (e.g., regression equations), or another model known to be accurate, and the subsequent adjustment of the model to best fit those measurements. Verification then tests the calibrated model against another set of data not used in the calibration. This step is not always possible due to the general shortage of data of any sort in stormwater management. Goodness of prediction is done through a simple comparison of the difference in observed and predicted peaks, pollution loads, flood elevations or volumes divided by the observed values and expressed as a percentage, or as simple ratio. Assessing the goodness of fit of a hydrograph is done by calculating the sum of the squares of the difference between observed and predicted values at discreet time steps.

Once the model is prepared for use, attention shifts to efficient production methods that minimize the potential for errors while maximizing efficiency. Often "production line"-type efforts are used for large modeling projects. However, constant attention must be paid to ensure the execution of correct procedures, detailed documentation of efforts and input/output data sets, and recognition of anomalies that would invalidate a particular model run. While it may be enticing to use simple user interfaces and black box approaches that simplify the input and output processes, there is an inherent danger that the modeler will not be aware of errors or problems that these may mask in the modeling process. For example, in hydraulic modeling, shifts from super-critical flow to sub-critical flow happen at sharp break points and are reflected in a jump in water surface elevation. If these changes are not detected, a model may under-predict flow elevation. Numeric instability in mathematical algorithms may give oscillating answers that have nothing to do with reality. Therefore, it is very important to understand the governing equations and principles that form the basis of the model being used. A structured review process must be established to ensure that accurate input values are being used in order to ensure a reasonable output. Labeling of data sets should be systematic and exact.

The consideration of all that is involved in using models can seem to be daunting. However, the complexities involved do not inhibit individuals who understand models and have experience using them. Furthermore, the benefits of using models may provide worthwhile cost-efficiencies in program implementation. So the use of models should not be easily discounted just because of their complexities.

## A.9.3.4 Summary of Commonly Used Models

Computer models can be simple, representing only a very few measured or estimated input parameters or can be very complex involving twenty times the number of input parameters. The "right" model is the one that: (1) the user thoroughly understands, (2) gives adequately accurate and clearly displayed answers to the key questions, (3) minimizes time and cost, and (4) uses readily available or collected information. Complex models used to answer simple questions are not an advantage. However, simple models that do not model key necessary physical processes are inadequate and practically useless.

There is no one engineering model or software that addresses all hydrologic, hydraulic and water quality situations. Design needs and troubleshooting for watershed and stormwater management occur on several different scales and can be either system-wide (i.e., watershed) or localized. System-wide issues can occur on both large and small drainage systems, but generally require detailed watershed models and/or design tools. The program(s) chosen to address these issues should handle both major and minor drainage systems. Localized issues also exist on both major and minor drainage systems, but unlike system-wide problems, flood and water quality solution alternatives can usually be developed quickly using simple engineering methods and design tools.

Table A-44 below lists several widely-used computer programs and modeling packages. The programs have been examined for their applicability to both system-wide and localized issues, the methodologies used for computations, and ease-of-use.

**Table A-44 Stormwater Modeling Programs and Design Tools**

| Model | Major System Modeling | Minor System Modeling | Hydrologic Features | Hydraulic Features | Water Quality Features |
|---|---|---|---|---|---|
| **Hydrology Software** | | | | | |
| HEC-GeoHMS | X | | X | | |
| HEC-HMS | X | | X | | |
| TR-55 | | | X | | |
| TR-20 | | | X | | |
| PondPack* | | X | X | X | |
| Hydraflow* | | X | X | X | |
| HydroCAD* | | X | X | X | |
| Watershed Modeling System (WMS)* | X | | X | | |
| Watershed Modeling* | X | | X | | |
| **Hydraulic Software** | | | | | |
| HEC-GeoRAS | X | | | X | |
| HEC-RAS | X | | | X | |
| WSPRO | X | | | X | |
| U.S. Environmental Protection Agency Storm Water Management Model | X | X | X | X | X |
| FHWA HY-8 Culvert Analysis | | X | | X | |
| CulvertMaster* | | X | | X | |
| FlowMaster* | | X | | X | |
| **Water Quality Software** | | | | | |
| VRRM | | X** | X*** | | X |
| HSPF | X | | X | | X |

| Table A-44 Stormwater Modeling Programs and Design Tools | | | | | |
|---|---|---|---|---|---|
| **Model** | **Major System Modeling** | **Minor System Modeling** | **Hydrologic Features** | **Hydraulic Features** | **Water Quality Features** |
| BASINS | X | | X | X | X |
| QUAL2E | X | | | X | X |
| WASP5 | X | | | X | X |
| SLAMM* | X | | X | | X |

**Note:**

Source: Adapted from ARC (2001)

* Proprietary Model

**While VRRM does track volumes through treatment trains it does not model it through the conveyance infrastructure linking treatment train.

***The only hydrologic feature the VRRM provides is adjusted CNs to account for runoff reduction provided by BMPst HEC-RAS = Hydrologic Engineering Center's River Analysis System

For the purposes of this table, major drainage systems are defined as those draining to larger receiving waters. These are typically FEMA-regulated streams, or lakes or reservoirs. Minor drainage systems are smaller natural and manmade systems that drain to the more major streams. Minor drainage systems can have both closed and open-channel components and can include, but are not limited to, neighborhood storm sewers, culverts, ditches, and tributaries.

## A.9.4 Hydrology Modeling Programs

### A.9.4.1 HEC-GeoHMS: Geospatial Hydrologic Modeling System

HEC-GeoHMS is a user-friendly Windows-based geospatial hydrology toolkit developed by the U.S. Army Corps of Engineers and partners for engineers and hydrologists with limited GIS experience. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analyses, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation.. HEC-GeoHMS, which interfaces with the ESRI ArcGIS 9.3 software.

Hydrologic modeling has evolved to represent the sub-basin in more detail than the traditional approach, where hydrologic parameters are averaged over large watersheds. With the availability of radar rainfall and spatial data, hydrologic modeling using smaller sub-basin areas or a grid system has introduced a more detailed representation of the watershed. HEC-GeoHMS is designed to meet the needs of both modeling approaches.

HEC-GeoHMS creates background map files, basin model files, meteorologic model files, and a grid cell parameter file that can be used by HEC-HMS to develop a hydrologic model. The basin model file contains hydrologic elements and their hydrologic connectivity. The basin model file includes sub-basin areas and other hydrologic parameters that could be estimated using geospatial data. To assist with estimating hydrologic parameters, HEC-GeoHMS can generate tables containing physical characteristics of streams and watersheds. The grid cell parameter file is required in order to use the ModClark transform method, grid-based precipitation (like radar rainfall), or gridded loss methods.

HEC-GeoHMS allows the user to analyze digital elevation models (DEMs) in a number of coordinate systems and projections. It also allows users to use a more sophisticated technique to impose the stream network and watershed boundaries onto the terrain.

### A.9.4.2 HEC-HMS: Hydrologic Modeling/Flood Hydrograph System

HEC-HMS replaces HEC-1, which is no longer used. It has more user-friendly input and output processors and graphical capabilities than HEC-1. It is considered by many in the engineering and regulatory communities to be a leading model for major drainage system applications such as Flood Insurance Studies and watershed master.

In the HEC-HMS model, the watershed is represented as an interconnected system of hydrologic (e.g., sub-basins, reservoirs, ponds) and hydraulic (e.g., channels, closed conduits, pumps) components. The model computes a runoff hydrograph for each component, combining two or more hydrographs as it moves downstream in the watershed. The model has a variety of rainfall-runoff simulation methods, including the popular USDA-NRCS (formally SCS) Curve Number methodology. The user can define rainfall events using gage or historical data, or HEC-GeoHMS can generate synthetic storms. Hydrograph generation is performed using the unit hydrograph technique. Clark, NRCS Dimensionless, and Snyder Unit Hydrographs are the available methodologies. Several common channel and storage routing techniques are available as well.

HEC-HMS is not considered a “design tool.” However, there are other hydrologic applications developed within the software that have been used with much success. Multiplan-multiflood analyses allow the user to simulate a number of flood events for different watershed situations (or plans). The dam safety option enables the user to analyze the impact of dam overtopping or structural failure on downstream areas. Flood damage analyses can be used to assess the economic impact of flood damage.

### A.9.4.3 USDA-NRCS Technical Release 55 (TR-55)

The TR-55 model was originally a DOS-based software package used for estimating runoff hydrographs and peak discharges for small urban watersheds. There is now a MS-Windows based version (WinTR55). The model was developed by the USDA-NRCS and therefore uses NRCS hydrograph methodology to estimate runoff, derived from TR-20 (discussed next). No other methodology is available in the program. Four 24-hour regional rainfall distributions are available for use. Rainfall durations less than 24-hours cannot be simulated. Using detailed input data entered by the user, the WinTR55 model can calculate the area-weighted CN, time of concentration and travel time. Detention pond (i.e., storage) analysis is also available in the WinTR55 model, intended for initial pond sizing. Final design requires a more detailed analysis. TR-55 has become a more robust model that can provide quick estimated answers.

WinTR55 is easy-to-use. Haestad Methods, Inc., included most of the TR-55 capabilities in its PondPack program, described below.

### A.9.4.4 USDA-NRCS Technical Release 20 (TR-20)

TR-20 was actually the pre-cursor to TR-55 and is more complex. In addition to the outputs generated by TR-55, TR-20 (which has been converted into WinTR20) will also generate storm routings and both the rising and falling curves of hydrographs at specified time intervals. Like WinTR55, WinTR20 is a more robust model now that can also provide quick estimated answers.

### A.9.4.5 PondPack

PondPack, by Haestad Methods, Inc., is Windows-based software developed for modeling general hydrology and runoff from site development. The program analyzes pre- and post-development watershed conditions and sizes detention ponds. It also computes outlet rating-curves with consideration of tailwater effects, accounts for pond infiltration, calculates detention times and analyzes channels.

Rainfall options are unlimited. The user can model any duration or distribution, for synthetic or real storm events. Several peak discharge and hydrograph computation methods are available, including NRCS, the Rational Method and the Santa Barbara Unit Hydrograph procedure. Infiltration can be considered, and pond and channel routing options are available as well. Like TR-55, PondPack allows the user to calculate hydrologic parameters, such as the time of concentration, within the program.

PondPack has limited, but useful hydraulic features, using Manning's equation to model natural and manmade channels and pipes. A wide variety of detention pond outlet structure configurations can be modeled, including low flow culverts, weirs, riser pipes, and even user-defined structures.

## A.9.4.6 Watershed Modeling System

Watershed Modeling System (WMS) was developed by the Engineer Computer Graphics Laboratory of Brigham Young University. WMS is a Windows-based user interface that provides a link between terrain models and GIS software, with industry-standard lumped parameter hydrologic models, including HEC-1, TR-55, TR-20 and others. The hydrologic models can be run from the WMS interface. The link between the spatial terrain data and the hydrologic model(s) gives the user the ability to develop hydrologic data that is typically gathered using manual methods from within the program. For example, when using NRCS methodologies, the user can delineate watersheds and sub-basins, determine areas and curve numbers, and calculate the time of concentration at the computer. Typically, these computations are done manually, and are laborious and time-consuming. WMS attempts to use digital spatial data to make these tasks more efficient.

**HydraFlow**

Hydraflow Extensions for Autodesk® Civil 3D® are comprised of the following applications: Hydraflow Storm Sewers Extension, Hydraflow Hydrographs Extension, and Hydraflow Express Extension. These software applications can be used to perform a variety of storm water management tasks, including storm sewer design, watershed analysis, detention pond modeling, and culvert, channel, and inlet analysis. The Hydraflow Express Extension can be used to generate informative graphs, rating curves, and on-screen reports as well as formal printed reports. The Hydraflow Hydrographs Extension can be used as a basic tool for determining runoff from various historical and synthetic storms, and in planning or modeling flood control measures, such as detention ponds. The Hydraflow Storm Sewers Extension can be used as a basic tool for determining the hydraulic grade line in an existing system or planning and designing new systems.

## A.9.4.7 Watershed Modeling

The Watershed Modeling program was developed to compute runoff and design flood control structures. The program can run inside the MicroStation CAD system. Like WMS, this feature enables the program to delineate and analyze the drainage area of interest. Area, curve number, land use and other hydrologic parameters can be computed and/or catalogued for the user, removing much of the manual calculation typically performed by the hydrologic modeler.

Watershed Modeling contains a variety of methods to calculate flood hydrographs, including NRCS, Snyder and Rational methods. Rainfall can be synthetic or user-defined, with any duration and return period. Rainfall maps for the entire U.S. are provide to help the user calculate IDF relationships. Several techniques are available for channel and storage routing. The user also has a wide variety of outlet structure options for detention pond analysis and design.

**HydroCAD**

HydroCAD, by HydroCAD Software Solutions LLC, is a Windows based Computer Aided Design tool for modeling stormwater runoff. HydroCAD provides a wide range of commonly used hydrology and hydraulics capabilities including: SCS, NRCS, and SBUH runoff hydrology; Rational Method with automatic IDF curves; local rainfall data or the built-in rainfall library; management and reporting of multiple rainfall events; hydrograph routing through ponds & reaches; automatic hydraulics and culvert calculations; advanced flow simulations including pumps and float valves; progressive dam breach simulations; pond storage calculations, including embedded storage chambers; layout and modeling of underground storage systems; land-use analysis and pollutant loading calculations; and built-in CAD watershed importing.

## A.9.5 Hydraulics Programs

### A.9.5.1 HEC-GeoRAS: Geospatial River Analysis System

The Hydrologic Engineering Center (HEC) Geo River Analysis System (GeoRAS) creates a file of geometric data for import into the HEC-River Analysis System (RAS) and enables viewing of exported results from RAS. The import file is created from data extracted from ArcGIS layers and from a digital terrain model (DTM). HEC-GeoRAS requires a DTM represented by a triangulated irregular network or GRID. The layers and the DTM are referred to collectively as the RAS Layers. Geometric data are developed based on the intersection of the RAS Layers.

Prior to performing hydraulic computations in HEC-RAS, the geometric data must be imported and completed, and flow data must be entered. Once the hydraulic computations are performed, exported water surface and velocity results from HEC-RAS may be imported back to the GIS using HEC-GeoRAS for spatial analysis. GIS data is transferred between HEC-RAS and ArcGIS using a specifically formatted GIS exchange file.

### A.9.5.2 HEC-RAS: River Analysis System

HEC-RAS is a Windows-based hydraulic model developed by the U.S. Army Corps of Engineers to replace the popular, DOS-based HEC-2 model. RAS has the ability to import and convert HEC-2 input files and expounds upon the capabilities of HEC-2. Since its introduction several years ago, the user-friendly HEC-RAS has become known as an excellent model for simulation of major systems (i.e., open channel flow) and has become the chief model for calculating floodplain elevations and determining floodway encroachments for Flood Insurance Studies. Like HEC-2, HEC-RAS has been accepted for FIS analysis by the FEMA. However, HEC-RAS is a much easier model to use than HEC-2 as it has an extremely useful interface that provides the immediate capability to view model input and output data in graphical, tabular, and report formats.

HEC-RAS performs one-dimensional analyses for steady, unsteady, and mixed flow water surface profiles, using the energy equation. Energy losses are calculated using Manning's equation. Contraction and expansion changes in the specific energy are considered around bridges, culverts, etc. Rapidly varied flow (e.g., hydraulic jumps) is modeled using the momentum equation. The effects of in-stream structures (e.g., bridges, culverts, weirs and floodplain obstructions) and in-stream changes (e.g., levees and channel improvements) can be simulated. The model allows the user to define the geometry of the channel or structure to the level of detail required by the application. One popular and useful feature of the HEC-RAS model is the capability to easily facilitate floodway encroachment analysis. Five encroachment methods are available to the user.

HEC-RAS4 provides the ability to conduct steady, unsteady, and mixed flow analyses. RAS4 includes sediment transport analysis with choices for the analyzing using surface or substrate bed sediments and simulating up to 5 layers within the channel bed. There are 5 choices of computation including those better suited to cohesives, non-cohesives, predominantly sand and gravel bedload, and predominantly suspended sediment transport. There is an analysis option that will allow the user to use a range of sediment transport equations within a single simulation to be sure that the different grain sizes are treated appropriately. RAS4 also includes water quality simulations. Linked with HEC-GeoRAS, the HEC-RAS model provides the capability to import GIS data for channel geometry and export HEC-RAS output for floodplain and floodway delineation.

### A.9.5.3 WSPRO

WSPRO was developed by the USGS to compute water surface profiles for one-dimensional, gradually varied, steady flow. Like HEC-RAS, WSPRO can develop profiles in subcritical, critical and supercritical flow regimes. WSPRO is designated HY-7 in the Federal Highway Administration (FHWA) computer program series and its original objective was analysis and design of bridge openings and embankment configurations. Since then, the model has been expanded to model open channels and culverts.

Open channel computations use standard step-backwater techniques. Flow through bridges is simulated using an energy-balancing technique that uses a coefficient of discharge and estimates an effective flow length. Pressure flow under bridges is simulated using orifice-type flow equations developed by the FHWA. Culvert flow is simulated using FHWA techniques for inlet control and energy balance for outlet control.

WSPRO is considered a fairly easy-to-use DOS-based model applicable to water surface profile analysis for highway design, flood insurance studies, and establishing stage-discharge relationships. However, the original form of the model is not Windows-based and therefore does not have the useful editing and graphical features found in HEC-RAS, nor does it do anything that HEC-RAS doesn’t do. Like HEC-RAS, a third party software developer (the Scientific Software Group) has designed SMS (Surface Water Modeling Software) to support both pre- and post-processing of WSPRO data.

### A.9.5.4 USEPA Storm Water Management Model

The U.S. Environmental Protection Agency (USEPA) Storm Water Management Model (SWMM) was developed by the to analyze storm water quantity and quality problems associated with runoff from urban areas. For many years USEPA SWMM has been the model of choice for simulation of minor drainage systems primarily composed of closed conduits. The model can simulate both single-event and continuous events and has the capability to model both wet and dry weather flow. The basic output from SWMM consists of runoff hydrographs, pollutographs, storage volumes and flow stages and depths.

SWMM’s hydraulic computations are link-node based, and are performed in separate modules, called blocks. The EXTRAN computational block solves complete dynamic flow routing equations to simulate backwater, looped pipe connections, manhole surcharging and pressure flow. SWMM is the most comprehensive model with respect to its capabilities to simulate urban storm flow, and many cities have used it successfully for storm water, sanitary, or combined sewer system modeling. Open channel flow can be simulated using the TRANSPORT block, which solves the kinematic wave equations for natural channel cross-sections.

Although represented here as a hydraulic model, SWMM has both hydrologic and water quality components. Hydrologic processes are simulated using the RUNOFF block, which computes the quantity and quality of runoff from drainage areas and routes the flow to the major sewer system lines. Pollutant transport is simulated in tandem with hydrologic and hydraulic computations, which calculate pollutant buildup and washoff from land surfaces and pollutant routing, scour and in-conduit suspension in flow conduits and channels.

USEPA SWMM is a public domain, DOS-based model. For large watersheds with extensive pipe networks, input and output processing can be tedious and confusing. Because of the popularity of the model, third-party commercial enhancements to SWMM have become more common, making the model a strong choice for minor system drainage modeling. Examples of commercially enhanced versions of USEPA SWMM include MIKE-SWMM, distributed by BOSS International, XPSWMM by XP-Software, and PCSWMM by Computational Hydraulics Inc (CHI). CHI also developed PCSWMM-GIS, which ties the SWMM model to a GIS platform.

### A.9.5.5 FHWA HY-8 Culvert Analysis

HY-8 is a computerized implementation of FHWA culvert hydraulic approaches and protocols. The FHWA has been producing computerized culvert hydraulic software since the early 1960's (with the HY-1 program). HY-8 Culvert Analysis automates the design methods described in FHWA publications HDS-5, "Hydraulic Design of Highway Culverts," HEC-14, "Hydraulic Design of Energy Dissipators for Culverts and Channels," and HEC-19, "Hydrology." The FHWA released the initial DOS-based version of the HY-8 program in the early 1980's. FHWA released the original Windows version (7.0) in March 2007 and the latest phase update (7.2) in August 2009). The HY-8 program has successfully operated on all current "flavors" of the Windows operating system. The HY-8 program is available at no charge to the hydraulic and transportation communities.

### A.9.5.6 CulvertMaster

CulvertMaster, developed by Haestad Methods, Inc., is an easy-to-use, Windows-based culvert simulation and design program. The program can analyze pressure or free surface flow conditions and subcritical, critical and supercritical flow conditions, based on drawdown and backwater. A variety of common culvert shapes and section types are available. Tailwater effects are considered and the user can enter a constant tailwater elevation, a rating curve, or specify an outlet channel section. Culvert hydraulics are solved using FHWA methodology for inlet and outlet control computations. Roadway and weir overtopping are checked in the solution of the culvert.

CulvertMaster also has a hydrologic analysis component to determine peak flow using the Rational Method or the SCS Graphical Peak Method. The user also has the option of entering a known peak flow rate. The user must enter all rainfall and runoff information (e.g., IDF data, rainfall depths, curve numbers, C coefficients, etc).

### A.9.5.7 FlowMaster

FlowMaster, also developed by Haestad Methods, Inc., is a Windows-based hydraulic pipe and channel design program. The user enters known information on the channel section or pipe, and allows the program to solve for the unknown parameter(s), such as diameter, depth, slope, roughness, capacity, velocity, etc. Solution methods include Manning's equation, the Darcy-Weisbach formula, Hazen-Williams formula, and Kutter's Formula. The program also features calculations for weirs, orifices, gutter flow, ditch and median flow and discharge into curb, grated, and slot inlets.

## A.9.6 Water Quality Modeling Programs

### A.9.6.1 Virginia Runoff Reduction Method

The VRRM is a compliance tool developed for VDEQ by the Center for Watershed Protection. The VRRM is based in a Microsoft Excel spreadsheet format. It is quick and easy to use, allowing the user to enter basic development site cover and area data to compute a runoff volume and phosphorus load from the site after development. Then the user chooses various combinations of BMPs to provide a phosphorus reduction necessary to meet the discharge load limit criteria in the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-590).

The methodology accounts for treatment trains (i.e., BMPs arranged in sequence) and generates a modified CN based on the site conditions and BMPs selected.

### A.9.6.2 Hydrologic Simulation Program FORTRAN (HSPF)

The HSPF model was developed by the USEPA for the continuous or single-event simulation of runoff quantity and quality from a watershed. The original model was developed from the Stanford Watershed Model, which simulated runoff quantity only. It was expanded to include quality components, and has since become a popular model for continuous non-point source water quality simulations. Non-point source conventional and toxic organic pollutants from urban and agricultural land uses can be simulated, on pervious and impervious land surfaces and in streams and well-mixed impoundments. The various hydrologic processes are represented mathematically as flows and storages. The watershed is divided into land segments, channel reaches and reservoirs. Water, sediment and pollutants leaving a land segment move laterally to a downstream land segment, a stream or river reach, or reservoir. Infiltration is considered for pervious land segments.

HSPF model output includes time series information for water quality and quantity, flow rates, sediment loads, and nutrient and pesticide concentrations. To manage the large amounts of data associated with the model, HSPF includes a database management system. To date, HSPF is still a DOS-based model and therefore does not have the useful graphical and editing options of a Windows-based program. Input data requirements for the model are extensive and the model takes some time to learn. Users link HSPF to the BASINs model (discussed below); together they provide robust advantages. The USEPA continues to expand and develop HSPF, and still recommends it for the continuous simulation of hydrology and water quality in watersheds.

### A.9.6.3 Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)

The BASINS watershed analysis system was developed by the USEPA for use by regional, state and local pollution control agencies to analyze water quality on a watershed-wide basis. BASINS databases, assessment tools and models integrate directly with the ArcView GIS environment, national databases containing watershed data, and modeling programs and water quality assessment tools into one stand-alone program. The program, which has a use-friendly graphical interface, will analyze both point and non-point sources and supports the development of total maximum daily loads (TMDLs). The assessment tools and models utilized in BASINS include TARGET, ASSESS, Data Mining, HSPF, TOXIROUTE and QUAL2E.

### A.9.6.4 QUAL2EU: Enhanced Stream Water Quality Model

QUAL2EU was developed by the USEPA and intended for use as a water quality planning tool. The model actually consists of four modules:

- QUAL2E, the original water quality model;
- QUAL2EU, the water quality model with uncertainty analysis;
- A pre-processing module; and
- A post-processing module.

QUAL2EU simulates steady state or dynamic conditions in branching streams and well-mixed lakes, and can evaluate the impact of waste loads on water quality. It also can enhance a field sampling program by helping to identify the magnitude and quality characteristics of non-point waste loads. Up to 15 water quality constituents can be modeled. Dynamic simulation allows the user to study the effects of diurnal variations in water quality (primarily DO and temperature). The steady state option allows the user to perform uncertainty analyses.

QUAL2EU is a DOS-based program, and the user will require some length of time to develop a QUAL2EU model, mainly due to the complexity of the model and data requirements for a simulation. However, to ease user interaction with the model an interactive pre-processor (AQUAL2) has been developed to help the user build input data files. A post-processor (Q2PLOT) also exists to display model output in textual or graphical formats.

### A.9.6.5 Water Quality Analysis Simulation Program (WASP5)

The WASP5 model was developed by the USEPA to simulate contaminant fate in surface waters. Both chemical and toxic pollution can be simulated in one, two, or three dimensions. Problems studied using WASP5 include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination. WASP5 has an associated stand-alone hydrodynamic model, called DYNHYD5, that simulates variable tidal cycles, wind and unsteady flows. DYNHYD4 supplies flows and volumes to the water quality model. The model is DOS-based. However, WASP packages can be obtained from outside vendors that include interactive tabular and graphical pre- and post-processors.

### A.9.6.6 Source Loading and Management Model (SLAMM)

The SLAMM model was originally developed as a planning tool to model runoff water quality changes resulting from urban runoff pollutants. The model has been expanded to included simulation of common water quality best management practices such as infiltration BMPs, wet detention ponds, porous pavement, street cleaning, catch basin cleaning and grass swales. Unlike other water quality models, SLAMM focuses on small storm hydrology and pollutant washoff, which is a large contributor to urban stream water quality problems. SLAMM computations are based on field observations, as opposed to theoretical processes. SLAMM can be used in conjunction with more commonly used hydrologic models to predict pollutant sources and flows.

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# APPENDIX B VIRGINIA RUNOFF REDUCTION METHOD

**Contents:**



## B.1 Virginia Runoff Reduction Method

The Virginia Runoff Reduction Method (VRRM) is a tool and methodology that allows persons engaged in land-disturbing activity to demonstrate their projects' compliance with water quality requirements in the Virginia Erosion and Stormwater Management Regulation (9VAC25-875). The VRRM is composed of one spreadsheet for new development and one for redevelopment as well as a user guide. Persons may use the appropriate spreadsheet(s) to calculate compliance with the total phosphorous loads of new development or redevelopment projects.

The VRRM is available at https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/guidance-vrrm.

### B.1.1 Background

In 2008, the Center for Watershed Protection (CWP) described an integrated methodology to examine a site's unique characteristics and build an optimized design using environmental site design principles (CWP 2008). This method has come to be referred to as the Runoff Reduction Method (RRM). The procedure is implemented by iteratively applying three major steps: 1) application of site designs that minimize imperviousness, land disturbance, and deforestation; 2) promotion of runoff reduction through groundwater recharge, evapotranspiration, and other techniques; and 3) pollutant removal by 'engineered' means (e.g., filtration, gravitational settings, hydrodynamic separation). A potential fourth step included nutrient offsets for otherwise unattained compliance deficits (CWP 2008). The RRM also proposed methodologies to estimate runoff treatment volumes for three distinct land covers (forest, disturbed soils/managed turf, and impervious cover) as well as runoff reduction and nutrient removal efficiencies for 15 distinct non-proprietary best management practices (BMPs; CWP 2008).

### B.1.2 Virginia's Adoption of VRRM and Accompanying Spreadsheets

In March 2011, the Virginia Department of Conservation and Recreation, which implemented Virginia's stormwater program at the time, published the initial VRRM instructions and documentation to describe the methodology to be included in amendments to the Virginia Stormwater Management Program (VSMP) Regulations (4 VAC 50-60-10 et al.). The Soil and Water Conservation Board adopted the amendments in May 2011, and they became effective in September 2011. A compliance and site planning spreadsheet was paired with the March 2011 documentation as a tool for the design community to apply the iterative RRM design principles described by CWP. The initial version of this spreadsheet integrated the Simple Method (Schueler 1987) for nutrient load estimation, used total phosphorus (TP) as the target pollutant for compliance with a target load of 0.41 lbs/acre/year, and set the target and annual rainfalls to 1 and 43 inches, respectively, for treatment volume and pollutant load calculations. In addition to treatment volume, the VRRM spreadsheets also included computation of adjusted curve numbers caused by runoff reduction provided in selected BMPs. Although hydrologic modeling was beyond the capabilities of the VRRM spreadsheets, the adjusted curve numbers could subsequently be used in other hydrologic software to model stormwater routing through a proposed site.

From the initial spreadsheet version through version 3.0 of the VRRM spreadsheets (VDEQ 2016), there have been few changes to the computational structure; although a major user interface change to improve organization and aesthetics was integrated into version 3.0 of the spreadsheets. VDEQ updated the VRRM in 2022 and 2023 (see Appendix B).

## B.1.3 VRRM Version 4.1

In 2022, VDEQ and Virginia Tech proposed updates to the VRRM. Such updates were consistent with the VSMP Regulation (9VAC25-870-63), which required review of the water quality design criteria standards upon completion of the 2017 Chesapeake Bay Phase III Watershed Implementation Plan.

Although Version 4.1 retains major iterative steps of the RRM (CWP 2008), it substantially modifies their application. The most significant of these changes replaces the methodology for nutrient load computations, which previously had been accomplished via the Simple Method (Schueler 1987) as described. Version 4.1 integrates direct annual loading rates for the multiple land covers and Hydrologic Soil Group (HSG) designations to align with values output by the Chesapeake Assessment and Scenario Tool (CAST; CBP 2020). CAST was originally developed in 2011 to simplify interaction with output data from the Chesapeake Bay Watershed Model and is continuously updated to provide data to state and local jurisdictions for decision making with regards to meeting their respective Chesapeake Bay total maximum daily load (TMDL) obligations. In addition to integration of CAST nutrient loading rates, an additional land cover ("mixed open") and two additional non-proprietary BMPs (Regenerative Stormwater Conveyance and Trees) have been integrated into the spreadsheets. Due to integration of the loading rate method for nutrient compliance, the layout of the site data tabs is significantly modified—otherwise, the layout of the spreadsheets is very similar to that of the previous version (3.0).

In addition, during development of the Version 4.1 spreadsheets, VDEQ calculated a revised TP load for new development projects (0.26 lb/acre/year) based on data from CAST scenario runs and integration of land cover (change) data from the Chesapeake Bay Land Use and Land Cover (LULC) Database (LULC 2023). Additional information regarding both the nutrient target computation and other modifications to the VRRM spreadsheets is provided in the User Guide.

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# APPENDIX C SOIL CHARACTERIZATION AND INFILTRATION TESTING

**Contents:**



## C.1 Introduction

This appendix details the infiltration testing and soil assessment procedures required for the selection and detailed design of best management practices (BMPs). Soil analyses and infiltration testing should be completed during the early design phase because the results can be used for identifying areas that are favorable for infiltration BMPs.

The designer is required to evaluate and document infiltration feasibility when using stormwater BMPs as a strategy to comply with stormwater management design standards. If infiltration is deemed feasible, the designer should use infiltration BMPs, such as bioinfiltration basins, to comply with water quality requirements. If infiltration is not feasible, the designer should document justification for this condition and follow alternative design recommendations to manage water quality.

## C.2 Soil Characterization

The initial screening of on-site soils should include review of basic soil characteristics such as the Hydrologic Soil Group (HSG) or groups found onsite, as well as the need for more detailed soil investigations and field determinations to define the types of soils underlying the proposed stormwater management areas for the site.

This is especially important on sites with previously disturbed soils, hydric soils, high groundwater conditions, shallow rock, and other soil-related characteristics that would impact stormwater management decisions. A site evaluation as described below can help document the actual soil characteristics for stormwater management.

## C.2.1 Hydrologic Soil Group

A soil's HSG is typically determined through information available in the Natural Resources Conservation Service (NRCS) Web Soil Survey (websoilsurvey.nrcs.usda.gov). Based on compiled and published U.S. Cooperative Soil Survey field mapping, the NRCS soil survey generally separates soils into four discrete HSG designations. Soils are grouped into Hydrologic Soils Groups A, B, C, or D based on similarities in soil characteristics such as:

- Soil texture and structure;
- Depth to a restrictive layer;
- Depth to water table;
- Hydraulic conductivity or transmission rate of water; and
- Degree of swelling when soils are saturated.

It should be noted that, in some locations, the soil survey does not have sufficient information to determine the HSG accurately, or it has been mapped as Urban Land (UL) with an assumed default HSG D. It is also possible that direct soil observations or tests onsite will indicate that a soil's HSG is different than that provided by the Soil Surveys in some cases due to mapping inaccuracies or the soil having been altered through cuts, fills, or other disturbances.

In all cases, the designer should evaluate the existing soils to ensure a proper HSG designation for calculating the design volume (Tv) as well as any other construction-related soil suitability limitations. The following guidance is intended to:

1. Assist in evaluating mapped soils for selecting BMPs;
2. Assist in determining the soil characteristics important to stormwater design; and
3. Determine the applicability of the soils for certain infiltration practices by field-verifying the permeability or infiltration rate of the soils.

In order to help designers work through the elements of soil science related to soils, the following paragraphs provide basic definitions of some of the more common terms used.

- Soil infiltration: the rate at which stormwater enters the surface of the soil. Infiltration is influenced by soil texture, structure, organic matter, compaction, moisture content, and other physical characteristics. The design infiltration rate is usually expressed as a constant value, such as inches per hour, but the actual infiltration rate will be proportional to the hydraulic head or gradient and will change depending on hydrology.
- Soil permeability: the rate at which stormwater flows through the soil. Infiltration and permeability are often used interchangeably in many reference manuals. Used correctly, "permeability" refers to the rate of water moving through a given depth of soil after it has already infiltrated into that layer.
- Saturated Hydraulic Conductivity: the hydraulic conductivity (K) of a soil is related to its infiltration and permeability. Under optimal conditions, infiltration starts very fast, then declines, and eventually approaches a more constant rate of entry. This constant rate of infiltration is sometimes called the soil's permeability but is technically defined as the saturated hydraulic conductivity ($K_{sat}$). In almost all cases, reference to an infiltration rate implies this long-term constant rate (permeability or $K_{sat}$) (Jarrett 2008). $K_{sat}$ often determines the soil's HSG (U.S. Department of Agriculture [USDA] NRCS 2007).

The four HSG types are described in the following paragraphs:

- Group A. Soils with low runoff potential. These soils have high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well drained to excessively well drained sands or gravels and have a high rate of water transmission.
- Group B. Soils having moderate infiltration rates even when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well drained to well drained soils with moderately fine to moderately coarse textures and have a moderate rate of water transmission.
- Group C. Soils having slow infiltration rates even when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures that have a slow rate of water transmission.
- Group D. Soils with high runoff potential. These soils have very slow infiltration rates even when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly National Engineering Handbook Chapter 7: Hydrologic Soil Groups (USDA-NRCS 2009) impervious material and have a very low rate of water transmission.

Refer to and the USDA Soil Survey Manual, Chapter 3 (USDA, 2018) for detailed guidance on the application of soil classification criteria for determining the hydrologic group of a particular soil. Classification is based on the characteristics observed and recorded from the soil profile pits and soil borings including soil texture, bulk density, depth to water table (or other restrictive layer), and if available, the saturated hydraulic conductivity.

"Restrictions" in the soil profile, defined in the National Soil Survey Handbook (USDA, 2018), include but are not limited to the presence of bedrock, dense material, fragipans, ironstone or calcrete. The seasonally high water table is based on either observed saturation or redoxomorphic features. The presence and depths of these restrictions must be included in the soil logs.

The lead investigator should evaluate the available soil survey information and compare it with site visit observations to determine if soil exploration is needed to identify and locate the HSGs on the site more accurately.

# C.3 Soil Evaluation

Where infiltration of runoff into the existing soil strata is part of the selected BMP runoff reduction strategy, the designer should determine the actual soil conditions through field tests. The failure of stormwater infiltration devices is often attributed to an inaccurate estimation of the design infiltration rate and/or depth to the seasonal high water table or other limiting conditions for the underlying soils such as bedrock. The purpose of this guidance is to provide clear recommendations for the numbers and types of soil tests required to determine if infiltration practices are appropriate for a specific site location or BMP type.

## C.3.1 Number, Location, and Depth of Soil Test during BMP Design

Soil testing during design should include soil profile test pits or soil borings and infiltration tests. At a minimum, any stormwater practice that requires confirmation of soil conditions should include one soil profile and two infiltration tests with increased testing recommendations shown in Table C-1.

| Table C-1 Number of Soil Profiles and Infiltration Tests per BMP | | |
|---|---|---|
| BMP Footprint | # of Soil Profile Explorations | # of Infiltration Tests |
| Up to 2,500 $ft^2$ | 1 | 1 * |
| 2,500 $ft^2$ to 10,000 $ft^2$ | 2 | 2 |

For footprints greater than 10,000 ft2, add one soil profile and one infiltration test for each additional 10,000 ft2 of practice.

* Linear practices should add one additional soil profile and infiltration test for each 100 linear feet of practice.

The depths of soil profiles should extend no shallower than 4 feet below the invert of the bottom of the BMP or a depth of two times the maximum potential water depth in the BMP below the proposed surface of the BMP, whichever is greater. Sampling should occur from a depth 2 feet above the proposed facility invert to the full depth of the boring with infiltration tests taken at or near the invert of the bottom of the BMP. For larger BMP footprints, the soil profiles and infiltration tests should be evenly spaced throughout the practice footprint.

Data recorded in each reference soil profile should be compared to the soil profiles described in the adjacent soil exploration(s) to confirm consistency. Where soil and/or groundwater properties vary significantly among soil explorations, additional soil profiles or infiltration tests should be conducted to resolve such differences and accurately characterize the soils in the area of interest. The locations of the soil explorations should be shown on a legible site plan or site map that:

- Is drawn to scale or fully dimensional;
- Illustrates the locations of the infiltration BMP footprints;
- Shows the locations of all soil profiles and infiltration tests; and
- Shows distance from infiltration BMP footprints to wetlands or similar features based on HSG and other reference materials for soil types.

All soil evaluations (including soil profiles such as test pits and boring logs) and infiltration tests should be conducted under the supervision of a licensed Geotechnical Engineer, Soil Scientist, or other Licensed and Qualified Professional acceptable to the local authority having jurisdiction.

## C.3.2 Soil Profiles (Test Pits and Soil Borings)

The documentation of soil profiles (including test pits or soil borings) should include a soil log prepared for each soil profile in general accordance with ASTM D 1452 Standard Practice for Soil Investigation and Sampling by Auger Borings and should include a description of all soil horizons encountered according to the Unified Soil Classification System (USCS) per ASTM D-2488 Standard Practice for Description and Identification of Soils Visual- Manual Procedures with the USDA textural classification. In addition, results from dynamic cone penetrometer (DCP) Testing [ASTM D6951] or standard penetration testing (SPT) [ASTM D1586-99] should be provided. The soil profile log should include the following:

a. Elevation of the existing ground surface and elevations of infiltration test locations;
b. Depth and thickness of each soil horizon and the depth to the substratum;
c. Dominant matrix or background and mottle colors, abundance, size, and contrast using the Munsell system of classification for hue, value, and chroma;
d. Appropriate textural class as shown on the USDA textural classification;
e. Volume percentage of coarse fragments larger than 2 millimeters in diameter;
f. Soil structure, particle sizes, and shape;
g. Soil moisture condition using standard USDA classification terminology;

h. Depth and occurrence of soil restrictions such as fragipans and bedrock;
i. Depth to the seasonally high ground water level (either perched or regional);
j. Any observed seepage or saturation; and
k. Elevation of the seasonally high water table (SHWT) based on soil redoximorphic features such as Fe-concentrations and depletions (drainage mottles).

# C.4 Infiltration Testing

Permeability tests (otherwise referred to as infiltration tests or hydraulic conductivity tests) should be conducted at the most restrictive layer between the bottom elevation of the proposed infiltration BMP footprint and a depth of 4 feet below the bottom, or two times the maximum potential water depth in the BMP, whichever is greater. For example, infiltration tests for a bioretention basin that is proposed to be 4 feet deep with a maximum potential water depth of 2.5 feet should be conducted at the most restrictive layer between a depth of 4 feet and the greater of 8 feet (or two times the water depth) or 5 feet below the surface. Elevations of existing ground surface and the depth of infiltration testing for each test location should be documented at the time of testing.

Where infiltration BMPs are near fractured bedrock, there should be a minimum of 2 feet of soil between the bottom of the infiltration BMP and the bedrock. Where the permeability rate of the bedrock is critical to the function of the basin, the design engineer should also demonstrate that appropriate testing methods (such as a Basin Flood Test) will be used to establish the design permeability rates of the infiltration BMP. The number of permeability tests for fractured bedrock should also be no less than the number of infiltration tests required for determining permeability in the soil.

The following tests are acceptable for use in determining soil infiltration rates. Other tests may be allowed at the discretion of the local plan approving authority. The infiltration test report should include a detailed description of the test methods used and published source references where necessary:

a. (ASTM D 2434) Standard Test Method for Permeability of Granular Soils (Constant Head);
b. (ASTM D 3385) Standard Test Method for Infiltration Rate of Soils in Field using Double-Ring Infiltrometer;
c. Basin Flood Test for Fractured Bedrock; or
d. Other non-ASTM infiltration test methods based on in-situ conditions and accompanied by a recognized published source reference that is approved by the local authority having jurisdiction.

# C.5 Seasonal High Water Table

The following guidance is excerpted from the Testing Guidelines for Infiltration Facilities published by Fairfax County Public Works and Environmental Services (now incorporated into the Fairfax County Public Facilities Manual (Fairfax County, 2018) to help accurately determine the seasonal high water table elevation for BMP design. Other local authorities, especially those in Virginia’s coastal plain, may elect to incorporate guidance specific to their local conditions in lieu of these recommendations.

The SHWT should be determined by direct observation of the soil morphology and observed groundwater levels by a qualified professional for each BMP footprint during the months of November through May. Alternatively, direct observations from June until October may be acceptable if the Palmer Drought Severity Index (PDSI) during those months of observation is equal to or greater than 2.0 (i.e., wet conditions). If the value of the PDSI is less than 2.0 (i.e., near normal or drier), the determination of SHWT during the months of June through October should only be used for preliminary design and then verified through a confirmatory investigation performed during the months of November through May (or at other times of the year when the PDSI is equal to or greater than 2.0). Weekly values of the PDSI are available online from the National Weather Service (NWS) Climate Prediction Center for study consideration (http://www.cpc.ncep.noaa.gov/products/monitoring_and_data/drought.shtml).

The height of the water table can be defined as the vertical separation distance between the point of effluent application and a limiting factor. The Virginia Department of Health defines "limiting factor" as a restrictive soil horizon or other impervious strata, rock, water table, seasonal water table, perched water table, shrink-swell soil, soil wetness feature or soil exhibiting wetness, or other feature that limits the adequate treatment and dispersal of wastewater.

The qualified professional should have training and experience in soil morphology (certified professional soil scientist, professional wetland delineator, or professional geologist). Professional engineers licensed in Virginia and experienced in the field of geotechnical engineering may also be considered qualified to determine the SHWT provided they have successfully completed training on Soil Morphology deemed to be acceptable to the local Virginia Erosion and Stormwater Management Program (VESMP) Authority. (Classes are offered by the Northern Virginia Soil and Water Conservation District [NVSWCD] http://www.fairfaxcounty.gov/nvswcd/; comparable classes may be offered in other regions of Virginia).

Evaluation of the SHWT using soil morphology should be based on low chroma colors, mottles, and redoximorphic features of the soil. Unlike other types of field tests, which may be performed by an individual under the responsible charge of the qualified professional, this SHWT determination should be performed by the licensed Onsite Soil Evaluator. If they determine that a follow-up confirmatory field measurement of SHWT is required, the follow-up evaluation should be performed by the qualified professional when the PDSI is equal to or greater than 2.0 or any time during the months of November through May.

Additional information on the use of soil morphology to determine the SHWT is available in these publications: Soil Morphology as an Indicator of Seasonal High Water Tables by Peter C. Fletcher, USDA-NRCS and Peter

L.M. Veneman, University of Massachusetts (Fletcher and Veneman 2013) and Vepraskas 2013.

## C.6 Confirmation Testing during Construction for Infiltration Capacity

While soil characterization and evaluation during the planning and design of infiltration BMP practices is useful for finding suitable locations for the planned construction work, there are many examples of infiltration BMP failures attributed to unforeseen conditions during construction. This includes unforeseen subgrade conditions and the lack of BMPs during construction, both of which can be addressed through better design, construction, and maintenance practices. Failures may also occur due to disturbance and compaction of the pre-existing soil profile at the proposed design infiltration depth and may need to be re-evaluated (see Section C.6.2).

### C.6.1 Unforeseen Subgrade Conditions

For each infiltration BMP designed for a project, a qualified professional should be consulted during construction to visually inspect subgrade conditions for consistency with the design soil evaluation and assumptions for the project. If subgrade conditions appear to have a significantly different infiltration capacity, SHWT concerns, underlying rock, or other unforeseen conditions, the qualified professional should recommend and supervise additional testing of the subgrade to modify the runoff reduction goals for the project. Where the runoff reduction benefits are intended to be maximized, locations and depths of BMPs may be adjusted in the field to optimize performance through a site investigation by a qualified professional during construction to inspect the BMP subgrade conditions and make recommendations.

### C.6.2 Best Management Practices during Construction

During construction, the exposed subgrade should be protected at all times from erosion and sedimentation issues. This is best managed by diverting construction runoff away from infiltration BMPs at all times during construction through proper erosion and sediment control practices (including water diversions) and by maintaining cover with native soils over the subgrade until the last stage of the construction work. Once the BMP has been excavated to subgrade, a qualified professional should visually inspect, test (if necessary), document, and approve the subgrade. Inspection and testing of the subgrade should be performed as quickly as possible once the subgrade has been exposed.

### C.6.3 Undisturbed Subgrade Conditions

In most cases, infiltration BMPs are designed to be constructed on an undisturbed subgrade with a design infiltration rate associated with the native or in-situ soils. In some cases, however, subgrade conditions may be modified to promote additional infiltration capacity, especially if conditions encountered during construction pose concerns for the design infiltration rates used for the project. To improve infiltration of subgrade soils, the mechanical ripping or tilling of the subgrade may be recommended and, in other cases, soil amendments or filter layers under the BMP footprint may be used to improve permeability of the underlying soils.

## C.7 Soil Amendments to Improve Practices or Subgrade

Soils with tested infiltration rates higher than 10 inches per hour will require soil amendments to be considered for infiltrating systems. A 2-foot-thick layer of amended soil should be placed across the entire cross-section of the infiltrating BMP, below the bottom elevation.

Similarly, if soil borings pose concerns with restrictive layers below the proposed infiltrating BMP, soil replacements should be considered. To improve infiltration of subgrade soils, the qualified professional may recommend mechanical ripping or tilling of the subgrade at a depth required to break through impermeable soil layers below and to maximize BMP runoff reduction benefits.

Infiltration tests should be performed within the amended soil layer during construction to verify rates using double-ring infiltrometer testing procedures. If soil amendments are installed, and the tested infiltration rate is determined to be outside of the acceptable range of 0.25 to 10 inches per hour or varies significantly from the design infiltration rate, additional soil amendments or a lined system should be considered.

## C.8 Contaminated Soils – Hotspots

Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or carry a greater risk for spills, leaks, or illicit discharges. The actual hotspot-generating area may only occupy a portion of the entire proposed site. Increased potential for stormwater contamination exists at commercial, industrial, institutional, municipal, or transport-related operations that produce higher levels of stormwater pollutants.

Refer to the Hotspots design guidance and recommendations within each BMP section and Appendix D.

## C.9 Special Conditions – Karst Terrain

Karst terrain is notorious for its spatial variability, meaning that subsurface conditions and the consequent risk of sinkhole formation can change within a matter of yards across a development site. As a result, a sequence of karst feature analyses, geotechnical investigations, and borings should be performed before site layout and the design of any stormwater practice to minimize the risk of a failure or other unintended consequences. The Virginia Cave Board has produced site assessment guidelines for karst terrain, available here: https://www.dcr.virginia.gov/natural-heritage/document/karst-assessment-guidelines.pdf.

The purpose of the investigation is to develop a karst feature plan that identifies the locations and elevations of subsurface voids, cavities, fractures, and discontinuities. The presence of any of these features could pose a danger to groundwater quality, a construction hazard, or an increased risk of sinkhole formation at a proposed centralized stormwater facility.

Refer to the Karst Terrain Design Guidance Section for individual BMPs as well as Appendix E for additional information regarding site investigations and limitations for stormwater systems in these locations.

# C.10 Special Conditions – Coastal Plain

The Coastal Plain is strongly influenced by unique physical constraints, pollutants of concern, and resource sensitivity of the coastal waters. Implementation of traditional stormwater practices in the Coastal Plain is severely constrained by physical factors such as flat terrain, a high water table, altered drainage, extensive groundwater interactions, poorly drained soils, and extensive wetland complexes.

Refer to the Coastal Plain Design Guidance Section individual BMPs for additional information regarding site investigations and limitations for stormwater systems in this region.

# C.11 References


Jarrett Albert R. (2008) Infiltrating Stormwater. A B E Fact Sheet No. F 260. Agricultural and Biological Engineering, Penn State University, University Park, PA 16802i

Fairfax County, Virginia. 2018. Public Facilities Manual.

Fletcher, P.C., and P.M. Veneman. 2013. Soil morphology as an indicator of seasonal high water tables. 5 p. Published online: https://sphweb.bumc.bu.edu/otlt/LPHI/MAPHITWW/Fletcher_Article_GW_Det.pdf

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# APPENDIX D STORMWATER HOT SPOTS

**Contents:**



## D.1 Why Hot Spots Matter

Stormwater hot spots are areas that can be a pollutant source to stormwater and affect stormwater management. Stormwater from hot spots may not meet National Pollutant Discharge Elimination System (NPDES) criteria and may contaminate receiving water. When developing stormwater management programs, the history of a site should be evaluated to determine if potential stormwater hot spots (PSHs) are present. If PSHs are identified, planning and designing to address PSHs should be included in the stormwater management program.

### D.1.1 Surface Water Contamination

Stormwater discharge from a PSH to surface water has the potential to cause surface water contamination. If stormwater discharge from a PSH to surface water is considered, a surface water mixing model should be performed to estimate surface water pollutant concentrations after stormwater discharge. Section 4.2 describes surface water mixing modeling.

### D.1.2 Sediment Contamination

Stormwater discharge from a PSH to surface water has the potential to cause sediment contamination. If stormwater discharge from a PSH to surface water is considered, an estimate of sediment mass loading should be performed to assess the potential for stormwater discharge to result in sediment contamination. Section 4.3 describes sediment mass loading evaluation.

### D.1.3 Groundwater Contamination

Stormwater infiltration at a PSH has the potential to cause groundwater contamination. If infiltration best management practices (BMPs) are considered at a PSH, a soil leaching to groundwater model should be performed to estimate groundwater pollutant concentrations after stormwater infiltration. Section 4.4 describes soil leaching to groundwater modeling.

## D.2 What A Hot Spot Is

Stormwater Hot Spots are any land use or activities that may generate high concentrations of hydrocarbons, trace metals or toxic pollutants than are typically found in stormwater or have a higher risk of spills, leaks or illicit discharges. These facilities are required to obtain stormwater discharge permits and maintain a series of pollution control practices to prevent or minimize contact of stormwater with pollutants. Areas of contamination can result in stormwater contact with pollutants. The stormwater can then transport pollutants to other media including surface water, sediment, soil, and groundwater.

### D.2.1 Potential Stormwater Hotspots

The following businesses and activities are examples of PSHs:

- Gasoline/fueling stations;
- Vehicle repair facilities;
- Vehicle washing/steam cleaning sites;
- Auto recycling facilities and junk yards;
- Commercial laundry and dry cleaning operations;
- Commercial nurseries;
- Golf courses;
- Swimming pools;
- Heavy manufacturing;
- Power generation;
- Metal production, plating, and engraving;
- Toxic chemical manufacturing and storage;
- Petroleum storage and refining facilities;
- Airports;
- Marinas and ports;
- Railroads and rail yards;
- Hazardous waste handling, transfer, and disposal facilities;
- Recycling and solid waste handling and transfer facilities;
- Composting facilities;
- Landfills;
- Incinerators;
- Vehicle and equipment maintenance and parking areas;
- Public works yards and material storage areas; and
- Water and wastewater treatment facilities.

Sites with contaminated soil, groundwater, surface water, and sediment may be considered PSHs.

### D.2.2 Pollutant-Generating Activities

PSHs should be evaluated to identify their potential for generating stormwater pollution. Table 1 identifies common PSH operation and stormwater polluting activities.

**Table D-1 Common PSH Operation and Stormwater Polluting Activities**

| PSH Operation | Stormwater Polluting Activity |
|---|---|
| Vehicle maintenance | Improper disposal of fluids to storm drains<br>Outdoor spilled fuel, leaks, and drips<br>Spraying water on outdoor paved surfaces<br>Outdoor uncovered storage of liquids, oils, batteries |
| Outdoor material storage | Spills<br>Spraying water on paved surfaces<br>Runoff from uncovered bulk materials |
| Outdoor waste management | Leaking dumpsters<br>Runoff from cleaning dumpsters<br>Accumulation of waste outside a container |
| Outdoor plant maintenance | Runoff from power washing and steam cleaning<br>Runoff from sandblasting<br>Runoff from paint removal |
| Turf and landscaping | Non-target irrigation<br>Runoff of nutrients and pesticides<br>Runoff from soil and organic matter deposition on impervious surfaces |

## D.3 How to Identify A PSH

Existing activities at a site, as described in Section 2.1, can be used to identify PSHs. There are publicly available resources to assess if an area is a PSH from historical activities. These resources include state and federal databases. The site history can also be reviewed to assess the PSH.

### D.3.1 Virginia Department of Environmental Quality Land Remediation Resource

Virginia Department of Environmental Quality (VDEQ) administers several programs to confirm that cleanup of contaminated areas in Virginia achieve a satisfactory level of human health and environmental protection. The Land Dataset (https://geohub-vadeq.hub.arcgis.com/pages/land-datasets), within VDEQ's Open Data Portal, is an online database of land-related, permitting, and remediation datasets. The Land Dataset includes non-National Priority List Federal Facilities, petroleum release areas, and Voluntary Remediation Program (VRP) areas.

Entering the stormwater site's address into the Land Dataset will identify if the site is or has been in any of these programs. The Land Datasets provide select site data to further assess if a site is a PSH. Additional information on a site can be obtained by contacting VDEQ staff.

### D.3.2 United States Environmental Protection Agency Resource

The United States Environmental Protection Agency (USEPA) administers the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also called Superfund, to confirm that cleanup of contaminated sites is protective of human health and the environment. Sites on USEPA's National Priority List (NPL) are undergoing long-term remedial response actions. NPL sites in Virginia are presented in USEPA's Superfund NPL map (https://epa.maps.arcgis.com/apps/webappviewer/index.html?id=33cebcdfdd1b4c3a8b51d416956c41f1).

USEPA administers the Resource Conservation and Recovery Act (RCRA) to confirm proper management of hazardous and non-hazardous solid waste. USEPA has a database of enforcement and compliance data for RCRA facilities (https://echo.epa.gov/facilities/facility-search).

USEPA's databases can be used to identify PSHs. These databases provide select site data to further assess if a site is a PSH.

### D.3.3 Site History

If current site activities do not indicate a PSH, and the site is not listed in VDEQ Land Datasets or USEPA NPL and RCRA webpages, the site history should be reviewed to evaluate whether a PSH exists at the site. There may be historical activities resulting in PSHs that have not been addressed under VDEQ or USEPA. These can be initially reviewed through existing site documents and internet research. If site history indicates the potential for a PSH, a Phase I environmental site assessment (e.g., using ASTM Standard E1527) can be considered to further evaluate a PSH.

## D.4 Planning and Designing for PSH

If a PSH is identified, the potential for stormwater to affect surface water, sediment, and groundwater quality and stormwater BMPs should be assessed to inform BMP selection.

### D.4.1 Planning for PSH

If a PSH is identified, transport may occur via stormwater carrying pollutants to surface water, sediment, soil, and groundwater. The following models evaluate PSH discharge on these media:

- Receiving surface water body. Surface water mixing modeling evaluates the potential for discharging stormwater to contaminate surface water.
- Sediment in the surface water body. Mass loading to sediment modeling evaluates the potential for discharging stormwater to contaminate sediment.
- Groundwater by stormwater infiltrating, leaching contaminants from soil, and carrying contamination to groundwater. Soil leaching to groundwater modeling evaluates the potential for infiltrating stormwater to contaminate groundwater.

Stormwater BMPs may be required to address PSH stormwater transport. Stormwater from PSHs may eliminate some BMPs as feasible options. BMP maintenance may be affected by PSH stormwater.

### D.4.2 Surface Water Mixing Modeling

If a PSH has the potential for stormwater to transport contaminants to surface water bodies, surface water mixing modeling will evaluate if the stormwater discharge will affect surface water quality. Surface water mixing models evaluate the mass loading of contaminants from stormwater, the mass of contaminants in surface water, and the mixing of the stormwater and surface water to estimate resulting surface water concentrations.

## D.4.3 Mass Loading to Sediment Evaluation

If a PSH has the potential for stormwater to transport contaminants to surface water bodies, sediment mass loading modeling may need to be performed to evaluate if the stormwater discharge will affect sediment quality.

The Clean Water Act (CWA) regulates discharge of stormwater. NPDES permits are based on protecting the designated uses of the receiving water body. Sediment contamination is typically regulated by CERCLA or state-specific regulations. Under these programs, sediment quality is usually evaluated with risk assessments for human and ecological health. CERCLA and state risk-based criteria are often lower than CWA designated use criteria. This can result in legal stormwater discharges under NPDES that have the potential to contaminate sediment evaluated by risk-based criteria. Mass loading of stormwater contaminants to sediment modeling will assess the potential for sediment contamination.

## D.4.4 Soil Leaching to Groundwater Modeling

If a PSH has contaminated soil and stormwater infiltration is being considered as a BMP, the infiltrating stormwater may leach contaminants from soil and carry contamination to groundwater. Soil leaching to groundwater modeling will evaluate if the infiltrating stormwater will affect groundwater quality. Soil leaching to groundwater models evaluate the partitioning of contaminants between soil and water, the mass loading of contaminants from soil leaching, and the mass of contaminants in groundwater to estimate resulting groundwater concentrations. VDEQ's Virginia Unified Risk Assessment Model https://www.deq.virginia.gov/our-programs/land-waste/land-remediation/voluntary-remediation/process-and-participation) includes a soil leaching to groundwater model to evaluate this pathway.

## D.4.5 BMPs at PSHs

PSH will have modified design approaches compared to non PSH. Section 6.3.3.5.2 in the main text describes design techniques and practices for PSH. Section 6.3.3.3.1 in the main text describes pollution prevention BMPs for PSHs.

## D.4.6 BMP Maintenance at PSH

Solids removed from BMPs at PSHs should be characterized for disposal. There may be contaminants in the solids that limit disposal options. VDEQ provides guidance on waste characterization and disposal (https://www.deq.virginia.gov/our-programs/land-waste/solid-hazardous-waste).

# APPENDIX E SITE ASSESSMENT AND DESIGN GUIDELINES FOR STORMWATER MANAGEMENT IN KARST

**Contents:**

# E.1 Introduction

Karst is a landform produced by the dissolution of soluble bedrock (most commonly limestone or dolostone) along fractures, faults, and boundaries between different rock layers over hundreds of thousands of years or more of geologic time. Karst is frequently characterized by landscape features such as sinkholes, sinking and losing streams, swallets, caves, and springs (see Section E.3). In karst areas, the land surface is typically underlain by a highly irregular, pinnacled soil-rock interface beneath which voids and conduits exist that have may have no surface expression (Denton, 2008). Land areas underlain at the surface or in the shallow subsurface by a bedrock map unit designated by the Virginia Department of Energy (VDE) to include limestone or dolostone or is otherwise all or in part soluble, are considered karst (https://energy.virginia.gov/webmaps/GeologyMineralResources/).

West of Virginia's Blue Ridge, soluble carbonate bedrock, especially limestone and dolomite, is exposed at the surface or in the shallow subsurface. Similarly, carbonate bedrock is exposed in small portions of Virginia's Blue Ridge, Piedmont and in some poorly consolidated deposits in the Coastal Plain. Therefore, karst is found across much of the Valley and Ridge Province in western Virginia, in small sections of the Piedmont, and in parts of the Coastal Plain. From a design/construction perspective, a lack of surficial karst features is not sufficient for failing to fully investigate a proposed development site in karst prone areas.

Because karst can be particularly problematic from a stormwater management perspective, this Appendix is included to assist with screening and planning for karst. In addition to potential onsite stability impacts, care should also be taken to avoid groundwater contamination in Coastal Plain areas with karst characteristics. These areas can carry a high risk of groundwater contamination, and a need to maintain aquifer recharge. Here, stormwater practices are preferred that achieve water quality treatment using infiltration practices, except in areas determined to be stormwater hotspots, where infiltration should be avoided.

# E.2 Stormwater Requirements for Discharge to Karst Features

VDEQ requirements and guidance for discharge in karst areas are summarized in this section. This guidance has been updated over time with the publication of DCR's Technical Bulletin No. 2 and more recently VDEQ's GM 22-2012 guidance. Subsequent sections of this manual support this guidance by providing additional background information, tools, and commentary on other considerations that may be crucial for consideration during land development/disturbance activities taking place in karst areas.

A. When land disturbing activities discharge to multiple karst features (see section E.3), channel protection and flood protection requirements should be applied independently to each (9VAC25-875-650 C).

B. When performing water quantity design computations, the pre-development peak flow rates should be adjusted to use the Karst Loss Modification Values found in Table E-1.

**Table E-1 Multipliers for adjusting pre-development runoff quantities in karst areas**

| % of Drainage Area in Karst | Design Storm Return Frequency | | |
|---|---|---|---|
| | 1 year and 2-year Storms | 10-year Storm | 100-year Storm |
| 100 | 0.33 | 0.43 | 0.50 |
| 90 | 0.35 | 0.46 | 0.56 |
| 80 | 0.38 | 0.51 | 0.62 |
| 70 | 0.47 | 0.58 | 0.68 |
| 60 | 0.55 | 0.66 | 0.74 |
| 50 | 0.64 | 0.73 | 0.80 |
| 40 | 0.73 | 0.80 | 0.85 |
| 30 | 0.82 | 0.86 | 0.89 |
| 20 | 0.91 | 0.92 | 0.93 |
| 10 | 1.00 | 0.98 | 0.97 |
| 0 | 1.00 | 1.00 | 1.00 |

Source: Laughland (2007) and VA DCR (1999)

C. When a land-disturbing activity discharges stormwater runoff to a karst feature, the design professional should screen for the existence of known natural heritage resources located in the karst feature. See 9VAC25-875-650 C. Screening should be performed in consultation with the Department of Conservations and Recreation's Natural Heritage Program (https://www.dcr.virginia.gov/natural-heritage/nhserviceform/).

D. Construction of stormwater management facilities in karst areas should only occur after a study of the geology and hydrology to determine the presence or absence of karst features that may be impacted by stormwater runoff or stormwater management facility placement. See 9VAC25-875-650 B and Section E.5.

   1. Site evaluations and investigations should comply with Section 4-6 of "Technical Bulletin No. 2, Virginia Department of Conservation and Recreation – Hydrologic Modeling and Design in Karst".

2. Site evaluations should be comprised of (1) a preliminary site investigation, completed prior to site design and development, and (2) a site-specific investigation, conducted once the decision is made to proceed with site design and development.
3. The preliminary site investigation should comply with the requirements outlined in the Virginia Cave Board "Karst Assessment Standard Practice".

E. Construction of a stormwater management facility in a karst feature should only occur after the completion of a geotechnical investigation that identifies any necessary modifications to the facility to ensure its structural integrity and to maintain its water quality and/or water quantity efficiencies. See 9VAC25-875-650 C and Section E.5. The use of centralized stormwater management facilities with large drainage areas is discouraged.
1. Site and stormwater designers should retain the services of a qualified consultant experienced in working in karst landscapes. The investigation should determine the nature and thickness of subsurface materials including the depth to bedrock and the water table in areas of the site where construction is planned. Detailed site and geotechnical investigations should be performed as outlined in "Chesapeake Stormwater Network: CSN Technical Bulletin No. 1 – Stormwater Design Guidelines for Karst Terrain in the Chesapeake Bay Watershed, Version 2.0".

F. Stormwater management facilities should disperse flows over the broadest area possible to avoid ponding, concentration, or soil saturation.

G. Stormwater management facilities requiring deep excavations or pools of standing water should be avoided.

H. The following stormwater management facilities or best management practices are preferred for use in karst areas:
- Rooftop (impervious surface) disconnection (P-FIL-01)
- Sheet flow to vegetated filter strip / conserved open space (P-FIL-07)
- Vegetated roof (P-FIL-02)
- Rainwater harvesting (P-BAS-04)
- Urban Bioretention (P-FIL-05, Appendix B)
- Dry swales (P-CNV-02)
- Filtering practices (P-FIL-06), including proprietary filters listed on the Virginia Stormwater BMP Clearinghouse

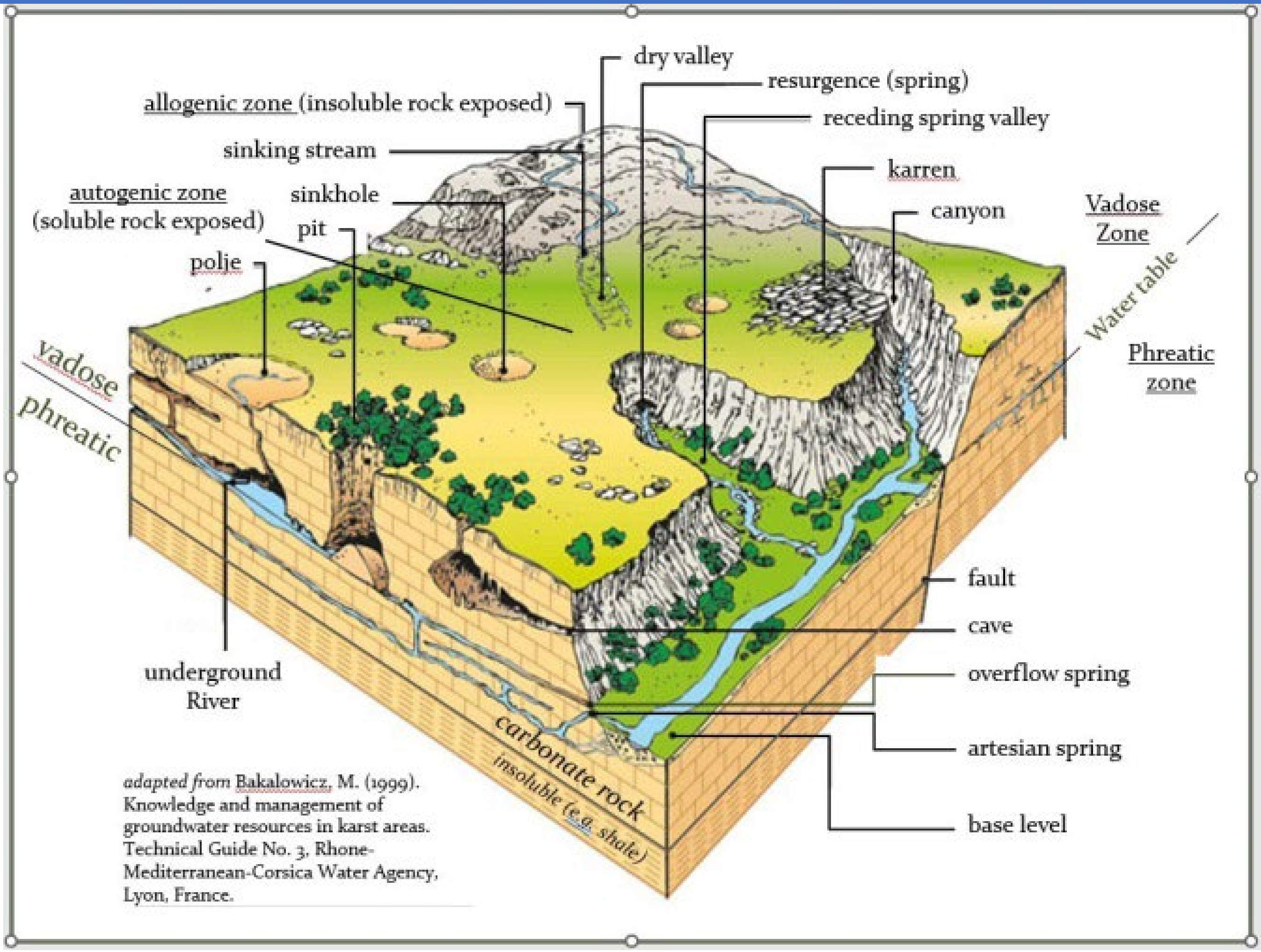
I. The following stormwater management facilities or best management practices are discouraged for use in karst areas:
- Large scale bioretention (P-FIL-05)
- Wet ponds (P-BAS-02)
- Extended detention ponds (P-BAS-03)

J. If these stormwater management facilities or best management practices will be used to provide water quality and/or water quantity, the karst terrain design adaptations outlined in the respective stormwater specification should be used. Copies of all Underground Injection Control (UIC) Class V Well inventory forms (EPA Form 7520-16) for discharges of stormwater runoff to improved sinkholes should be included in the Stormwater Pollution Prevention Plan (SWPPP) for the land disturbing activity.

# E.3 Typical Karst Features

In the Virginia Erosion and Stormwater Management Regulation, 9VAC25-875-20, "karst features" refers to "sinkholes, sinking and losing streams, caves, large flow springs, and other such landscape features found in karst areas." Karst areas means "any land area predominantly underlain at the surface or shallow subsurface by limestone, dolomite, or other soluble bedrock regardless of any obvious surface karst features." Figure E-1 is a block diagram showing karst features typical of those found in western Virginia, with features indicated in the landscape context. Karst feature descriptions as mentioned in 9VAC25-875-20 occur in sections E.3.1 through E.3.4 below in more detail.

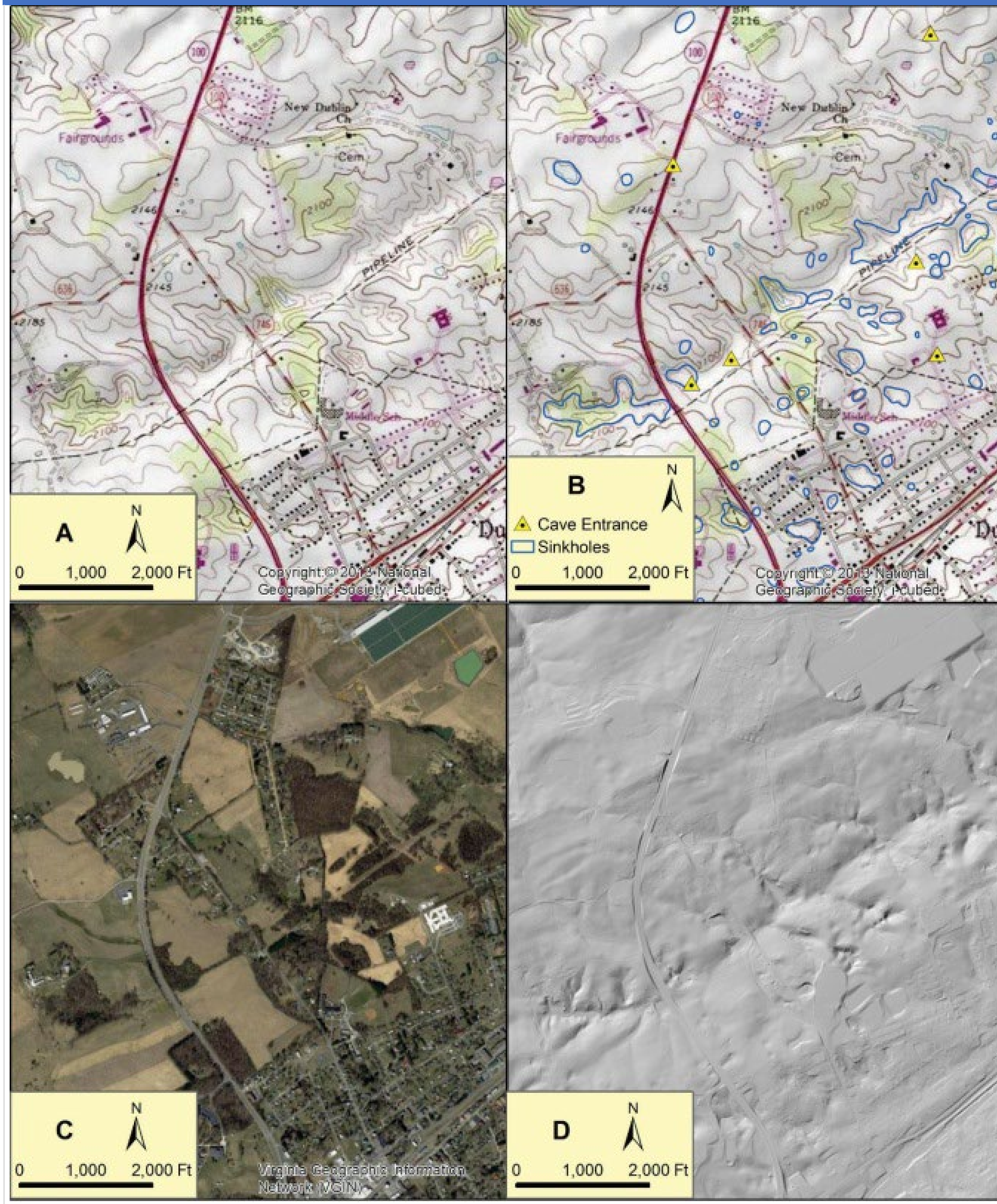
***Figure E-1 A block diagram of karst areas showing characteristic landscape features and relationships***




## E.3.1 Sinkholes

Per § 10.1-1000 of the Code of Virginia, a sinkhole is “a closed topographic depressions or basin, generally draining underground, including, but not restricted to, a doline, uvala, blink valley, or sink.”. Formation of sinkholes is a natural process that can occur gradually or catastrophically. Most subsidence in karst is related to sinkhole formation. Changes in soil moisture, drainage patterns, and groundwater levels can increase sinkhole formation. Once formed, sinkholes capture precipitation and funnel it directly into the ground. Sinkholes existing prior to development may have watersheds that extend beyond the boundary of the closed depression and receive intermittent or perennial flow through sheet flow or defined channels. Figure E-2, Figure E-3, and Figure E-4 show examples of sinkholes on undeveloped land, though in some cases these sinkholes may have been due to human activity on adjacent properties. Over 50,000 naturally occurring sinkholes thirty feet or more in diameter were mapped by the Virginia Division of Mineral Resources using aerial photography (Hubbard, 1983, 1988, and 2001). Since small sinkholes are much more common than large ones, and since many sinkholes in forested areas were not detectable using aerial photography, the actual number of sinkholes in western Virginia is significantly larger.

## Figure E-2 Karst as depicted at 1:24,000 map scale




*Same area along I-81 corridor shown as: A) USGS topo, B) Topo with documented karst features, C) Aerial imagery, and D) Lidar derived terrain model.*

**Figure E-3 Examples of sinkholes on undeveloped land**

**Figure E-4 More sinkholes on undeveloped land**

## E.3.2 Sinking and Losing Streams

Sinking streams disappear entirely underground through features called ***swallets*** or insurgences, while a portion of the flow from ***losing streams*** goes underground beneath streambeds. Sinking streams are in some cases streams flowing into sinkholes, while in other cases they occur where the stream channel has eroded into underlying solution voids or conduits. See Figure E-5 and Figure E-6.

**Figure E-5 Insurgence for I-81 Cave (Smyth County): Example of a sinking stream in western Virginia**

*Figure E-6 Typical cave passage underlying the karst of western Virginia*

## E.3.3 Caves

Per § 10.1-1000 of the Code of Virginia, a cave is “any naturally occurring void, cavity, recess, or system of interconnecting passages beneath the surface of the earth or within a cliff or ledge including natural subsurface water and drainage systems, but not including any mine, tunnel, aqueduct, or other man-made excavation, which is large enough to permit a person to enter.” Some caves are dry and contain beautiful mineral formations. Many are partially or completely filled with younger sediments that have been washed in. Caves with underground streams can transmit water laterally beneath surface watershed boundaries, and many caves reach the water table. Caves in Virginia range to nearly 30 miles in length and to over 1,200 feet in depth. Cave explorers have to date (April 2023) surveyed 600 miles of passage in almost three thousand Virginia caves (www.virginiacaves.org), and new caves and cave passages are commonly discovered. It is widely accepted that most cave passages beneath western Virginia have no traversable connection to the land surface, and that the actual length of cave passages is much higher than that which has been – or can be – entered and surveyed.

Even more extensive in karst are naturally occurring underground voids and conduits that are too small for human access but still store and transmit water, sediment, and any contaminants introduced by man. Fissures and cracks enlarged by dissolution transmit water vertically from the surface to underlying networks of caves.

The volume of rock between the base of the soil and the caves below comprises the ***epikarst***. The epikarst has high porosity, and functions somewhat like a giant sponge, storing runoff that makes it through the soil profile and slowly releasing that water into the caves and conduits below. The water you observe in a show cave dripping from cave formations such as stalactites is water from the epikarst. The epikarst is a critical yet frequently ignored part of the natural stormwater drainage network.

The network of epikarstic storage, cave streams, and flooded caves and smaller solution voids and conduits beneath the water table together comprise a karst aquifer. Many homes, farms, local water authorities, and industries across western Virginia rely on groundwater wells and springs that derive their water from karst aquifers. Much of the flow in streams and rivers of western Virginia first passed through karst. Protecting karst water helps maintain both drinking water quality and surface water quality. Protection of the karst aquifer is the overriding environmental priority when developing in karst areas.

## E.3.4 Springs

Springs are places where groundwater flows to the surface. In karst areas, these are typically formed where cave streams or the karst aquifer intersect the land surface. In some cases, springs are used as public water supplies (see Figure E-7). A drainage network comprised of an interconnected assemblage of these features makes the determination of exact discharge points for runoff and groundwater difficult, and variable depending on runoff rates and aquifer levels. Therefore, designers of stormwater management systems in karst areas need to think in three dimensions, rather than just two, and infer what they cannot see.

***Figure E-7 A karst spring used as a public water supply***

*Photo by Bob Denton*

# E.4 Hydrology/Hydrogeology Characteristics in Karst Areas

In karst, patterns of subsurface dissolution are at least as and, in some settings, more important than surface topography in determining where and how fast runoff flows. This has profound implications for stormwater management and erosion and sediment control.

In an undeveloped state, a site on karst typically produces about two-thirds less stormwater runoff than a comparable site in the Piedmont or Coastal Plain (VA DCR, 1999). In areas that drain to sinkholes, precipitation is routed underground. As land is developed, the impervious surfaces and compacted soils produce a much greater rate and volume of runoff. As a result, the increase in surface runoff following development is much greater than in non-karst terrain. This phenomenon is greatly exacerbated when sinkholes are filled or when water is diverted away from sinkholes.

Site designers working in karst areas face a confusing surface drainage pattern, reflecting that much of the drainage takes place hidden from view beneath the ground. Drainage patterns are highly dynamic in karst and involve a great deal of interaction between surface water and groundwater. Often, there is not a well-defined stream network that moves water to a downstream point. Subsurface conduits commonly convey their flow in different directions than the overlying surface streams, commonly passing beneath topographical divides at various scales. In addition, unlike surface streams, subterranean streams generally do not have floodplains, resulting in dramatic increases in water level fluctuations following storm events. This phenomenon is greatly amplified when development increases flow rates and volumes, leading to an increased risk of both sinkhole formation and flooding.

Due to the complexity of karst, sinkholes or surface depressions should never be filled unless a comprehensive evaluation of the feature is completed first. Karst is notorious for its spatial variability, meaning that subsurface conditions and the consequent risk of karst-related hazards can change within a matter of feet across a development site. Detailed site assessment at the earliest stage of any project in karst is the best way to reduce the risk of karst hazards and/or environmental impacts. This issue is discussed in detail under E.5.4.1 Stormwater Design and Modeling. Three important consequences arise due to greater increase in runoff when sites in karst are developed:

- More runoff is conveyed into a poorly defined surface drainage system that often lacks the capacity to handle it. In other words, it is more difficult to find an adequate receiving channel, or to evaluate if underground channels are adequate.
- More runoff greatly increases the risk of new sinkhole formation (e.g., collapse or subsidence), particularly if runoff is allowed to pond on the landscape or if it flows at increased rates and volumes into karst features. The increased risk for sinkholes typically extends to down-gradient off-site areas.
- Development-related changes that increase surface runoff reduce recharge to the karst aquifer below, thereby lowering the water table, diminishing both spring discharge and well levels. These changes can profoundly alter the hydrology of surface streams and can damage both subterranean and surface aquatic ecosystems.

Because of these factors, stormwater management practices that promote dispersed, disconnected upland infiltration are preferable to those that result in concentrated infiltration or surface discharge. Large basins and associated conveyances can be a problem in karst areas, but small ponds present much less risk. However, urban bioretention and other small-scale, distributed infiltration practices are best.

The following are important stormwater management design principles for karst areas:

- As a general rule, the stormwater system should avoid large contributing drainage areas, deep excavation, and pools of standing water. Distributed treatment is recommended over centralized stormwater facilities, and wherever possible treat runoff as sheet flow in a series of small runoff reduction practices before it becomes concentrated. Stormwater management facilities should be designed to disperse flows over the broadest area possible to avoid ponding, concentration, or soil saturation.

- To the maximum extent practicable, pre-development watershed boundaries and outlets (including receiving sinkholes) should be maintained post-development.
- Stormwater management conveyances, including grassed waterways, diversions, and lined waterways, should be designed to disperse the flows across the broadest channel area possible. This reduces the level of soil saturation and reduces the potential for soil movement. Shallow trapezoidal channel cross-sections are preferred over parabolic or V-shaped channels.
- Small-scale low impact design (LID) types of practices work well in karst areas, although they should be shallow and may require perforated drains to prevent groundwater interaction. For example, micro-bioretention and infiltration practices can be a key part of the treatment train. Karst specific modifications and considerations are included in the individual BMP descriptions in the Virginia Stormwater Management Handbook.
- Consider manufactured water quality BMPs which can serve as pre-treatment devices or even spill containment BMPs for commercial/industrial development in karst areas. While these structures do not eliminate the potential for karst collapse, they do provide water quality treatment that helps to minimize the potential for the contamination of groundwater.
- The use of centralized stormwater practices (e.g., extended detention or retention basins) with large drainage areas is discouraged, and when used in karst terrain both the basins and associated conveyances require impermeable, geosynthetic liners to discourage subsidence. Centralized treatment practices require more costly geotechnical investigations and design features than smaller, shallower distributed LID practices. Furthermore, such practices generally increase site runoff and decrease groundwater recharge. In cases where ponds are used, please refer to the karst specific modifications and considerations included in the individual BMP descriptions in the Virginia Stormwater Management Handbook.
- Stormwater management facilities requiring deep excavations or pools of standing water should be avoided.
- When sinkholes are determined to require remediation, the mitigation should use appropriate techniques as outlined in USDA-NRCS Conservation Practice Standard “Sinkhole Treatment” Code 527.
- Designers should refer to the list of preferred and acceptable erosion and sediment control and stormwater practices for use in karst terrain as follows. As previously mentioned, karst associated limitations and modifications are included in the individual BMP descriptions in the Virginia Stormwater Management Handbook.

## E.4.1 Karst Swales/Stream Density

Per 9VAC25-875-560 19.a, concentrated stormwater runoff leaving a development site shall be discharged into an adequate natural or man-made receiving channel, pipe or storm sewer system. This is of particular concern in karst areas since ‘adequate’ channels as defined by standard conveyance definitions may not be present at many sites in karst terrain (VA DCR, 1999). Karst has less perennial stream mileage per unit area than most other landforms. Consequently, many development sites on karst cannot discharge to the surface stream drainage network or to defined surface channels within their property boundaries.

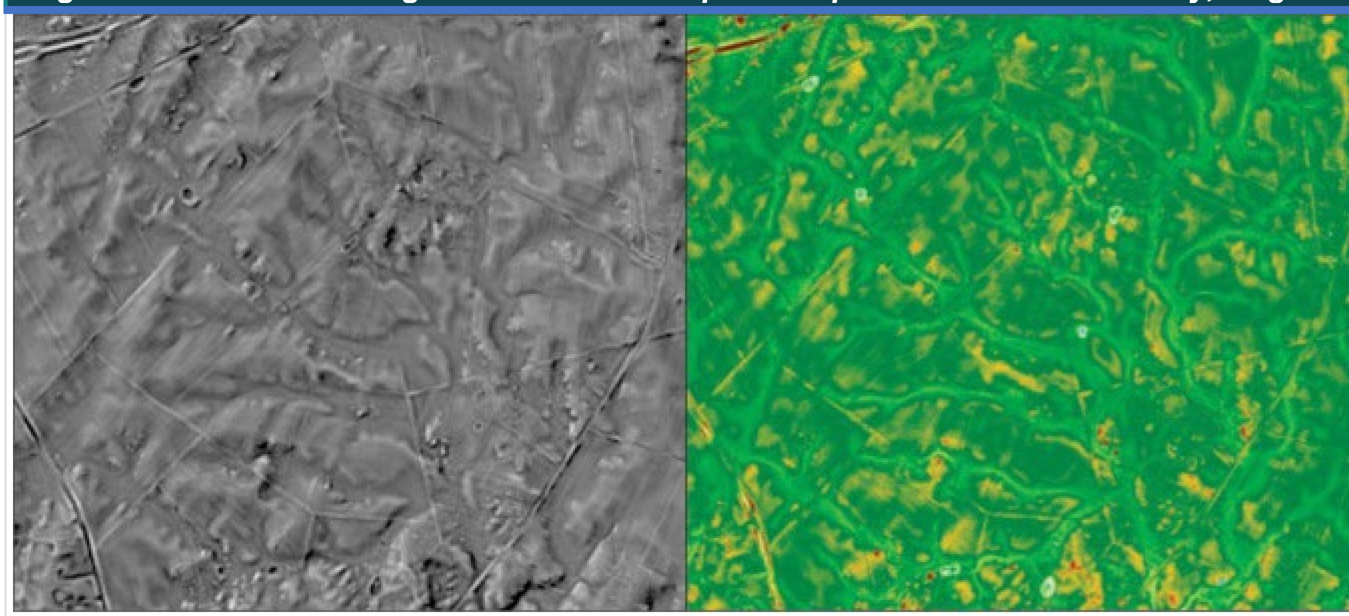
Instead of well-defined channels, much of the length of the headwater stream network in karst terrain is composed of karst swales, which appear as relatively wide and shallow parabolic valleys (Fennessey, 2003). Karst swales lack defined channels, beds, or banks and may only briefly hold water during extreme storm events. Nevertheless, karst swales are an integral element of the natural drainage system and often exhibit significant infiltration capacity (SEA, 2000). The protection of natural karst swales is an important element of effective stormwater design in karst regions. Because karst swales are not identified as such on topographic maps, their accurate delineation may require site-specific investigations by a Certified Professional Geologist (CPG) or soil scientist familiar with karst.

When possible new stormwater conveyance structures in karst terrain should use and mimic karst swales. Use of practices that produce concentrated flows and ponding is discouraged. Grass channels can be effective storm-water-diversion structures in karst areas. Particularly effective are waterway designs that are shallow and broad, providing maximum bottom width and wetted perimeter to disperse flow over the greatest area. Effective incorporation of karst swales into stormwater management design helps to maintain recharge to the epikarst while protecting water quality.

## E.4.2 Karst Surcharge

In this phenomenon, instead of receiving flow from the surface, a sinkhole or other karst feature discharges subterranean flow to the surface. This is due to the connectivity of the underground conveyance network and its limited overbank capacity. Karst surcharge can have substantial impact by subjecting developed areas to inundation. A feature that sometime accepts flow while at other times discharging flow is termed an estavelle. Low lying areas that can become flooded when groundwater levels rise above the land surface are termed turloughs. Identification of these features during site assessment is critical, especially since the frequency of karst surcharge may be low but have devastating results when it occurs. Such areas are essentially flood plains with ill-defined frequencies. Figure E-8 shows an aerial view of an area in Clarke County where karst surcharge is common.

***Figure E-8 Karst surcharge to swales developed in a portion of Clarke County, Virginia***



*Left image shows shaded relief of terrain derived from a high resolution digital elevation model. The right image shows the same area, colored by topographic position. Light blue areas are sinkholes that discharge water during groundwater high stands and after severe storm events.*

## E.4.3 Hydrologic Rural Development Stressors

Development pressure is variable within the karst region of Virginia, increasing dramatically in some areas. Many communities lying on karst along the I-81 corridor are experiencing increased commercial and industrial development, as well as high density residential development. Low density rural residential development is more widespread, and frequently occurs in subdivisions constructed outside of water and/or sewer service areas. Consequently, many residents of Virginia's karst region rely on private wells or springs to provide drinking water, and on septic systems to dispose of wastewater. These developments are commonly interspersed with agriculture activities that also rely on the same water, and that can introduce contaminants into groundwater. Together, these types or rural land development increase the demand on groundwater resources which, in times of drought, lowers the water table and causes wells and springs to fail. These problems are exacerbated when poorly designed stormwater management reduces groundwater recharge.

## E.4.4 Groundwater Contamination Risks

In karst areas, contaminants in polluted runoff and spills can pass rapidly from the surface into groundwater, with little or no filtration or decomposition. In other cases, contaminants are "hung up" above the water table in the epikarst, releasing toxins into groundwater more gradually, allowing these resources to remain contaminated for years to decades. The strong interaction in karst areas between surface runoff and groundwater poses increased risk to quality of the drinking water upon which residents and the ecosystem rely. Remediation of a contaminated aquifer can be expensive and may take decades.

If a proposed development site on karst also falls within a stormwater hot spot (as defined in Appendix D), then additional restrictions apply. Specifically, infiltration practices, including discharge of treated stormwater runoff to a karst feature and/or discharge of stormwater to an improved sinkhole (Class V Stormwater Injection Well), are prohibited except as authorized by a permit issued under the underground injection control program (40 CFR 144.11).

## E.4.5 Accelerated Sinkhole Formation

Land development/disturbance activities in karst areas can result in the formation of new sinkholes due to increases in runoff rates and volumes from increased impervious surfaces, disruption of natural drainage patterns, excavation, and filling of natural sinkholes. Such sinkholes can short circuit the stormwater drainage system, and damage public infrastructure and buildings (Figure E-9). To reduce sinkhole risk, designers need first to carefully assess the pre-development site drainage, then design a storm water management system that minimizes disturbance. In most cases, this means installing a series of small, shallow, and preferably disconnected runoff reduction practices across the site, rather than using the traditional pipe-to-pond approach. Large retention basins often fail due to subsidence in karst areas (see Figure E-10, Figure E-11, and Figure E-12).

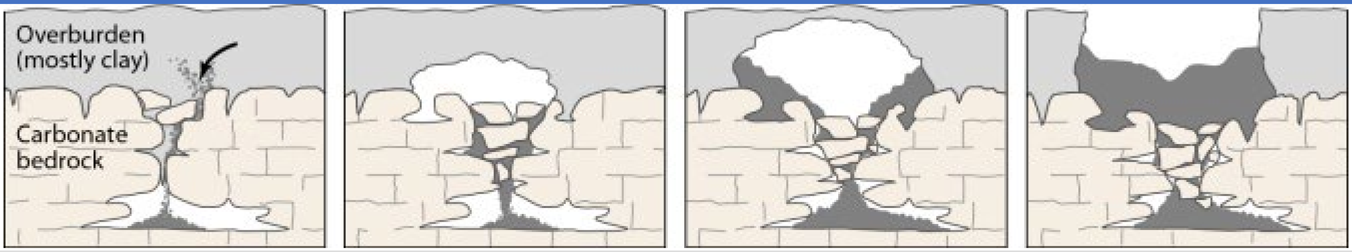
Sinkholes cause instability of the land surface and can short circuit the stormwater management system. Serious consideration should be given to sinkhole prevention and mitigation in the development of erosion and sediment (ESC) control and stormwater management (SWM) plans. Sinkhole formation (subsidence) in karst terrain is often accelerated by construction activities that disturb existing soil and bedrock conditions directly by grading (cut and fill) and/or by modify a site's hydrology through re-routing of water flows, installation of impervious surfaces, or impoundment of water. The most common type of sinkhole associated with land disturbance is a cover collapse sinkhole, where soil or sediment with physical properties altered by site development ravels downward into underlying solution voids and conduits, a process which can occur gradually or catastrophically.

**Figure E-9 Subsidence along stormwater conveyance channels**

**Figure E-10 Typical subsidence failure (sinkhole formation) within a large stormwater detention basin**

*Figure E-11 A house swallowed by a sinkhole near Berryville, Virginia in 1992, believed to be induced by nearby well drilling*

*Figure E-12 Schematic of sinkhole formation by cover collapse*




## E.4.6 Summary of Development Related Impacts Due to Karst

Stormwater management practices can have significant negative impacts to karst-associated natural resources, as described in the preceding sections. Karst features can also impact the design and operation of a stormwater management system.

Negative impacts to karst associated natural resources include:

1. Reduced recharge to the karst aquifer and waters to which it discharges, resulting in lower spring discharges and decreased water well levels.
2. Introduction of contaminants into the aquifer and subsurface.
3. Erosion and sedimentation of the karst system.
4. Impacts to subterranean and aquatic ecosystems.
5. Destruction of existing surface-subsurface connections.

6. Creation of new surface-subsurface connections (sinkholes).

Impacts to stormwater management system design and operations include:

1. Miscalculation of pre- and post- development site runoff resulting in undersized BMPs.
2. Formation of sinkholes that damage and bypass the stormwater management system, leading to environmental impacts described above.
3. Obstruction of sinkholes and subterranean karst conduits that can lead to both site flooding and increase in the magnitude and frequency of subsidence (sinkhole formation, Section E.4.5)

An awareness of the limitations to site development posed by karst features can prevent problems, including damage to property, structures and life, and contamination of ground water. Conventional methods of design and engineering areas are often incompatible with karst. Appropriate site assessment, testing, planning, design, and remediation help to reduce the likelihood of these problems when developing on a site with karst features. Karst appropriate designs informed by site-specific investigations can prevent persistent, costly, and environmentally detrimental post-development problems.

# E.5 Stepwise Stormwater Analysis in Karst Areas

## E.5.1 Identify Presence of Karst

The first and most obvious step is to determine whether the site lies on karst. Any site underlain by carbonate bedrock should be treated as karst, regardless of the presence of surface karst features like sinkholes. Historically, some of the more significant issues with stormwater management in Virginia's karst have occurred on sites with little to no surface expression (e.g. the stormwater detention pond shown in Figure E-10). Fortunately, a carbonate bedrock map developed by the Virginia Division of Mineral Resources (Virginia Department of Energy, https://energy.virginia.gov/webmaps/GeologyMineralResources/), streamlines this determination:

1. For purposes of this Handbook, land areas underlain at the surface or in the shallow subsurface by a bedrock map unit designated by the Virginia Department of Energy to include limestone or dolostone or is otherwise all or in part soluble are considered "karst" and should be investigated by a licensed Certified Professional Geologist. A lack of surficial karst features is not sufficient for failing to fully investigate a proposed development site in karst.
2. A site in an area depicted as "Mixed carbonate and non-carbonate bedrock" should have a determination made by a Certified Professional Geologist as to whether the site is underlain by carbonate bedrock and thus karst, with the result provided to the permit issuing authority. Site investigations and characterization are required for sites where stormwater management impoundment facilities will be constructed in karst areas (9VAC25-875-650).
3. For a site in an area depicted as "Minor carbonate rock", the developer is encouraged to determine if carbonate bedrock is present, and if so to follow the karst specific provisions of the regulations and this Handbook.
4. For sites lying upslope of and draining to "Carbonate bedrock" or "Mixed carbonate and non-carbonate bedrock", determination should be made if stormwater enters karst features once flowing onto the carbonate rock. If so, regulatory provisions related to water quality and quantity in karst apply.

## E.5.2 Site Investigation/Characterization Guidelines

Site evaluation for karst features is usually carried out in two phases: (1) a preliminary site investigation, completed prior to preliminary site design and development, and (2) a site-specific investigation, conducted once the decision is made to proceed with a site plan development. The workflow should be as follows:

1. Preliminary Site Investigation (see E.5.3)
2. Preliminary Site Design (see E.5.4)
3. Detailed Site Investigation (see E.5.5)
4. Modifications to and Finalization of Site Design
5. Submission of Permit Application with Stormwater Pollution Prevention Plan and supporting documents

9VAC25-875-650 states "Construction of stormwater management impoundment structures or facilities may occur in karst areas only after a study of the geology and hydrology of the area has been conducted to determine the presence or absence of karst features that may be impacted by stormwater runoff and BMP placement." Furthermore, 9VAC25-875-650 C states "permanent stormwater management impoundment structures or facilities shall only be constructed in karst features after completion of a geotechnical investigation that identifies any necessary modifications to the BMP to ensure its structural integrity and maintain its water quality and quantity efficiencies."

In addition to the guidance outlined in the Handbook, developers, their agents, and regulators may wish to consult ASTM D8512-23, "Standard Practice for Preliminary Karst Terrain Assessment for Site Development". Developers may also wish to consult site assessment guidelines developed by the Virginia Cave Board and available here: https://www.dcr.virginia.gov/natural-heritage/document/karst-assessment-guidelines.pdf.

## E.5.3 Preliminary Site Investigation

Developers should undertake a preliminary site investigation prior to conducting any design work for projects or building in karst areas. The purpose of the preliminary investigation is to identify areas of concern that may require additional investigation, and to review the preliminary site design in relationship to potential problem areas. The preliminary site investigation will often result in immediate changes to the site layout to avoid future problems.

Various methods are available to collect information about the bedrock and soil conditions at a proposed development site. The preliminary site investigation involves analysis of geological maps, topographic maps, soil surveys, and aerial photography.

Note that even if surface karst features are not identified in the preliminary site investigation, subterranean karst features may be present. Therefore, any site shown on published geologic maps to be underlain by soluble bedrock should be considered karst for purposes of BMP selection, subsidence risk mitigation, and karst loss adjustment calculations, unless a Certified Professional Geologist certifies that at the site scale, soluble bedrock units are not exposed at the surface or present in the shallow subsurface. The following sources of information may be useful in developing the preliminary site investigation.

### E.5.3.1 Topographic Maps

These maps contain information about the relative positions and elevations of natural or man-made features of an area (e.g., buildings, roads, plains, hills, mountains, degree of relief, steepness of slopes and other physiographic features) related to the contours and configuration of the earth's surface. Topographic maps are available from the US Geological Survey National Geospatial Program at https://www.usgs.gov/programs/national-geospatial-program/topographic-maps. Topographic maps are also available at various scales, the most common being 1:24,000.

### E.5.3.2 Geologic Maps

These maps contain information on the physical characteristics and distribution of the bedrock and/or unconsolidated surficial deposits in an area. Geologic features such as the strike and dip of strata, joints, fractures, folds, and faults are usually depicted. The orientation of strata and geologic structures generally controls the location and orientation of solution features in carbonate rock. Geologic contacts, faults, and certain fractures sets may be more prone to solution than others. The relationship between topography and the distribution of geologic units may reveal clues about the solubility of the specific rock units. Geologic maps are often available at various scales, the most common being 1:24,000. Digital geologic data may be available as well. Geologic maps can be obtained from the Virginia Department of Energy, Division of Mineral Resources and from the United States Geological Survey.

### E.5.3.3 County Soil Surveys

The USDA-NRCS soils survey maps show the distribution of soil types or other soil mapping units in relation to the prominent physical and cultural features of the Earth's surface. Soil surveys can be obtained online using the USDA-NRCS web soil survey (https://websoilsurvey.nrcs.usda.gov/app/), or from local NRCS soil service offices. USDA and Virginia Soil Survey soils maps commonly indicate sinkholes and other karst features, even in cases where such features are too small to be visible on a 1:24,000 topographic map.

### E.5.3.4 Aerial Imagery

Aerial imagery is readily available, and provides a simple, quick method of site reconnaissance. Most recent aerial imagery (generally less than 3 years old) is available through ESRI, through third party GIS servers, and through other commercial online applications such as Google Earth. Inspection of photos can quickly reveal vegetation and moisture patterns that provide indirect evidence of the presence of cavernous bedrock. Piles of rock or small groups of brush or trees in otherwise open fields can indicate active sinkholes or rock pinnacles protruding above the ground surface. Circular and linear depressions associated with sinkholes, and linear solution features and bedrock exposures are often visible when viewed using stereo imagery. Inspecting photos taken on multiple dates can be especially valuable in revealing changes that take place over time. Images defined at wavelengths other than visible light can be useful in detecting vegetative or moisture contrasts.

### E.5.3.5 Sinkholes

The Virginia Department of Energy, Division of Mineral Resources has publicly available geospatial data in ESRI shapefile format that displays the locations of more than 50,000 sinkholes as identified using aerial photogrammetry (Hubbard 1983, 1988, and 2001). Any development on karst should include screening against this layer as a component of the preliminary investigations. Larger scale (smaller) features will likely be revealed through LiDAR analysis.

### E.5.3.6 Heritage Resources/Caves

Developers should screen for the presence of documented caves in the project vicinity through the DCR Natural Heritage Environmental Review service: https://www.dcr.virginia.gov/natural-heritage/ereview. The DCR Division of Natural Heritage maintains a data sharing agreement with the non-governmental Virginia Speleological Survey, which maintains a comprehensive inventory of caves within the Commonwealth.

### E.5.3.7 LiDAR (Light Detecting and Ranging)

LiDAR data has become an invaluable tool for the investigation of karst terrains and specifically surface karst features. LiDAR digital elevation data with 1 meter horizontal and sub-meter vertical resolution is available statewide at (https://vgin.vdem.virginia.gov/apps/VGIN::virginia-lidar-downloads/explore). From this data, GIS analysts can image and delineate surface topographic features, including karst features such as sinkholes, as well as the watersheds draining to individual features. In some areas derived products such as sinkhole and watershed maps are available, while in others only raw data currently exists.

### E.5.3.8 Hydrologic Data

In some areas, flow maps based on dye tracing show the relationships between surface karst features, subterranean waters (caves, wells), and surface springs. This data, where available, are extremely valuable in determining features potentially impacted by land development in karst. The DCR Natural Heritage Environmental Review provides, as part of project screening, existing proximal hydrological delineation data (dye traces near or on the site).

### E.5.3.9 Site Reconnaissance

An on-site (boots on the ground) reconnaissance is an important step in finding potential karst-related site constraints and is an essential part of the preliminary investigation. Although many karst features are obvious to the eye, it is an advantage to conduct the site visit with a qualified investigator knowledgeable about karst. Prior to the site visit, the investigator(s) should review the relevant desktop resources described above to identify where problems might be found. It is important to review drainage patterns, vegetation changes, depressions, and bedrock outcrops to find evidence of ground subsidence. Sinkholes in subdued topography can often only be seen at close range. Disappearing and losing streams are common in karst areas, and bedrock pinnacles that can be a problem in the subsurface will often protrude above the ground surface. A simple and effective but often overlooked source of information during site reconnaissance is an interview with the property owner (or in many cases, former property owner). Often property owners can recount a history of problems with ground failure that may not be evident at the time of the site reconnaissance.

The product of the preliminary site reconnaissance is usually a site map, which shows the location of any known or suspected karst features for later reference. The site map can be compared to other information collected to assess the potential risk of karst-related problems. It is important to understand that while the presence of sinkholes or caves indicates the presence of karst, their absence does not necessarily mean that karst will not cause problems at the site (Hubbard 2004). As stated earlier, any site shown on published geologic maps to be underlain by soluble bedrock should be considered karst for purposes of BMP selection, subsidence risk mitigation, and karst loss adjustment calculations, unless a Certified Professional Geologist certifies that at the site scale, soluble bedrock units are not exposed at the surface or present in the shallow subsurface.

## E.5.4 Preliminary Site Design

The preliminary site design should carefully consider the results of the Preliminary Site Investigation, and to the maximum extent practicable avoid karst features and subsidence prone areas. Ideally, the site plan should minimize major site disturbance, especially cuts and fills. The amount of impervious cover on the site should be minimized to reduce stormwater runoff. Alteration of pre-development drainage patterns should also be avoided, or at least minimized, to protect existing flow paths (such as karst swales) and their ecological functions. Disconnected stormwater management BMPs are strongly preferred over centralized facilities. Karst specific issues with individual BMPs are addressed in each BMP under “Site Considerations”. Please note that karst loss adjustments also apply to post-development runoff calculation for portions of a site left undisturbed during the development project.

## E.5.4.1 Stormwater Design and Modeling

One of the first steps in site design is the calculation of pre-development runoff rates and volumes. The presence of karst terrain complicates these calculations. Two major factors reduce the amount of pre-development runoff when compared to non-karst sites. First, any areas draining to sinkholes (termed internally drained areas) do not contribute to site runoff. Instead, the watershed for each individual sinkhole should be delineated and pre-development runoff to the sinkhole calculated. Secondly, there is typically more infiltration (aka **karst loss**) in karst than in other areas.

### E.5.4.1.A Karst Loss

Karst loss is a term given to the loss of surface runoff into bedrock strata in areas underlain by limestone. Unlike other calculation factors, such as curve numbers (which deal with characteristics of the land surface), a karst loss factor is intended to depict projected losses into bedrock. The discussion herein is adapted from DCR Technical Bulletin 2 (VA DCR, 1999), and includes a simple method to account for "karst loss" in pre-development runoff calculations, as first proposed by J. C. Laughland (1996).

By accounting for karst loss through hydrologic modeling, the site designer can more accurately simulate actual conditions in deriving runoff rates. Mapping of a geographic area (when limited in size) may be productive in defining a karst loss zone (an area underlain by karst bedrock). However, the delineation of such zones is simply a method for estimating karst loss, not an accurate representation of the actual site-specific rate of karst loss. Accurate karst loss modeling requires a detailed field investigation at each site under consideration to obtain information about subsurface strata. In many cases the cost to fully model a site is prohibitive. Therefore, as an alternative, karst runoff loss estimations may be comparatively simple but still reasonably accurate.

The premise behind karst runoff loss estimation and adjustment is to better approximate actual site conditions, which produce lower peak rates of runoff than those than would occur on a similar site where karst is not present. Typically, adjustment for karst loss primarily applies to pre-development site conditions. Post-development, karst loss calculations only apply to portions of the site left undisturbed. This is because once development occurs, karst features may become more obliterated from extensive site grading activity. Calculations of pre-development runoff should be performed independently for each sub-watershed on a development site, including those that drain to sinkholes (internally drained). The karst loss factor should also be applied to the undisturbed portions of the sinkhole watersheds. Also, the addition of impervious cover and the construction of a surface drainage system may eliminate karst losses (infiltration) that may have existed prior to development.

Karst adjustment for post-development site conditions is only necessary for portions of the site that remain substantially undisturbed and uncompacted after development. In any event, the multipliers shown in Table E-1 apply only to runoff from undisturbed or minimally disturbed portions (no grading, paving, filling, or compaction) of the site, whether pre- or post-development.

Projecting karst loss in hydrologic modeling requires some specific examination (field inspection) of the subject area, along with a geologic examination of the underlying strata, in order to predict the extent of the karst loss zone. Many urban development sites of limited size will fall exclusively inside or outside of a karst loss zone. In such cases, the watershed does not need to be split into karst and non-karst areas.

### E.5.4.1.B Runoff Adjustments

Many of the traditional NRCS hydrologic models over-predict pre-development runoff from karst areas, because of the high initial abstraction that occurs in karst areas, as well as the fact that concentrated storm flows are often rapidly converted to subsurface flows. In general, over-predictions are more likely to occur when modeling the smaller storms and less likely to occur when modeling larger storm events, such as the 100-year storm. Consequently, designers should carefully modify their NRCS hydrologic and hydraulic computations to reflect the lower pre-development peak discharge rates. It is important to understand that more hydrologic monitoring and modeling research is needed to get predictions that are more reliable.

The following method for estimating stormwater runoff losses in karst settings is adapted from Laughland (1999, 2007). This method provides the multiplier (shown in Table E-1) used to adjust TR-55 and TR-20 pre-development rates, as follows.

1. Delineate the contributing drainage area or watershed to be studied.
2. Define any sinkhole areas within the contributing drainage area where surface drainage has no means of escaping offsite, other than downward through the karst feature (i.e., cracks, sinks, etc.). These areas can be assumed to contribute no surface discharge and can be subtracted from the contributing drainage area from Step 1.
3. Determine the amount of the contributing drainage area (from Step 2) underlain by karst strata (in percent).
4. Calculate the peak rate of runoff from the contributing drainage area using standard hydrologic methods and reduce the calculated value by multiplying by the Karst Loss Modification Value Table E-1 based on the percent karst (% Karst) calculated in Step 3.

Table E-1 (developed using the PSU-IV Program by G. Aron et. al.) provides modifiers based on the percentage of the contributing drainage area that is underlain by karst strata. The modifiers are used to adjust the peak rate of runoff calculated using standard modeling techniques. For example, the calculated 2-year peak discharge of 12 cubic feet per second (cfs) from a drainage area that has been determined to be underlain by 80% karst zone (with no observed sinkhole areas) would be reduced as follows:

$$12 \text{ cfs} \times 0.38 = 4.5 \text{ cfs}$$

This represents a peak rate reduction of 62%. Note that as the storm frequency decreases (i.e., 2-year frequency to 10-year frequency storm), the multiplier may decrease and have less effect on the result. This is due to the fact that karst typically exerts less of an influence as the rainfall rate increases and underground voids fill with water. However, the change in infiltration capacity with storm frequency will vary between sites. Some sites may actually experience karst gain (a surcharge) in response to large flood events.

Other potential methods that can be used to model karst include applying a TYPE I rainfall distribution to a karst area that actually has a TYPE II rainfall distribution or manipulating the Runoff Curve Number (RCN) or Initial Abstraction (IA) values (when using NRCS methodology). However, each method of manipulation has both advantages and disadvantages in accurately representing the impacts of karst topography on runoff rates. However, more hydrologic monitoring and modeling research is needed to get predictions that are more reliable.

The pre- and post-development karst loss calculations should be performed in both the preliminary and final site design phases in order to avoid under sizing BMPs.

### E.5.4.2 Other Considerations for Preliminary Site Design

When it is necessary to construct facilities near or over karst features or in subsidence prone areas, remedial measures, and design standards (i.e., BMPs) may be employed to minimize the likelihood of failure. Remedial sealing of voids in the soil or bedrock and/or compaction of soil and rock voids may be viable measures in some areas.

Stormwater flow from many sites in karst areas will necessarily discharge to a karst feature such as a sinkhole or sinking stream. Under the Virginia Erosion and Stormwater Management Regulation (9VAC25-875-650 C), "Discharge of stormwater runoff to a karst feature shall meet the water quality criteria set out in 9VAC25-875-580 and the water quantity criteria set out in 9VAC25-875-600." This means adequate space is necessary in the site layout and design for appropriate BMPs to be placed upstream of the receiving karst feature. Note that discharge to a channel leading to a karst feature constitutes discharge to a karst feature. For any project discharging stormwater to a karst feature, the channel protection and flood protection requirements outlined in Chapter 5 and Chapter 6 of this Handbook should be applied independently to each karst feature. In addition, the location(s) of the receiving karst feature(s) and the contributing drainage area should be clearly shown on site design maps. This applies whether or not the receiving karst feature is considered by the United States Environmental Protection Agency (USEPA) to be an improved sinkhole and thus required to be registered with USEPA as a Class V stormwater injection well. It is best to coordinate early with USEPA if it looks like registration, and in some cases a federal permit may be required.

A dye trace study (see E.5.5.1.D) can be performed on any karst feature receiving stormwater runoff to understand in what direction, how far, and how quickly additional stormwater flows will move through the groundwater, particularly if drinking water wells are located nearby. If the preliminary site investigation determines that sinkholes are likely to receive stormwater runoff from developed areas, dye tracing should be performed as part of the Detailed Site Investigation.

## E.5.5 Detailed Site Investigation

The purpose of the detailed investigation is to develop a karst feature plan that identifies the location and elevation of both surficial karst features and subsurface voids, cavities, fractures, and discontinuities. The presence of any of these features could pose a danger to groundwater quality, a construction hazard, or an increased risk of sinkhole formation at a proposed centralized stormwater facility. Note that location and geometry of subsurface features is generally inferred from the techniques described below. The geotechnical investigation should determine the nature and thickness of subsurface materials including the depth to bedrock and the water table in area of the site where construction is planned. The investigation is an iterative process that may need to be expanded until the desired amount of detailed knowledge of the site is collected and fully understood.

The scope of the geotechnical investigation should reflect the size and complexity of the development project, the preliminary site plan, and the requirements of the plan reviewing authority. No single investigative approach works in every location. The sequence begins with a visual assessment of diagnostic karst features, and analysis of subsurface heterogeneity through geophysical investigations and/or excavation under the direction of a qualified geotechnical consultant with experience working in karst terrain. In many cases, results of geophysical investigations will inform which excavation techniques may be needed and at what locations. The following are some of the techniques that can be used in the detailed site investigation.

Geophysical methods can serve as a rapid reconnaissance tool to detect physical anomalies in the subsurface that may be caused by karst features. Geophysical evaluations are often preferred over exclusive soil borings. In many cases, the results of geophysical studies can target invasive subsurface investigation using excavation methods such as test pits, air track test probes, and soil borings. There are many different non-destructive geophysical techniques to reveal the nature of subsurface conditions in karst terrain, including:

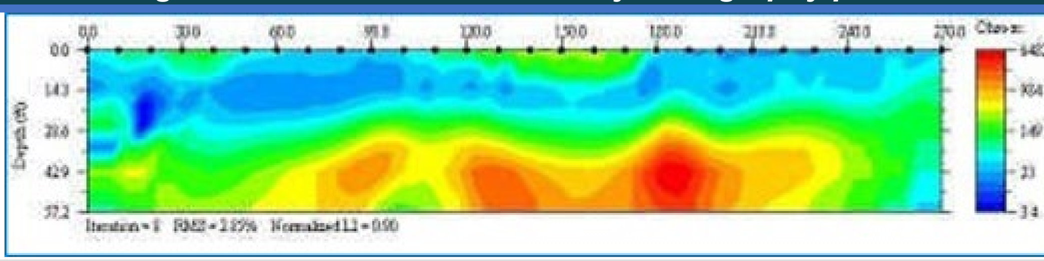
- Electrical resistivity tomography

- Shallow seismic refraction
- Microgravity surveys
- Ground penetrating radar
- Electromagnetic (EM) inductance/conductivity surveys

These methods are generally non-disruptive to the land (direct sampling methods are found in E.5.5.1). Geophysical data are often useful for extrapolating between locations where different, direct sampling methods are used. Generally, it is advisable to apply more than one geophysical technique, owing to the variability in physical properties of karst. Geophysical methods require an experienced professional to interpret the data collected. The properties of weathered limestone, including a highly variable bedrock surface and soils with high clay content, often hinders the depth of penetration and resolution of some geophysical signals, which can compromise the effectiveness of geophysical surveys. Despite these limitations, geophysics can sometimes provide a cost-effective, relatively rapid means of determining the potential for problems with karst features, including the location of shallow bedrock and significant cavities in the soil or bedrock. Geophysical anomalies should be targeted for additional direct testing procedures.

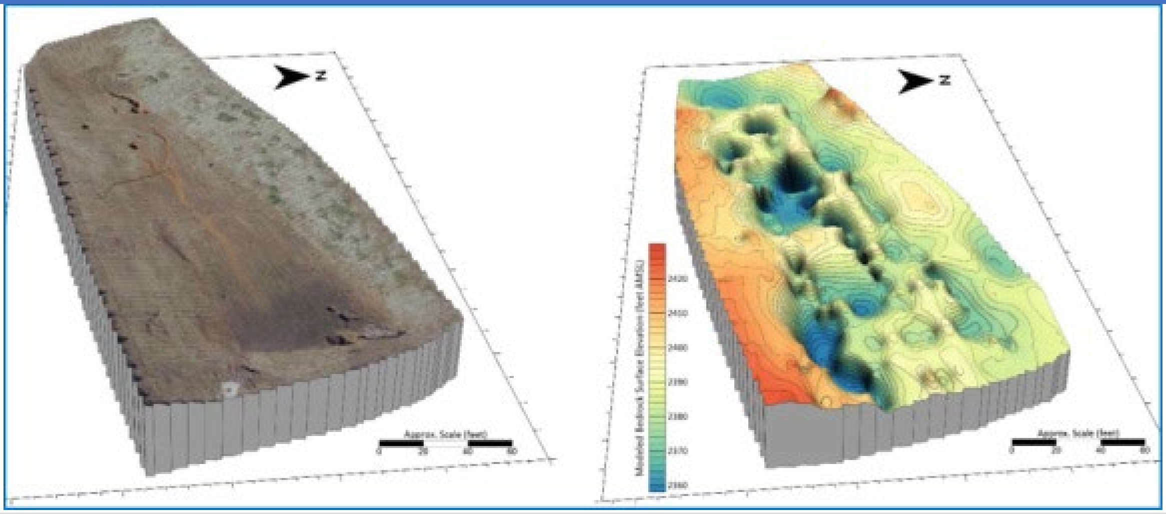
Electrical resistivity tomography (see Figure E-13 and Figure E-14) has proven to be a particularly useful technique to identify subsurface anomalies at a scale that impacts stormwater design. This method allows high resolution imaging of features in the shallow subsurface. These surveys provide a qualitative evaluation of the site area and may identify "suspect areas" to be further evaluated by borings. The use of these surveys may reduce the total number of soil borings by narrowing down the locations of suspect areas at the site.

***Figure E-13 An electric resistivity tomography profile***




*Red colors represent high resistivity associated with voids or dry rock, while blue colors represent moist areas that conduct electricity.*

**Figure E-14 Surface of detention basin (left) and soil-bedrock interface (right) derived from ERT imaging, Wythe County, VA**



*Note the "sinkholes" in the bedrock surface beneath the soil.*
*Courtesy of Chris Printz, TRC*

## E.5.5.1 Direct Sampling Methods

### E.5.5.1.A Test Pit Excavations

Test pit excavations are a simple, direct way to view the condition of soils that may reveal the potential for ground subsidence, and to inspect the condition and variability of the bedrock surface where bedrock is sufficiently shallow. Soil texture is an important indicator of soil strength and, therefore, the ability of soils to bridge voids. An inspector should look for evidence of slumping soils, former topsoil horizons, and fill material (including surface boulders, organic debris, and other foreign objects) in the test pit. Voids in the soil or underlying bedrock can be revealed. The presence of organic soils at depth is an indicator of potentially active sinkhole sites. Leached or loose soils may also indicate areas of existing or potential ground subsidence. Observations of this type should be recorded in the soil log.

### E.5.5.1.B Test Probes

Test probes are performed by advancing a steel drill bit into the ground using an air-percussion-drilling rig. Probes can be installed rapidly and are an effective way to quickly test subsurface conditions. Penetration depths are usually less than 50 feet. During the installation of a test probe the inspector should be aware of the rate of advance of the drill bit, sudden loss of air pressure, soft zones, free-fall of the bit, and resistant zones. These observations can provide clues to the competency of the bedrock and the presence of cavities in soil or bedrock. The volume of fluid cement grout needed to backfill the probe hole can yield a measure of the size of subsurface voids encountered during drilling.

### E.5.5.1.C Soil Borings and Rock Coring

Soil borings and rock coring can yield virtually complete and relatively undisturbed soil and rock samples. Borings may provide direct evidence of the presence and orientation of fractures, weathering, fracture fillings, and the vertical dimensions of cavities. They provide undisturbed samples that can be subjected to laboratory testing. However, it is possible that borings could be located which miss key subsurface features and thus do not accurately represent karst features under the surface. Soil borings with subsequent rock coring can also create the conditions for surface collapses if they are not properly filled and sealed.

In general, borings are divided into “soil” borings and “rock coring.” Soil borings involve advancing a boring into soil or unconsolidated sediment and are typically used to derive soil strength and consistency data by driving a 24-inch long, 2-inch outside diameter split spoon sampler with a 140 pound hammer dropping 30 inches. The number of hammer strikes (blows) required to advance the 12 inches (1 foot) for the 6- to 18-inch increment of the 24-inch sampler is defined as the “standard penetration resistance” or the “N-value” which is reported in blows per foot (bpf). This value is fundamental for many of the different types of geotechnical calculations such as bearing capacity and settlement estimates. The soils samples are also used to determine factors such as sorting, grain size, and overall lithology. Refusal of the spoon sampler is defined as a total of 50 blows over any 6-inch increment, a total of 100 blows per foot (bpf), or there is no noticeable advancement of the sampler during 10 consecutive blows of the hammer. Once refusal is reached then the rig can be adapted to perform rock coring to obtain data regarding the underlying bedrock. Rock coring is conducted to evaluate the type, quality, soundness, strength, and other properties of the rock. It is generally accomplished with a water-lubricated diamond tipped rock core barrel fitted to the drill rig. The coring recovers a cylindrical core of rock by rotating and advancing the hollow core barrel, and this method collects a relatively undisturbed sample of bedrock. Losses of drilling fluid while coring can indicate the presence of voids in the bedrock mass. As with test probes, the volume of fluid cement grout placed to seal the drill hole can also provide a measure of the size of openings in the subsurface.

Once the general character of the surface cover is understood, borings are used to reveal its characteristics at specific locations at the site where construction, including site stormwater management infrastructure, is planned. The number and depth of borings at the site will depend entirely on the results of the subsurface investigations, the experience of the geotechnical consultant, and the requirements of the local review authority. The extreme spatial variability in subsurface conditions cannot be over-emphasized, with major differences seen a few feet away. Therefore, the consultant should obtain borings:

- Into suspected zones of bedrock solution as suggested by geophysical investigations;
- Adjacent to sinkholes or related karst features at the site;
- Along known zones of bedrock solution, or along known zones of geologic weakness, such as faults or fracture traces, including alignment of sinkholes;
- Adjacent to bedrock outcrop areas;
- Within the planned boundaries of any centralized stormwater facility;
- Through surficial materials to determine depth to bedrock; and
- Near any areas identified as anomalies from geophysical or subsurface studies.

All borings or excavations should include the following:

- Descriptions, logged data, and sampled interval over the entire depth of the boring;
- Descriptions of any stains, odors, or other indications of environmental degradation;
- A minimum laboratory analysis of two soil samples representative of the material penetrated, including potential limiting horizons, with the results compared to field descriptions; Minimum identified characteristics should include:

    - Color
    - Mineral composition
    - Grain size and shape
    - Sorting
    - Depth to water
    - Depth to bedrock
- Any indications of water saturation should be carefully logged to include both perched and ground water table levels, and descriptions of soils that are mottled and gleyed. Note that groundwater levels in karst terrain can change dramatically in a short period of time and will not always leave evidence of mottling or gleying.
- Water levels in all borings should be measured both during drilling and at 24 hours after drilling. If there is data to suggest the water table fluctuates throughout the year (i.e., a seasonal high water table), then the borings may need to be converted to monitoring wells for extended water level measurements.
- A record of the estimates of soil engineering characteristics, including "N" or the estimated unconfined compressive strength, from a standard penetration test.
- Electromagnetic (EM) inductance/conductivity surveys

At the locations of centralized stormwater management facilities, the density of soil borings should result in a representative sampling over the area of the proposed facility. In general, a minimum of five borings should be taken for each centralized stormwater facility (or five per acre, whichever is greater), with at least one on the centerline of the proposed embankment and the reminder within the proposed impoundment area. For carbonate rocks, borings should extend at least 20 feet below the bottom elevation of the proposed centralized stormwater facility. Where refusal is encountered, the boring may either be extended by rock coring or moving to an adjacent location within 10 linear feet of the original boring site, to attain the 20-foot minimum depth. Upon completion, the boring should be backfilled with an impermeable plugging material such as grout mixed with bentonite, particularly when the boring intercepts subsurface voids.

### E.5.5.1.D Dye Tracing

If karst features are expected to receive drainage from developed land, or are planned for mitigation during construction, it is advisable to conduct dye tracing to determine the flow direction of water once it enters the subsurface, the distance the water travels within the subsurface, the location of the spring(s) where water returns to the surface and associated receiving surface water body, and any subterranean waters where the dye is detected (e.g., cave streams, groundwater wells). This is accomplished by introducing non-toxic fluorescent dyes into groundwater and monitoring downgradient groundwater and springs for the dye's presence (Figure E-15). Typically, this is done in multiple iterations to determine drainage divides, recharge area boundaries, et cetera. Locations of dye injections and recoveries are plotted on maps, then considered in combination with the geology and other factors to delineate subterranean flow paths (Figure E-16).

Developers or their agents should retain the services of a qualified karst hydrologist or hydrogeologist to perform dye tracing studies. Also, designers or their agents are advised to coordinate with the DCR Natural Heritage Karst Program and VDEQ prior to initiating a trace to acquire pre-existing information on karst hydrology in the area and avoid potential cross-contamination with dyes from other investigations. Lastly, designers should remind their agent performing the dye tracing to notify local emergency response staff prior to introducing dye into the aquifer. The unexpected appearance of a fluorescent dye at a spring or in faucet or toilet fed by a well has been known to cause alarm (Figure E-17).

## *Figure E-15 Examples of fluorescent dye injections*

*1) Left: A naturally occurring sinking stream in Tazewell County, and 2) Right: A swallet in the trench of the Mountain Valley Pipeline*

## *Figure E-16 Example of a dye tracing flow map, Rye Cove area of Scott County, VA*

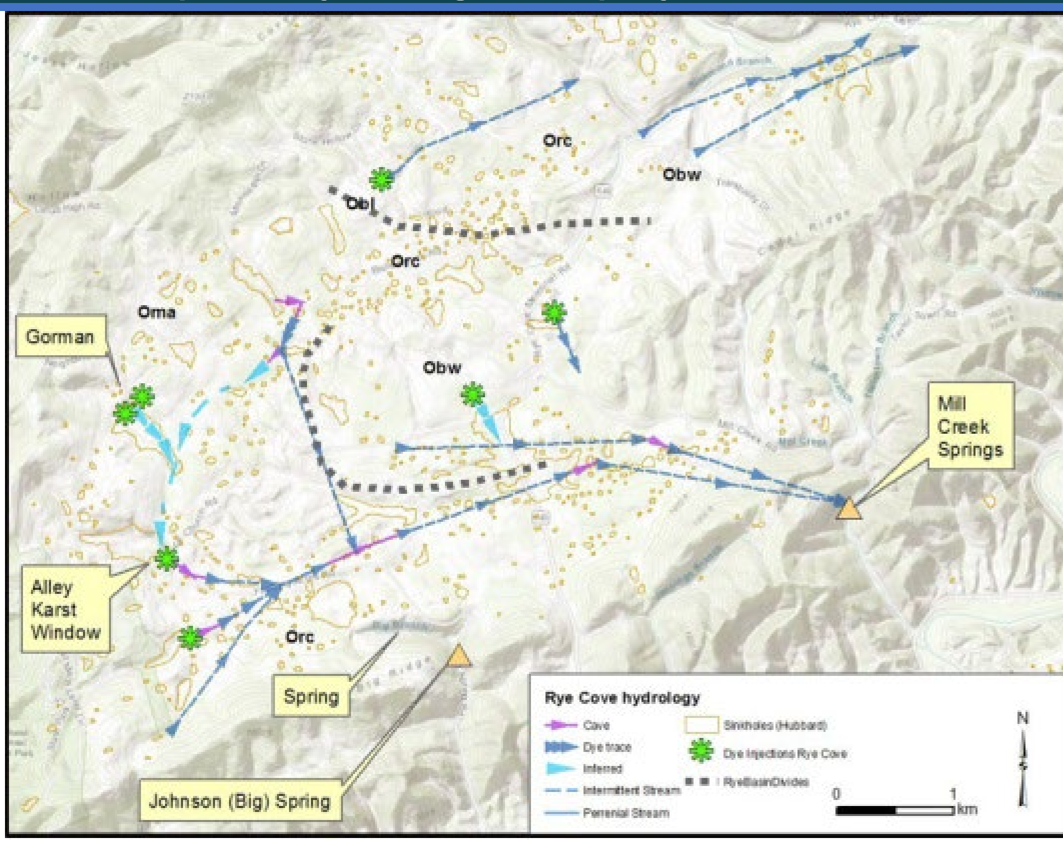


***Figure E-17 The appearance of fluorescent dye in surface waters or from taps can cause alarm, as in the spring-fed tributary to the Clinch River, which turned green for several hours***

## E.5.5.2 Detailed Site Investigation Report - Site Data

The final report should include the following information, with all location data available in an ESRI compatible geo-spatial format:

- Bedrock characteristics (e.g., formation, lithology, geologic contacts, geologic structure – faults, fractures, and folds).
- Identification/verification of geological contacts if present, especially between karst and non-karst geological formations. Bedrock outcrop areas should be identified and delineated.
- The locations and descriptions of all surface karst features, including
  - sinkholes (i.e., any closed depressions):
    - Geometry, dimensions (approximate depth, width, length), orientation of long axis
    - Type of sinkhole: cover collapse, solution, or bedrock collapse?
    - Is there an open throat? Is the throat formed in bedrock or soil?
    - Evidence of ponding?

        - Does the sinkhole receive external flow?
        - Are there channels, intermittent or perennial, terminating in the sinkhole?
        - Signs of active subsidence or collapse (e.g. exposed soil surfaces, freshly broken rock)
        - Anthropogenic alterations including but not limited to (rock fill, excavations, exclusionary fencing, solid waste or debris);
    - cave entrances (dimensions, nature of any improvements);
    - soil pipes (typically small, vertical to steep-walled to overhung openings in soil cover);
    - fractures enlarged by dissolution; and
    - Sink-points of perennial and intermittent channels.
- Pre- and Post- development runoff calculations incorporating karst loss factors and accounting for internally drained areas.
- Results of any dye trace studies at or near the site, conducted during the investigation or from earlier studies
- Results of geophysical surveys
- Logs of test pits, probes, and borings, including observations such as:
    - evidence of cavities in soil and rock;
    - loss of air pressure or drilling fluid during drilling; and
    - the condition of soil and bedrock determined from samples collected.
- Locations and descriptions of subsurface features either inferred by geophysical methods or intersected via direct investigation:
    - voids (specify nature of fill: air, water, and/or sediment);
    - mud seams;
    - fractured or brecciated zones;
    - water-bearing fractures; and
    - depth to groundwater.
- A fracture trace map based on lidar and photo-lineaments.
- Overlying soil characteristics (type, thickness, spatial variability, mapped unit, geologic parent/history, infiltration rate, depth to seasonally high water table).
- The locations of perennial, intermittent and ephemeral streams and their flow behavior and surface or subsurface discharge points (e.g., losing or gaining streams), channels and surface drainage network.
- The locations of site-scale watershed or drainage area boundaries, including watersheds of individual sinkholes, based on large scale site topography (i.e., one foot or less contour intervals, can be derived from 1m LiDAR data).
- The existing stormwater flow pattern (if site has prior improvements or receive runoff from developed land)
- The locations of springs and wetlands
- The locations of public and private wells, at a minimum, within 1/4-mile of the site. However, to be thorough, wells within up to 10 miles (reflective of the direction of subsurface flow and the distance of the discharge’s flow) of the site should be located if they could be impacted due to the nature of water flow in karst areas.
- If available, the layout of proposed buildings, roads, and stormwater management structures (and estimated locations and areas of site impervious and turf cover).

If unstable subsurface conditions are encountered and indicated in the detailed site investigation, a decision can be made to (1) remediate/mitigate the instability prior to construction or (2) to modify the site layout to avoid problem area(s). Because of the high likelihood of encountering issues in karst, the earlier in the planning process that the detailed site investigation is performed, the better.

## E.5.6 Modifications to and Finalization of Site Design

The Detailed Karst Site Investigation Report (see E.5.5.1) should be submitted as a supporting document with Soil Erosion and Stormwater Management Plan and Stormwater Pollution Prevention Plan (SWPPP). It is strongly recommended that locations of pre-existing sinkholes, cave entrances, streams sinks, and springs be permanently recorded on the property deed as well to be known to any future property owners. At least one subsurface cross-section should be submitted with the soil erosion and stormwater management plan, showing confining layers and depth to bedrock and the water table, if encountered. The cross-section(s) should extend through the centerline(s) of any proposed centralized stormwater facilities, using actual geophysical and boring data. A sketch map or construction drawing indicating the location and dimension of the proposed facility should be included for reference to the identified subsurface conditions.

### E.5.6.1 Federal Underground Inject Control Regulations and Karst

The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control (UIC) Program. The UIC regulations are intended to protect underground sources of drinking water from potential contamination. Depending on their design, some stormwater infiltration practices and all improved sinkholes receiving stormwater runoff may be regulated as “Class V” underground injection wells. In Virginia, the UIC Program is administered by the USEPA, Region 3 (Philadelphia): www.epa.gov/uic/underground-injection-control-epa-region-3-de-dc-md-pa-va-and-wv

Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. By definition (40 CFR 144.3), a well is “any bored, drilled, or driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system.” Under the USEPA Underground Injection Control Program, sinkholes improved for the purposes of receiving stormwater are classified as Class V stormwater injection wells, and registration by the operator with US EPA Region 3 is required.

The act of directing stormwater runoff from developed land into a sinkhole or other karst feature may in and of itself constitute a “modification” and as such, becomes a de facto improved sinkhole requiring that the developer or owner obtain an USEPA authorization and provide the required registration of the facility (40 CFR 144.12). This is even true if the improved sinkhole is downstream of stormwater treatment practices, whether on-site or off-site. Discharges to improved sinkholes on downstream properties may require legal agreements with the owner(s) of the property where the improved sinkhole is located. It is strongly recommended to coordinate with USEPA Region 3 if karst features will receive stormwater runoff from the development project. Only USEPA has the authority to determine if the feature will constitute an improved sinkhole in the post-development context.

Federal regulations require all owners and operators of Class V wells to submit information to the appropriate state or federal authority. See 40 CFR Part 144, Subpart G. This includes the facility name and location, the name and address of a legal contact, ownership of the property, the nature and type of injection well(s), and the operating status of the injection well. Additional information on Class V well requirements can be accessed online at: https://www.epa.gov/uic/federal-requirements-class-v-wells

USEPA staff then review this registration data and may (1) determine the injection is authorized, (2) require more information, (3) issue a UIC permit with best management practice requirements, or (4) order the well closed. Due to the risk of groundwater contamination, the USEPA may require that locations of public and private wells and springs should be identified, at a minimum, within 1/4-mile of the site. However, due to the high transport rates within some karst systems, EPA may require that wells and springs within up to 10 miles of the site (reflective of the direction of subsurface flow and the distance of the discharge's flow) be located if they could be impacted due to the nature of water flow in karst areas. If a connection to a navigable surface water is established through the groundwater (e.g. via dye tracing), then the discharge into the sinkhole may be subject to federal NPDES requirements based on revised draft guidance applying the 2020 U.S. Supreme Court decision in County of Maui vs. Hawaii Wildlife Fund (Nov. 2023). As of December 2023, EPA had not released final guidance on how the agency will implement the decision.

In addition to improved sinkholes, a UIC authorization may be required for stormwater practices that infiltrate runoff into the subsurface or have a subsurface fluid distribution system.

Copies of all UIC Class V Well inventory forms (EPA Form 7520-16) for discharges of stormwater runoff to improved sinkholes should be included in the Stormwater Pollution Prevention Plan (SWPPP) for the land disturbing activity.

# E.6 General Erosion and Sediment Control and Stormwater Design Principles for Karst

The following are general principles that should be considered in site layout and the design of erosion and sediment control (construction) and stormwater management (post-construction) systems.

## E.6.1 Final Site Design Considerations

Thoughtful site design and careful construction practices can significantly reduce the risks of new sinkhole development, site flooding, and environmental impacts. Successful site design depends on completion of the preliminary and detailed site investigations described above. Sinkholes most often form in areas where storm-water runoff is concentrated or impounded, subterranean anomalies exist, evidence exists for active subsidence prior to construction, bearing loads are concentrated, and/or ground water is pumped out in large volumes. When planning the development, consideration should be given to the following general guidelines to minimize the risk of ground failure:

- Require notification procedures on the design plans to direct the contractor who to contact if karst features are encountered or during sinkhole formation caused by construction activities to determine effective and time-sensitive remediation measures for both erosion and sediment control and stormwater management.
- Increase setbacks from building and other infrastructure (typically specified in individual BMP description).
- Minimize the amount of impervious cover created at the site so as to reduce the volume and velocity of stormwater runoff generated.
- Employ storm-water management BMPs that minimize flow velocities and ponding to avoid erosion of over-saturated soils.
- Consider subsurface conditions determined during the Detailed Site Investigation when locating building pads and place foundations on sound bedrock. Perform additional geotechnical investigations if necessary.

## E.6.2 Erosion and Sediment Control Principles for Karst Areas

The selection, design, and implementation of erosion and sediment control practices in karst areas should be guided by the following objectives and should incorporate the following design elements:

- The site should be designed to be compatible with pre-development topography. Modifications of site topography should be minimized.
- Changes to the existing soil profile, including cuts, fills, and excavations, should be minimized.
- Where practical, drainage facilities should consist of embankments at or above grade. Excavation into the existing soil profile to construct swales and basins should be minimized to the degree possible as such excavation increases the likelihood of sinkhole formation.
- Temporary and final grading of the site should provide for any sheet flow drainage of storm-water runoff away from structures.
- Wherever possible, conveyances should be designed to disperse the flows across a broad area (sheet flow preferred) to limit channel incision. This reduces the level of soil saturation and thus the potential for soil movement, both laterally and downward. Shallow, wide trapezoidal channel cross-sections are preferred over parabolic or V-shaped channels.
- Sediment traps and basins in karst terrain should be lined and/or inspected frequently, preferable both. Unlined traps and basins are prone to failure by subsidence (sinkhole formation). Ideally, they should serve small drainage areas (2 acres or less) and be located away from known karst features. The ESC plan should attempt to minimize drainage area sizes and therefore the need for large basins or traps.
- Vegetative cover should be established as rapidly as possible over exposed areas of soil. Construction scheduling should strive to minimize the time that soil excavations are open and non-vegetated. This reduces the time that the site is exposed to periods of concentrated flows as well as preventing excessive drying of soils.
- Utility trenches should be back-filled with in-situ soils or low permeability fill material, in order to discourage sub-surface water flow along the trench. Clay dams should be used at intervals along the trench excavation to impede subsurface flow along the trench. These are particularly important in karst because "blind" sinkholes can form beneath utility trenches where flow along the trench occurs. Trench backfill should be compacted to prevent future settlement and ponding. Backfill densities for open areas should exceed 90% of ASTM D-1557 maxima. Densities for areas supporting structures such as roadways should equal or exceed 95% ASTM D-1557 maxima.

# E.7 Response to or Remediation of Sinkholes Occurring During Construction

It is possible for sinkholes to form during construction of a project (Figure E-18). Sinkholes that occur during construction should be repaired immediately to prevent their enlargement and associated adverse impacts. Sometime these sinkholes form in stormwater conveyance channels and convey sediment and other contaminants directly into the groundwater (Figure E-19).

Figure E-18 Sinkhole at a construction site

**_Figure E-19 Subsidence during pipeline construction following storm event, Giles County_**


*Left: Swallet formed by collapse in sump at end of water bar. Right: same feature, next day after mitigation.*

When sinkholes occur during construction, the site superintendent should take the following steps:

- Report the occurrence to the local plan approving authority immediately.
- Halt construction activities in the immediate area of the sinkhole until it is stabilized. Secure the sinkhole area.
- Surround the sinkhole with appropriate sediment control BMP (silt fence, compost sock, et cetera).
- Direct the surface water away from the sinkhole area, if possible, to a suitable storm drainage system.
- Mitigate and stabilize the sinkhole as appropriate using the NRCS National Engineering Handbook (Title 210), Part 633, Chapter 26, “Gradation Design of Sand and Gravel Filters” as referenced in the USDA-NRCS Conservation Practice Standard “Sinkhole Treatment” Code 527.
- Communicate the proposed remediation plan to the local plan approving authority. Some jurisdictions may have local requirements for notification and review as well.
- All sinkhole remediation activities should be under the direct supervision of a geologist or geotechnical engineer with experience in limestone investigations and remediation practices.
- Repair any damage to erosion and sediment control measures and restore ground cover and landscaping.

- In those cases where the hazard cannot be repaired without modifying the erosion and sediment control design, the applicant should contact the local plan approving authority for approval of changes to the plan.

# References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# APPENDIX F BIORETENTION DESIGN – BACKGROUND INFORMATION

**Contents:**



## F.1 Guidance for Amending Soils with High Hydraulic Conductivity

### F.1.1 Amended from 2020 Minnesota Stormwater Manual

The primary concern raised by the Minnesota criteria described here are with high rates of internal hydraulic conductivity above ~ 8 inches per hour and include: (1) a diminished ability to attenuate pollutants due to the relatively short contact time between the soil and infiltrating stormwater and (2) a higher potential for rapid contaminant transport to local groundwater or other receiving surface water systems (e.g., in the event of chemical spills).

Similar concerns could occur under Virginia conditions for certain soils with: (a) no underlying clay + iron enriched Bt or Bw horizon (e.g., Entisols) in combination with (b) a seasonal high water table or mound that exceeds a two foot standoff criteria. In Virginia, it is unlikely that these soil conditions would be encountered in most upland soil landscapes as long as appropriate setbacks from jurisdictional wetlands and ephemeral drains are maintained coupled with the minimum two-foot standoff criteria above the seasonal high water table or mound. However, this combination of soil properties is possible in certain soil landscapes in Virginia, particularly in the lower Coastal Plain and Eastern Shore. Therefore, the procedures recommended below could potentially be utilized to decrease $K_{sat}$ of the receiving base elevation soil. Therefore, this overall best management practice (BMP) sets a maximum soil infiltration zone $K_{sat}$ of 10 inches/hour under the assumptions outlined above.

### F.1.2 Soil Amendment Approaches

Amending soils with high hydraulic conductivity typically involves either physically decreasing the hydraulic conductivity or increasing the pollutant attenuation capacity.

- Physically decreasing hydraulic conductivity: This approach involves designing the soil matrix to achieve a specific permeability that both reduces the speed at which stormwater runoff reaches the groundwater and increases contact time with the soil.
- Increasing pollutant attenuation: This approach does not specifically link to a target hydraulic conductivity.

Rather, the soil is amended to meet a threshold, such as organic matter content, that satisfies permit requirements. Compost or other adsorptive materials such as biochar or alum sludge are commonly used to achieve higher pollutant attenuation capacity.

**Note:** Because of the site-specific nature for amending soils, this document offers general guidance on amending soils rather than a specific approach and was not developed for Virginia conditions per se.

## F.1.3 Complications

One of the most common complications of amending soil is decreasing the hydraulic conductivity so much that it becomes unacceptably slow. This is often caused by the introduction of fine-grained materials, which become clogged in the native soil. Subsequent consequences of clogging the soil may include failure to meet 48-hour drain time requirements and killing vegetation that was not intended for prolonged inundation. Another complication is the potential for the soil amendment to serve as a pollutant source. For example, certain amendment media such as compost can export soluble phosphorus in higher concentrations than the incoming stormwater runoff, thus contributing to increased phosphorus loading.

## F.1.4 Guide to Developing a Soil Amendment Plan

Designers developing a soil amendment plan to slow the hydraulic conductivity below 10 inches per hour should seek to physically decrease the hydraulic conductivity or to increase pollutant attenuation capacity while taking steps to prevent common complications.

**Step 1 – Determine soil conditions.**

The first step in developing a soil amendment plan involves understanding the baseline conditions of the native soils in which the amendment will be performed including:

- **Hydraulic conductivity:** Measure hydraulic conductivity using appropriate methods and number of measurements.
- **Soil gradation (grain-size distribution):** Grain-size (particle-size) distribution provides an indication of the presence of fine-grained material (e.g., clay) which can slow infiltration and attenuate pollutants. Samples for grain size analysis are typically collected with soil borings. Sieve analysis is commonly used to determine grain size distribution, although other methods (e.g., hydrometer) are available.
- **Soil type:** This can be determined from published soil survey maps, Natural Resources Conservation Service (NRCS) Web Soil Survey, or preferably via on-site investigation coupled with lab data once the overall soil horizonation (e.g., A-B-C) and grain-size distribution is known.
- **Organic matter content:** Soil organic matter (or organic carbon) affects both soil hydraulic conductivity and attenuation of many potential pollutants in stormwater runoff (e.g., metals, organic chemicals, certain forms of nitrogen and phosphorus, bacteria).
- **Degree of compaction:** Compacted soils will have reduced hydraulic conductivity. Similarly, hydraulic conductivity in uncompacted soils can be decreased by compacting soils to some extent, but this is highly depending upon moisture content at the time of operations. Several methods are available to evaluate soil compaction, including penetration tests (with moisture content adjustment)

and preferably measuring soil bulk density via core-ring sampling, neutron scattering, or other approved methods.

Soil samples should be taken in close proximity to the infiltration test locations.

**Step 2 – Develop site plan and select amendment application option(s).**

Depending on the site-specific conditions determined from the first step, the soil amendment plan should define one or more of the following.

- Areas where native soil will be retained in place due to sufficient hydraulic conductivity.
- Areas where native topsoil or subsoil will be amended in place.
- Areas where native topsoil will be stripped and stockpiled prior to grading for reapplication.

**Step 3 – Identify available material source.**

Compost and topsoil are the most used soil amendment media.

**Step 4 – Calculate amendment volume.**

When calculating the volume of soil amendment material needed, the following should be taken into consideration.

- Desired hydraulic conductivity ($K_{sat}$) of the amended soil;
- Desired pollutant attenuation capacity based on texture or cation exchange capacity (CEC) or other appropriate indices;
- Amendment material characteristics (e.g., density, gradation, organic matter);
- Desired depth of amendment; and
- Degree to which native soil will be mixed with amendment material.

**Step 5 – Specify construction procedures.**

Implementation of the soil amendment construction procedure needs to ensure the appropriate volume of amendment is used and that the mixing process results in a consistent, homogeneous media across the entire site to the proper depth (typically 12 to 18 inches). The mixing process can be accomplished by either:

- Blending the native and amendment materials in place with tilling equipment such as a multiple shank ripper or chisel plow followed by disking, or
- Excavating the native soil, mixing with the amendment material, and reapplying the mixture to achieve the desired depth and gradation.

The specified construction procedure must also ensure that common complications are prevented and may include the following.

- Avoid layering – creating two or more soil layers with an abrupt linear contact that are significantly different in $K_{sat}$ that can lead to: (a) perching of saturated conditions above the dissimilar contact or (b) enhanced lateral flow downgradient.
- When leaching of nutrients could be harmful to a receiving water, the combined influence of the compost source on extractable P (see Table F1) should be taken into consideration.

**Step 6 – Specify final inspection procedures.**

The soil amendment plan should specify post-soil amendment infiltration testing, which is critical to ensuring the amended soil performs as expected (that the new hydraulic conductivity is not too high, too low, or uneven throughout the site).

**What rate should I use if I follow the procedure?**

If the above procedure is followed, we recommend one of the following:

- Set a minimum target rate that is clearly lower than the stated $K_{sat}$ level of concern (e.g., 10 in/hr.).
- Conduct field tests to determine the hydraulic conductivity ($K_{sat}$).

# F.2 References


US Army Corps of Engineers. EM 1110-2-2300. 2004. General Design and Construction Considerations for Rock-Fill Dams – Appendix B.

US Army Corps of Engineers. EM 1110-2-1901. 1986. Seepage Analysis and Control for Dams – Appendix D. 1986.


# F.3 Filter Media

The filter media of a bioretention practice consists of an engineered soil mixture that has been carefully blended to create a filter media that maintains long-term permeability while holding and providing sufficient nutrients to support plant growth. The final filter media shall consist of a well-blended mixture of medium to coarse sand, loamy native soil mineral components, and an organic amendment (compost). The sand maintains the desired permeability of the media while the limited amount of silt + clay particles and compost amendment help support initial plant growth and provide for pollutant adsorption, particularly for P. It is anticipated that the gradual increase of organic matter through natural processes of root dieback, surface litter additions and mixing by the soil biota will continue to support plant growth without the need to add fertilizer beyond establishment, and the root structure of maturing plants along with biological activity of the media and accumulating organic matter will lead to aggregation to help maintain medium to long-term permeability.

## F.3.1 Filter Media Criteria and Testing for Bioretention

The criteria listed in Table F-1 below are key factors to consider in determining an acceptable filter media mixture and are required to be certified by the media blender or supplier. While the ability to maintain minimum $K_{sat}$ over time is an overriding consideration, all components of the criteria should be adhered to. Furthermore, it is particularly important for vendors to keep plant available P levels within the prescribed range and carefully screen large rock fragments out of native soil components before blending. Depending on the source of compost or other suitable organic amendment utilized, vendors may need to design for the lower acceptable range of total organic matter (3%) in the fine earth (< 2mm ground) fraction.

| Table F-1 Filter Media Criteria and Testing for Bioretention | | | |
|---|---|---|---|
| **Filter Media Criterion** | **Description** | **Standard(s)** | **Testing Method** |
| General Composition | Filter media must have the proper proportions sand, fines, and organic matter to promote plant growth, drain at the proper rate over time, and filter pollutants, particularly P. | 80%–90% sand;<br>10%–20% soil fines (silt+clay); maximum clay content:10%<br>3%–5% organic matter content by weight | Particle size analysis via Soil Survey Staff (2014) on mineral blend only or following organic matter removal; Grind sample to < 2.0 mm for organic matter via Loss on Ignition (LOI) or Walkley-Black. Nelson & Sommers (1982). Also in Sparks et al. 2020. |
| Sand Component | Medium to coarse aggregate natural mineral source or quartz substitute. Do not use ground concrete, aggregate, bottom ash, or other similar materials. | (< 2.0 to 0.05 mm); Mica < 5%. | Standard dry sieve analysis |
| Topsoil | Loamy sand, Sandy Loam, or Loam<br>Based on U.S. Department of Agriculture (USDA) Textural Triangle | NRCS texture class based on < 2mm. For whole sample, no more than 20% total > 2.0 mm; all must pass 9.5 mm. | PSA via Soil Survey Staff (2014) |
| Organic Amendment | Stable, well-aged, clean compost from leaf litter, humus, peat moss or other suitable organic source(s) | See P-FIL-08 Soil Compost Amendment for criteria for suitable organic materials. | See the following for methods: Compost Research & Education Foundation: https://www.compostfoundation.org/Portals/2/Images/Bioretention.pdf |
| Cation Exchange Capacity (CEC) | CEC measures soil reactivity and ability to retain ions against leaching. CEC generally increases with OM and clay content and pH. | CEC: > 5.0 milliequivalents per 100 grams (or cmolc per kg) via pH 7 NH4OAc method. | Soil Survey Staff 2014. Based on Sumner & Miller (1996) or other similar unbuffered salt methods. Also in Sparks et al. (2020). |

| Table F-1 Filter Media Criteria and Testing for Bioretention | | | |
|---|---|---|---|
| **Filter Media Criterion** | **Description** | **Standard(s)** | **Testing Method** |
| Permeability (Ksat) | Refers to the hydraulic conductance (Ksat) of the filter media. | Ksat = 1 to 2 inches/hour. Rates will most likely be higher. Initial rates ≤ 10 inches/hour acceptable | Virginia Department of Transportation (VDOT) × Virginia Department of Environmental Quality (VDEQ) 2021 VTM-134, or procedures in Appendix C Infiltration Practices. https://www.virginiadot.org/business/resources/Materials/bu-mat-VTMs.pdf |
| Extractable P | Filter media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters. | Mehlich I 5–15 mg/kg or Mehlich III 18–40 mg/kg | Mehlich I or Mehlich III extraction of < 2mm ground whole media sample. |
| pH | Soil pH influences plant nutrient availability, microbial populations and net soil charge/reactivity. | Between 5.5 and 7.5 | 1:1, 1:2 soil:water or saturated paste soil extract. Soil Survey Staff (2014) |
| Soluble Salts | Filter media with high levels of soluble salts can injure or kill plants and can clog the filter media | Less than 4.0 mmhos/cm | Saturated paste soil extract. Soil Survey Staff (2014) |

**Recommended Analytical Methods:**

CEC, Organic Matter, Extractable P and other Chemical Methods: Sparks, D.L., Page, A.L., Helmke, P.A, and R.H. Loeppert. 2020. Methods of Soil Analysis, Part 3: Chemical Methods, Soil Science Soc. Amer., Madison WI. Methods of Soil Analysis, Part 3: Chemical Methods | Wiley (accessed August 26, 2023).

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Particle Size Analysis, CEC and Organic Matter: Soil Survey Staff. 2014. Soil Survey Field and Laboratory Methods Manual. Soil Survey Investigations Report No. 51, Version 2.0. R. Burt and Soil Survey Staff (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service. NRCS Publications - Item Detail (usda.gov) (accessed August 26, 2023.

pH and Soluble Salts: Soil Survey Staff 2014 or Sparks et al. 2020. See above.

## F.3.2 General Composition

The ultimate performance goal of the filter media is to achieve a verified soil permeability or hydraulic conductivity (Ksat) of 1 to 2 inches per hour (or 60 to 120 cm/day). Initially, the Ksat will be higher. The recommended maximum initial Ksat should not exceed 10 inches per hour and that value will be expected to decline as the media settles and larger compost fragments decompose.

In order to achieve recommended Ksat, the bioretention soil mixture must be classified as a sand, loamy sand for the fine earth fraction (< 2 mm) on the USDA NRCS Texture Triangle, with the following composition:

- 80%–90% sand;
- 10%–20% silt+clay; maximum clay content: 10%;
- 3%–5% organic matter content; and
- USDA NRCS coarse/rock fragment fraction (> 2mm) must be < 20% for the entire media blend for all mineral/soil fragments including the sand and topsoil blended materials.

Additionally, the sand utilized in the mineral blend must meet the grain size distribution indicated in Table F-2. The final combined particle size analysis must be conducted on the mineral fraction only or follow appropriate treatments to remove organic matter (e.g., 30% $H_2O_2$ oxidation) before particle size analysis.

**Table F-2 Sand Grain Size Distribution**

| Sieve | Size | % Passing |
|---|---|---|
| 3/8 in | 9.50 mm | 100 |
| No. 4 | 4.75 mm | 95 to 100 |
| No. 8 | 2.36 mm | 80 to 100 |
| No. 16 | 1.18 mm | 45 to 85 |
| No. 30 | 0.6 mm | 15 to 60 |
| No. 50 | 0.3 mm | 3 to 15 |
| No. 100 | 0.15 mm | 0 to 4 |

The following is the recommended composition of the three media ingredients:

- **Sand.** Sand shall consist of alumino-silica-based native sands, rock fines or coarse aggregate that isangular or round in shape and meets the mixture grain size distribution above. No substitutions of alternate materials such as diabase, calcium carbonate, rock dust or dolomitic sands are accepted. In particular, the material shall contain less than 5% mica by weight when tested with ASTM C295.

  ASTM C-33, Standard Specification for Concrete Aggregates, concrete sand will typically meet the requirements for the sand to be used in filter media. However, some samples of ASTM C-33 sand may have too high a fraction of fine sand and silt- and clay-sized particles to meet the final filter media particle size distribution requirements. In general, coarser gradations of ASTM C-33 will better meet the filter media particle size distribution and hydraulic conductivity requirements. Do not use ground concrete, aggregate or bottom ash due to concerns over high pH influences.

- **Topsoil.** Topsoil is generally defined as the A + E horizons of the native soil profile which contains a combination of sand (2 to 0.5 mm), silt (0.05 to 0.002 mm) and clay (< 0.002 mm) sized mineral particles. Native topsoils usually also contain 0.5 to 5% finely divided organic matter (humus) by weight, but that is not considered in assignment of USDA NRCS mineral soil texture classes. Since the objective of the specification is to carefully establish the proper blend of these ingredients in the final filter media, the vendor must carefully select the topsoil source material to meet the overall final topsoil+sand blend criteria of no more than 20% silt+clay, and no more than 10% clay.

Generally, the use of a topsoil defined as a loamy sand, sandy loam, or loam (per the USDA Textural Triangle) will be an acceptable ingredient and in combination with the other ingredients meet the overall performance goal of the soil media. However, it is important to note the following:

1. USDA NRCS soil texture is determined on the < 2mm fraction only. Organic matter should be removed for all source topsoil with more than 5% OM via the $H_2O_2$ oxidation pre-treatment method.
2. For the purpose of this specification, the topsoil component utilized shall not contain > 20% coarse/rock fragments > 2.0 mm and no particles may be > 9.5 mm (3/8 inch). This will provide a final sand+topsoil mineral component blend that limits the total > 2mm fraction to < 20%.

- **Organic Matter.** Organic matter shall consist of stable, well-composted, natural, carbon-containing organic materials such as leaf mulch, peat moss, humus, or yard waste (consistent with the material specifications found in P-FIL-04 Soil Compost Amendment and/or the Compost Research & Education Foundation). The material shall be free of debris such as plastics, metal, concrete, stones larger than 0.5 inch, larger branches and roots, and wood chips over 1 inch in length or diameter. The organic matter content of the final media blend must be determined on the appropriate size fraction with one of the methods (LOI or Walkley-Black) specified in Table F-1.
- **Other organic (e.g., biochar, stable sludges) or inorganic residuals or additives (e.g., alum sludge, steel slag, recycled glass)** may be considered to meet or enhance Table F-1 requirements for mineral texture, CEC, P, or organic matter levels, but must be approved by VDEQ or Virginia Department of Agriculture and Consumer Services (VDACS) for such application and approved on a case-by-case basis.

In order to achieve a proper mix of these three ingredients, start with an open-graded coarse sand material and proportionately mix in the topsoil materials that may contain anywhere from 10% to 20% soil fines (sandy loam, loamy sand, loam) to achieve the desired ratio of sand and fines. Sufficient suitable organic amendments (e.g., stable compost) can then be added to achieve the 3% to 5% soil organic matter target. The exact composition of organic matter and topsoil material will vary, making the exact particle size distribution of the final total soil media mixture difficult to define in advance of evaluating available materials.

**Plant Available Phosphorus (P) content.** The filter media should contain sufficient plant-available P to support initial plant establishment and plant growth, but it should not serve as a significant source of P for long-term leaching losses. This range should be between 5 to 15 mg/kg P for the Mehlich I extraction procedure or 18 to 40 mg/kg P for the Mehlich III extraction procedure. The Virginia and/or NRCS P-Index is not applicable to biofiltration media per se.

**Cation Exchange Capacity (CEC).** The minimum CEC of a bioretention soil media mix for pollutant removal is 5.0 (meq/100 g or cmol+/kg) or greater. The filter media CEC should be determined by the Unbuffered Salt, Ammonium Acetate, Summation of Cations or Effective CEC techniques (Sumner and Miller 1996) or similar methods that do not utilize strongly acidic extracting solutions. Methods used by USA Soil Taxonomy that employ the BaCl2-TEA extract to estimate exchangeable acidity (H+) may not be used.

**Hydraulic Conductivity ($K_{sat}$).** The bioretention soil media should have a minimum saturated hydraulic conductivity of 1 to 2 inches per hour (or 60 to 120 cm/day) and an initial $K_{sat}$ of no more than 10 inches per hour before settling following initial wetting events.

**pH.** The pH of bulk media should be in the range of 5.5-7.5.

**Soluble Salts.** The specific conductance of a saturated paste extract of the bulk media should never exceed 4 mmhos/cm (or dS/m) and should be below 2 mmhos/cm.

# F.4 Calculating Treatment Volume Peak Discharge

## F.4.1 Introduction

The water quality treatment volume ($Tv_{BMP}$) is defined as the amount of runoff from a contributing drainage area generated by the rainfall from the 90th percentile storm event, which has been established as the 1-inch storm for Virginia. In order to properly size water quality BMPs, the water quality treatment volume must be calculated using the Virginia Runoff Reduction Method (VRRM). This treatment volume can then be converted into peak discharge ($q_{pTv}$) in order to ensure non-erosive conditions and BMP flow capacity. The peak discharge is further needed for the design and sizing of pretreatment cells, level spreaders, by-pass diversion structures, overflow riser structures, grass swales, water quality swale geometry, and manufactured treatment devices (MTDs).

The VDEQ has reviewed several methods for calculating peak discharge. The Modified Curve Number Method is VDEQ's preferred way to calculate the peak discharge for the water quality treatment volume associated with the BMP drainage area. The method is based on the Small Storm Hydrology Method (Pitt 1999) and NRCS Graphical Peak Discharge Method in Technical Release 55 (TR-55; USDA 1986).

The equation used for the Modified Curve Number Method is provided below.

$$q_{pTv} = q_u \times A \times Q_a$$

*Equation 11.12 in VDEQ, 2013 (Modified NRCS TR-55 Eq. 4-1)*

Where:

$q_{pTv}$ = treatment volume peak discharge (cfs)

$q_u$ = unit peak discharge (cfs/mi$^2$/in)

$A$ = BMP drainage area (mi$^2$)

$Q_a$ = runoff volume (watershed inches = *$Tv_{BMP}$/BMP drainage area*)

## F.4.2 Modified Curve Number Method

Follow the steps below to use the Modified Curve Number Method to compute the peak discharge of the BMP's treatment volume ($q_{pTv}$).

**Step 1: Calculate the BMP treatment volume ($Tv_{BMP}$) using the VRRM .**

The VRRM spreadsheets for new development and redevelopment are available at https://www.deq.virginia.gov/our-programs/water/stormwater/stormwater-construction/guidance-vrrm. The $Tv_{BMP}$ is expressed in the VRRM spreadsheets in cubic feet (ft3). The $Tv_{BMP}$ is used to compute the runoff volume ($Q_a$).

Note: When using a treatment train, the designer should consult the VRRM spreadsheet to determine the total treatment volume from both the immediate contributing drainage area and any additional volume remaining from the upstream BMP.

**Step 2: Calculate the modified curve number (CN) for the BMP contributing drainage area.**

The CN is needed to compute the initial abstraction (Ia), which is used to determine the unit peak discharge (qu) (Step 4).

The following equation is derived from the NRCS Curve Number Method, which is described in detail in Chapter 2 (Estimating Runoff) of TR-55 (USDA 1986):

*Equation: Derivation of NRCS Curve Number and Runoff Equation*

$$CN = \frac{1000}{[10 + 5P + 10Q_a - 10(Q_a^2 + 1.25Q_aP)^{0.5}]}$$

Where:

*CN* = modified curve number

*P* = rainfall (inches), equal to 1.0 inch in Virginia

$Q_a$ = runoff volume (watershed inches), equal to TvBMP ÷ BMP drainage area

Note: When using a hydrologic/hydraulic model for sizing a runoff reduction BMP or calculating $q_{pTv}$, designers must use this modified curve number for the drainage area to generate runoff equal to the $Tv_{BMP}$.

**Step 3: Compute the time of concentration ($T_c$) for the site or drainage area.**

Tc influences the shape and peak of the runoff hydrograph. Chapter 3 of TR-55 (Time of Concentration and Travel Time; USDA 1986) provides detailed procedures for computing the Tc.

**Step 4: Determine the unit peak discharge ($q_u$).**

The unit peak discharge ($q_u$) is described in Chapter 4 of TR-55 (Graphical Peak Discharge Method; USDA 1986).

Note: The Virginia Stormwater Management Program (VSMP) regulations require that designers use updated rainfall data based upon the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 publication for stormwater management computations and modeling.

Note: Exhibit 4-II in TR-55 reports $q_u$ in units of csm/in, which equals cubic feet per second (cfs) per square mile (mi2) of drainage area per inch of runoff (cfs/mi2/in).

**Step 5: Calculate the water quality treatment volume's peak discharge ($q_{pTv}$).**

The $q_{pTv}$ is computed using equation 11.12 in VDEQ's Draft 2013 Virginia Stormwater Management Handbook and is shown in the Introduction section of this document. The equation is a modified version of equation 4-1 in TR-55 (Chapter 4: Graphical Peak Discharge Method; USDA 1986).

# F.5 References


NOAA. 2023. Atlas 14 Point Precipitation Frequency Estimates for Virginia. Available at https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=va (accessed June 12, 2018).

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United States Department of Agriculture (USDA). 1986. Urban Hydrology for Small Watersheds: TR-55. 210-VI- TR-55, Second Ed., June 1986. Natural Resources Conservation Service, Conservation Engineering Division.

VDEQ. 2013. Draft 2013 Virginia Stormwater Management Handbook, Second Ed. Available at https://www.swbmp.vwrrc.vt.edu/references-tools/ (accessed July 5, 2018).

# APPENDIX G PLANT SELECTION

**Contents:**



## G.1 Introduction

Plants are an important part of stormwater management systems. They effectively reduce runoff by intercepting rainfall, encouraging evaporation, promoting infiltration, and increasing water absorption. Plants also help reduce erosion; remove pollutants from the environment; establish habitats for beneficial wildlife; and create attractive, comfortable spaces for users. Plant performance is vital to the success of vegetated best management practices (BMPs) and many characteristics must be considered to select the proper plants for these systems.

### G.1.1 Purpose of Appendix

This appendix provides a clear methodology and toolkit for choosing plants in BMP systems. Follow the steps provided to determine the correct selection criteria for specific stormwater projects and use the included plant lists to pick appropriate species. This appendix is meant to streamline the BMP design process by providing a distilled, comprehensive resource for plant selection.

### G.1.2 Using the Appendix

To properly choose plants for stormwater management systems, first, determine the type of BMP being used and verify its design. Identify key components of the design that may influence plant selection. These include conveyance methods, inlet/outlet structures, pooling/pond conditions (impoundment zones), liner type (if present), maintenance needs, drain information, buffer requirements, and soil specifications.

Once the design of the BMP has been considered, thoroughly analyze the project site to understand solar conditions, existing hydrology, topography, views (from both inside and outside of the site), circulation, site maintenance requirements, adjacent uses (e.g., parking areas, walkways, entries), utility locations, and any other site features that may influence the landscape design. Also, confirm the physiographic region and hardiness zone of the project site.

Finally, work with the client, stakeholders, and design team to establish a vision for the landscape. Determine the desired aesthetic, maintenance capacity, and functional needs of the design. Once the BMP design, existing site conditions, and design concept have been considered, use the plant lists provided to select species that satisfy the functional, sustainable, and aesthetic requirements of the project.

Ongoing maintenance of vegetated BMPs is critical to the system's continued effectiveness. Develop a landscape maintenance plan that provides instructions and schedules for monitoring and routine care. The maintenance plan should include information regarding soil/moisture monitoring, supplemental water, pruning, and weeding.

## G.2 Plant Information

There are several selection criteria to consider when choosing plants for stormwater applications. The plant lists provided include information needed when determining which species are appropriate for specific applications. This section explains the data and discusses how it should be used when selecting plants.

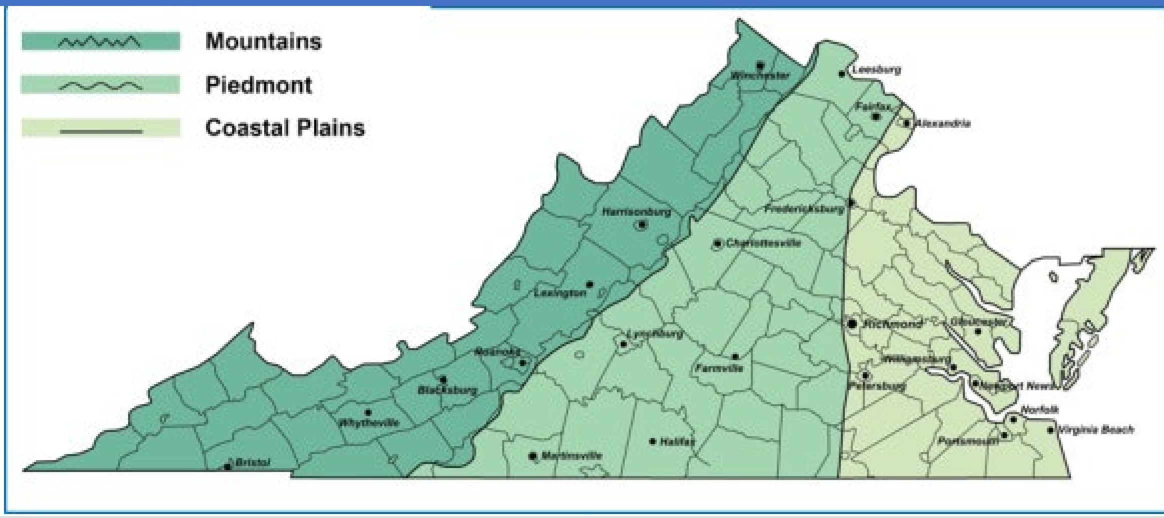

1. **Plant Type** - Regardless of BMP type, use a variety of plant types to improve biodiversity, aesthetics, and function of the stormwater system. Verify the design of the BMP to determine which plant types are most appropriate to the design. Plants are divided into the following categories:
    a. **Canopy Trees** - Large, woody plants with a central trunk. For this document, canopy trees are generally considered taller than 30 feet and can include both evergreen and deciduous plants.
    b. **Understory Trees** - Woody plants that are typically taller than 10 feet. Usually, these species are found below the forest canopy and can have single- or multi-stem trunks.
    c. Shrubs - Woody plants, usually shorter than 10 feet, that do not develop a canopy or central trunk but instead have several stems branched from the ground.
    d. **Flowering Perennials** - Generally herbaceous (soft tissue) plants, though some develop woody growth. These plants persist for multiple years (unlike annuals) but usually die back to the ground in winter. Species in this category typically develop showy, ornamental flowers.
    e. **Grasses and Groundcovers** - Low-growing, non-woody, ornamental plants with bladelike leaves. This group also includes perennials that spread effectively to cover the ground.
    f. **Green Roof Plants** - Herbaceous plants suitable for highly exposed rooftop environments and complex green roof assemblies. Green roof plants do not include impoundment zone information, as they are not used in these applications.
2. **Plant Name** – Scientific/botanical names and common names are provided for reference. Only use scientific names in specifications and drawings, as common names can vary.
3. **Virginia Native Range** - The use of native plants is becoming increasingly preferred in landscape architecture; however, the term "native" is not often clearly defined. The Virginia DCR defines native species as "those that occur in the region in which they evolved. Plants evolve over geologic time in response to physical and biotic processes characteristic of a region (the climate, soils, timing of rainfall, drought, and frost) and interactions with the other species inhabiting the local community." Because they have evolved within these conditions unique to an area, native plants have adapted to thrive in their local area. These plants are well-suited for use in landscaping, conservation, restoration projects, and as livestock forage in their native area as native plants often surpass non-

natives in resistance to drought, insects, and disease. For the purposes of this manual, “native” refers to the three primary physiographic zones of Virginia:

Mountains (which include the Valley and Ridge, Blue Ridge, and Appalachian Plateau provinces), Piedmont, and Coastal Plains. Figure 1 highlights the extents of these regions.

Note: Prior to specifying plant species, review the VA State Code 2VAC5-317-20. Tier 1, Tier 2 and Tier 3 noxious weeds. Noxious weeds can be detrimental to crops, surface waters, desirable plants, livestock, land, or other property and should not be used on planting plans.

***Figure G-1 Physiographic regions of Virginia. Adapted from C.M. Bailey, College of William and Mary, 1999***




Locations within these zones share similar environmental conditions and provide a more suitable classification when discussing native plants. When selecting plants for stormwater applications, locate the project site, determine its physiographic region, and prioritize species native to that zone. BMPs do not have to use plants exclusively from that region. However, incorporating vegetation native to a particular area may improve planting performance and better integrate into the local ecology.

a. **Mountains -** The Mountain region includes the Valley and Ridge, Blue Ridge, and Appalachian Plateau provinces and covers much of western Virginia. The area is characterized by rugged, higher-elevation terrain often taking the form of long parallel ridges, upland plateaus, and narrow valleys. Because of its diverse topography and landforms, the region supports a wide variety of plant communities across various climatic conditions.

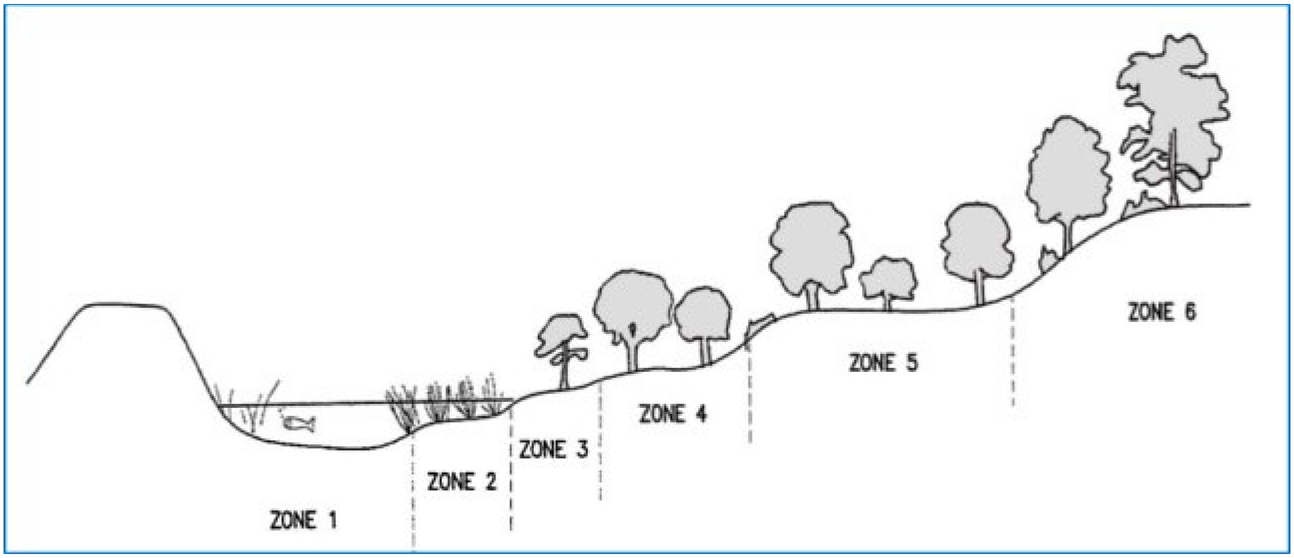
b. **Piedmont** - The Piedmont encompasses central Virginia and serves as a transitional zone between the lower coastal lands and the Appalachian Mountains. The region includes rolling hills, mixed hardwood forests, farmlands, and clay soils.

c. **Coastal Plains** - The Coastal Plains run along the Atlantic Ocean and feature flatter topography, sandy soils, and well-developed ravines and tidal river systems. Sandy beaches, marshes, swamps, and mixed forests comprise the Coastal Plains region.

While native species are preferred, there are several adapted non-natives and native cultivars that are suitable for stormwater systems. The lists in this appendix include species that, while not native to Virginia, are non-invasive and suitable for use in BMPs. Many of these plants have specific characteristics (e.g., disease resistance, ornamental traits, improved drought tolerance) that make them appropriate for stormwater systems, particularly in challenging urban environments. Before specifying these plants, consider the location in which they will be used. Non-native species and selected cultivars are more suitable for urban areas as opposed to restoration projects in more natural areas.

4. **Hardiness Zones -** Hardiness zones are geographic areas defined by the United States Department of Agriculture (USDA) based on long-term average annual minimum winter temperatures. The system includes 13 zones arranged in increments of 10° Fahrenheit (and 5° half zones), which help determine the appropriateness of plants for specific locations. Virginia hardiness zones are identified in Figure C-SSM-10-2. Before selecting plants for a landscape, accurately determine the project site's hardiness zone. Keep in mind that hardiness is based on averages, and selections should be adjusted to specific site conditions. For instance, a BMP may be located within hardiness zone 7a, but its placement on the north side of a building, where it experiences deep shade and strong winter winds, may be more suited for plants with great cold hardiness (zone 5 or 6).
5. **Size -** Typical plant sizes (height x width) help when selecting plants properly sized for a site. The measurements given are averages; therefore, plant sizes often vary. This can be a result of environmental conditions such as available light and water, but soil volume is often a major contributor to mature plant size. When working in urban areas, it is particularly important to maximize soil volume to encourage the best plant growth. This can be achieved using soil cells and designing large or connected planting areas. There can also be size differences between cultivars. Therefore, verify all plant sizes before including them in the final design.
6. **Recommended Plant Spacing -** For shrubs, perennials, grasses, and groundcovers, recommendations for plant spacing are given on the planting lists. Spacing is based on typical plant growth but can be adjusted to satisfy budgetary or aesthetic goals. Keep in mind that plants spaced closer together will fill in quicker and better suppress weedy growth. However, the planting may become too dense and lead to poor plant development. Also, consider the sizes of installed plants when determining spacing. Smaller material may need to be more tightly spaced to outcompete weeds and fill in quicker. Generally, smaller plant material is easier to establish and has lower mortality rates.
7. **Stormwater Impoundment Zone Suitability -** Stormwater BMPs feature various hydrologic zones with different inundation frequencies and soil moisture conditions. There are six defined zones, and information is provided as to what zones are suitable for each recommended plant species. Properly identify what zones will be included in the BMP and select plants accordingly. Figure 3 illustrates impoundment zones, and the subsequent paragraphs describe each one.

***Figure G-3 Planting zones for typical stormwater BMPs (Source: VDEQ 2011)***




a. **Zone 1 (Deep Water Area)** - This zone includes areas submerged in 18 inches or more of water. Only submerged and floating aquatic vegetation is appropriate for this zone. These areas are often found in retention basins, constructed wetlands, and extended detention basins. Plants in Zone 1 require extended inundation to survive and provide habitat for invertebrates.

b. **Zone 2 (Shallow Water Area)** - The depth of water in Zone 2 ranges from 0 to 18 inches, and plants typically include emergent wetland species. Usually present in retention basins, constructed wetlands, and enhanced extended detention basins, Zone 2 planting functions to reduce flow velocities, erosion, and resuspension of sediment and provides food, cover, and habitat for wildlife and insects.

c. **Zone 3 (Shoreline Fringe)** - Areas in Zone 3 are regularly inundated during storm events and may remain saturated due to their proximity to the permanent pool. Zone 3 extends 1 foot above the normal water surface for wetlands and retention basins, and to the maximum volume elevation for extended detention basins. While plants experience extended saturation, they must all tolerate periodic drying. Plants in Zone 3 help stabilize shores and bottoms of slopes and provide food, cover, and habitat for wildlife.

d. **Zone 4 (Riparian Fringe Area)** - This zone sees brief inundation during storm events and experiences both wet and dry conditions. These areas typically occur on the slopes of BMP systems and thus help reduce erosion and stabilize slopes in addition to providing ecological services to wildlife.

e. **Zone 5 (Floodplain Terrace)** - The floodplain terrace typically falls between the 2-year and 100-year water surface elevations, only experiencing inundation during large storms.

f. **Zone 6 (Upland Areas)** - These are well-drained areas often forming the edges or buffers for BMPs. Zone 6 rarely experiences inundation, and successful plants are typically more drought-tolerant.

8. **Sun Requirements** - Preferred sun requirements are provided for all species and categorized as full sun (6+ hours of sunlight/day), part shade (4-6 hours of sunlight/day), and full shade (<4 hours of sunlight/day).

Proper site analysis is needed to determine what light levels will be available for plants. If possible, perform a solar study to understand existing conditions and document how available light will change throughout the year. Also consider how nearby vegetation will grow over time and how these changes may affect available light for proposed planting. For instance, canopy trees will, over time, cast more shadows than when they are newly installed. Select plants suited for the anticipated light levels to avoid replacement or poor performance.

The following symbols indicate the sun requirements of each plant on the plant list:

● The filled circle indicates that the plant needs full shade.
◑ The half-filled circle indicates that the plant needs partial shade.
○ The empty circle indicates that the plant needs full sun.

9. **Moisture Requirements** - Stormwater BMPs often include zones of hydrologic conditions. Tops of berms and basins may be quite dry, while detention areas and depressions may see frequent inundation and consistently wet soil conditions. In many cases, BMPs see high variability in water availability, seeing both drought and flood conditions in a short period of time. Select appropriate plant species based on the design of the BMP, the vegetation's location within the BMP, anticipated hydrologic conditions, and the extent of irrigation. Moisture requirements are provided as high (wet with periodic inundation), medium (moist but well- drained), and low (well-drained with periods of dryness). The lists also provide recommendations for plants to be used at BMP entries. These are areas that see increased water volumes and velocities as well as higher concentrations of sediment and pollutants. Plants suitable for these areas demonstrate high durability and strong structures. Species that can tolerate moisture extremes, such as drought or flooding, are identified in the "Additional Features" section of the plant list.

The following symbols indicate the sun requirements of each plant on the plant list:

The single wave indicates that the plant has low moisture requirements.
The two waves indicate that the plant has a medium moisture requirement.
The three waves indicate that the plant has a high moisture requirement.

The three waves on a black background indicate that the plant is suitable for use at BMP entries.

10. **Additional Features** - Additional features highlight special characteristics of the plant that may be helpful when considering use in stormwater BMPs.

Water Tolerant   Drought Tolerant   Salt Tolerant   Urban/Pollution Tolerant

Wildlife/Pollinator   Phytoremediation   Year-Round Interest

a. **Water Tolerant** – The water droplet indicates these species can handle occasional inundation and increased soil moisture. These plants are suitable for lower zones (e.g., conveyance channels, basins) within BMPs or areas with more frequent flooding.

b. **Drought Tolerant** – The cactus indicates these are drought tolerant plants and can withstand dry periods and sites that drain quickly. Species that can tolerate dry conditions require less maintenance and irrigation and typically demonstrate higher survival rates due to their ability to handle stress.

c. **Salt Tolerant** – The spots indicate these plants are salt tolerant. Salt tolerance refers to plants that can withstand coastal salt spray or salt from road deicing. Salt, whether through air or from roadways, can cause plant dehydration; disrupt nutrient intake; and burn leaves, buds, and stems. Stormwater systems in coastal areas and adjacent to parking lots and roads that receive winter deicing should prioritize salt tolerant species.

d. **Urban/Pollution Tolerant** – The building indicates plants which can be used in urban environments. Urban environments can be difficult for plants. Added heat, restricted root zones, and pollution can limit plant growth and cause additional stress. Urban-tolerant plants should be used in cities to improve performance and survivability.

e. **Wildlife/Pollinator** – The butterfly indicates these plants are pollinator- and wildlife-friendly vegetation. These are plants that promote biodiversity by providing food and habitat for beneficial insects and animals.

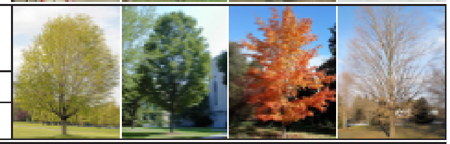
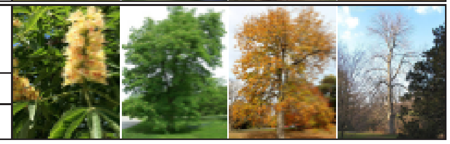
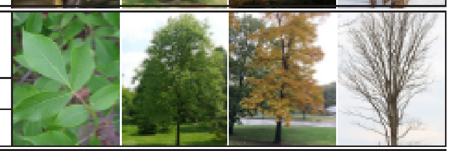
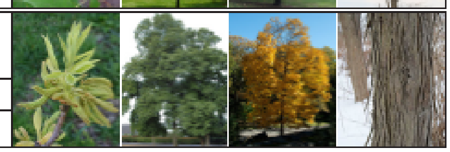
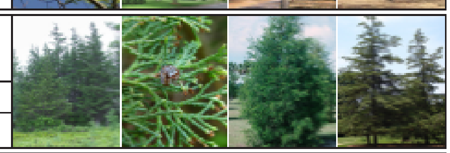
f. **Phytoremediation** – The leaf indicates species with phytoremediation qualities. These plants are capable of absorbing or breaking down harmful compounds in the soil. These plants help cleanse the soil biome and reduce pollution in runoff and aquifers.

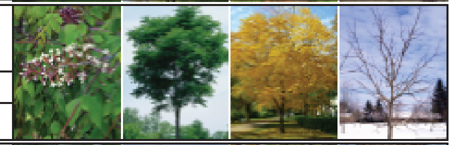
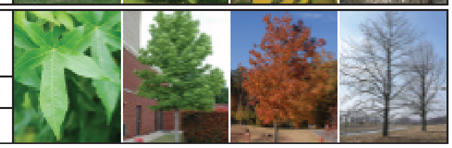
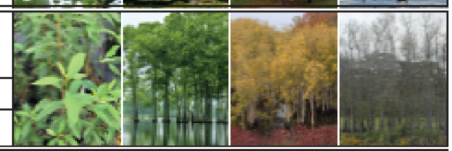
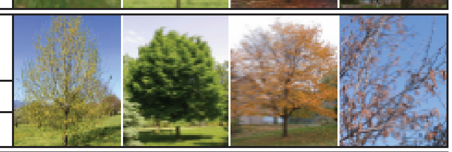
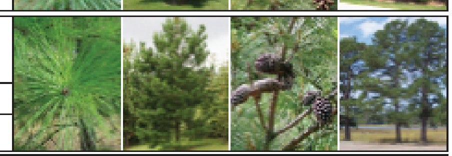
g. **Year-Round Interest** – The clock indicates these plants provide year-round interest. Vegetation that provides year-round interest is useful in creating dynamic landscapes that provide beauty across all seasons. Winters can be visually mundane, so using plants with multi-season interest ensures that landscapes are aesthetically pleasing, even in colder months.

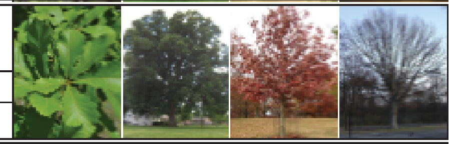
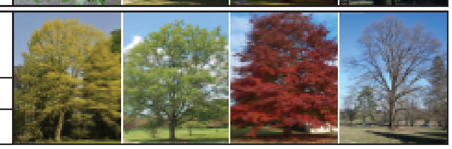
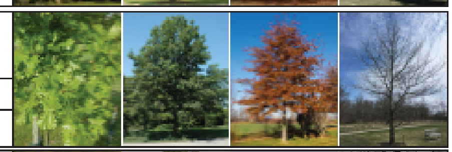
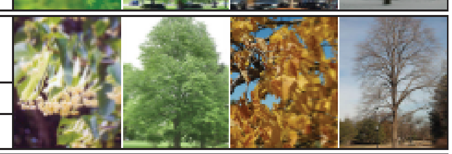
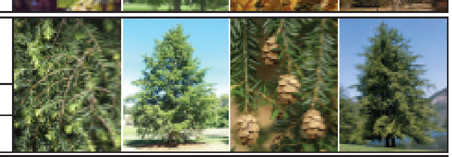
10. **Additional Notes** - Additional notes include recommendations and information not covered in other sections. These notes are useful when considering plant material and highlight specific plant characteristics that may influence selection and performance.
11. **Pruning Time** - Pruning time indicates when plants are best suited for trimming. These recommendations consider flowering characteristics (do blooms occur on current year or previous year growth?), seasonal stresses, and other plant-specific criteria. Virginia crosses several hardiness zones, so adjust pruning times based on specific site location. Pruning to correct damage, hazards, or structural issues can occur at any time. Consider the desired landscape aesthetic when creating a pruning program. For instance, many perennials can be pruned to remove seed heads or spent flowers; however, these features often provide winter interest.
12. **Bloom Time** - Bloom times refer to the peak flowering periods for specific plants. Consider the timing of blooms relative to specific site uses and programs. For instance, at schools, use plants that flower during the academic year. Combine different species to provide an extended blooming period instead of having all flowers show at the same time.
13. **Fruit Time** - Fruit time is the time in which fruits are at their most ornamental. As with flowers, design landscapes to take advantage of ornamental fruits. Keep in mind that fruiting plants, especially trees, can produce additional litter, which may increase maintenance. They may also be inappropriate for pedestrian areas or along roadways and parking areas.
14. **Seasonal Photos** - Seasonal photos are typical images of plants throughout the year. Use these photos to develop a planting palette that provides visual interest and complementary characteristics. Photos are representative, and variations may exist between cultivars of the same species. Verify specific plant characteristics before final selection to ensure the desired aesthetic is achieved.

# G.3 Recommended Planting List

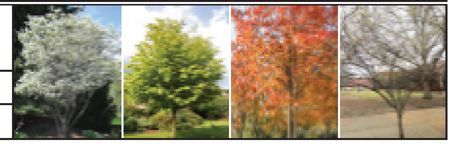
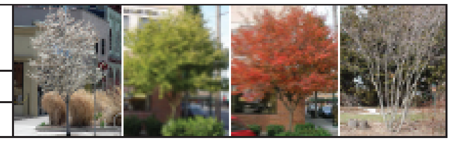
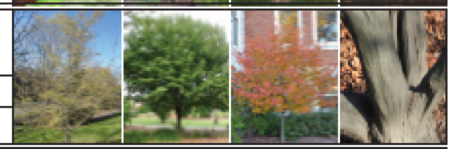
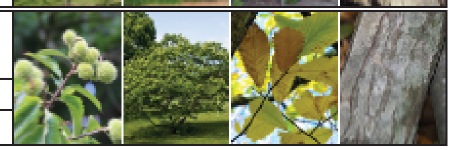
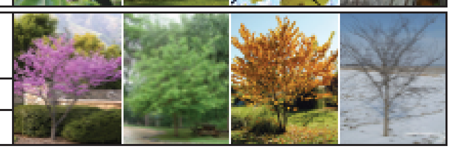
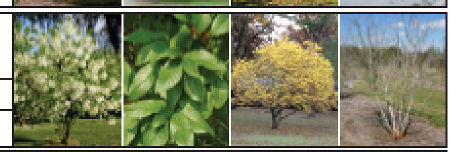
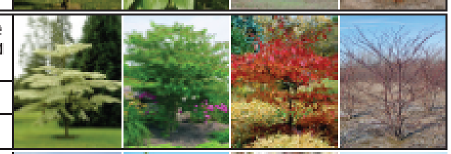
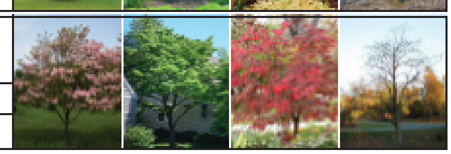
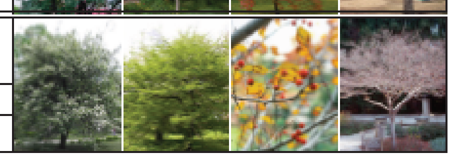
## G.3.1 Canopy Trees

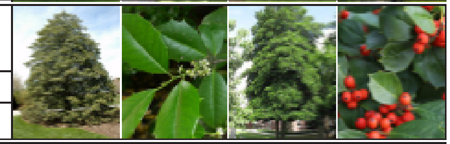
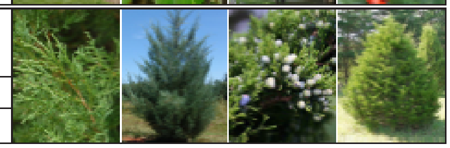
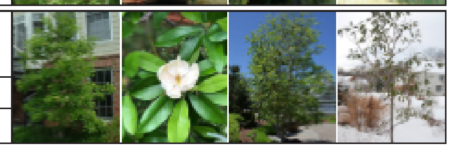
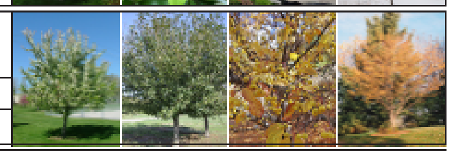
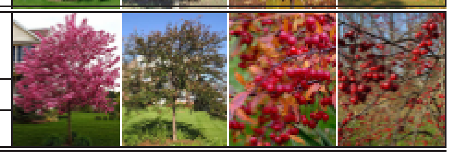
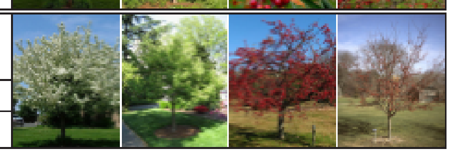
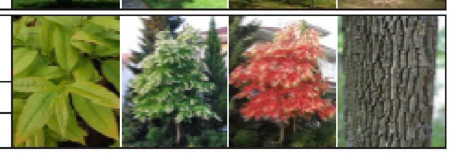
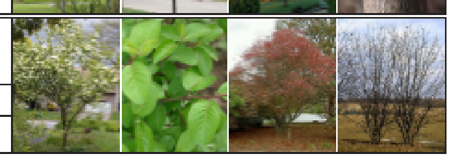
| Plant | Zones | Size | | Notes | Pruning | Bloom | Fruit | Photos |
|---|---|---|---|---|---|---|---|---|
| *Acer rubrum* **Red Maple** | 3 to 9 | 60' x 40' | 1 2 3 4 5 6 | Shallow roots can inhibit other plant growth. Prioritize cultivars. | Early Winter | March-April | April-July |  |
| *Acer saccharum* **Sugar Maple** | 4 to 8 | 70' x 50' | 1 2 3 4 5 6 | Great fall color. Suitable as a street tree in less polluted areas with less salt treatment. | Early Winter | April | July-Sept |  |
| *Aesculus flava* **Yellow Buckeye** | 4 to 8 | 70' x 40' | 1 2 3 4 5 6 | Outstanding fall color. Can be messy around walkways and parking. | Summer | April-June | Aug-Sept |  |
| *Betula lenta* **Sweet Birch** | 3 to 8 | 50' x 40' | 1 2 3 4 5 6 | More adaptable to drier sites than Betula nigra. Great fall color. | Early Winter | April-May | |  |
| *Betula nigra* **River Birch** | 4 to 9 | 60' x 50' | 1 2 3 4 5 6 | Handles drier sites but grows best with moisture. Use cultivars, especially on urban sites. | Early Winter | April-May | |  |
| *Carya glabra* **Pignut Hickory** | 4 to 9 | 70' x 30' | 1 2 3 4 5 6 | Don't use near pedestrian areas due to nuts. Not as adaptable to wet site as Shagbark Hickory. | Winter | | Sept-Nov |  |
| *Carya ovata* **Shagbark Hickory** | 4 to 8 | 80' x 50' | 1 2 3 4 5 6 | Long-lived tree but place away from pedestrian areas due to fruit. | Winter | | Sept-Nov |  |
| *Celtis occidentalis* **Hackberry** | 3 to 9 | 60' x 60' | 1 2 3 4 5 6 | Tolerant of dry sites and urban areas. Use cultivars for improved form and less fruiting. | Late Winter - Early Spring | | Sept-Oct |  |
| *Chamaecyparis thyoides* **Atlantic Whitecedar** | 4 to 8 | 50' x 30' | 1 2 3 4 5 6 | Evergreen that can handle boggy sites. | | | |  |
| *Cladrastis kentukea* **Yellowwood** | 4 to 8 | 40' x 45' | 1 2 3 4 5 6 | Smaller canopy tree that's highly adaptable and tolerant of drier areas. | Summer | May-June | Sept-Oct |  |
| *Diospyros virginiana* **Persimmon** | 4 to 9 | 60' x 30' | 1 2 3 4 5 6 | Interesting bark. Fruit valued by wildlife but not suitable around walkways or parking. | Late Winter - Early Spring | | Sept-Nov |  |
| *Ginkgo biloba* **Ginkgo** | 4 to 8 | 70' x 40' | 1 2 3 4 5 6 | Adaptable and suitable as a street tree. Use only male (non-fruiting) trees. | Late Winter - Early Spring | | |  |

| Plant | Zone | Size | Region | Notes | Pruning | Bloom | Fruit | Photos |
|---|---|---|---|---|---|---|---|---|
| *Gleditsia triacanthos* **Honeylocust** | 3 to 8 | 45' x 35' | 1 2 **3 4 5 6** | Use fruitless and thornless varieties such as 'Shademaster' or 'Skyline'. | Fall | May-June | |  |
| *Gymnocladus dioicus* **Kentucky Coffeetree** | 3 to 8 | 70' x 50' | 1 2 3 **4 5 6** | Use fruitless varieties like 'Espresso' or 'Stately Manor'. | Late Winter - Early Spring | May-June | |  |
| *Halesia tetraptera* **Carolina Silverbell** | 4 to 8 | 40' x 30' | 1 2 3 **4 5** 6 | Handles shade better than most canopy trees. Container-grown transplant best. | Late Winter - Early Spring | March-April | Aug-Sept |  |
| *Liquidambar styraciflua 'Happidaze/Rotundiloba'* **Fruitless Sweetgum** | 5 to 9 | 70' x 50' | 1 2 **3 4 5 6** | Roots can cause damage to walkways and paving. | Winter | | |  |
| *Liriodendron tulipfera* **Tulip Poplar** | 4 to 9 | 80' x 40' | 1 2 3 **4 5 6** | Provide ample space for growth. Can be weak wooded. | Winter | May-June | |  |
| *Nyssa aquatica* **Tupelo Gum** | 6 to 9 | 80' x 40' | 1 **2 3** 4 5 6 | Tolerant of standing water and flooded areas. | Winter | | Sept-Oct |  |
| *Nyssa sylvatica* **Blackgum** | 4 to 9 | 40' x 25' | 1 2 **3 4 5 6** | Suitable as a street tree but doesn't handle excessive pollution. One of best fall colors. | Winter | | Sept-Nov |  |
| *Ostrya virginiana* **Hop Hornbeam** | 3 to 9 | 40' x 30' | 1 2 3 **4 5 6** | Has some tolerance of urban conditions and could be considered for street plantings. | Late Winter - Early Spring | April | June-Feb |  |
| *Pinus strobus* **Eastern White Pine** | 3 to 8 | 70' x 30' | 1 2 3 **4 5 6** | One of the most popular landscape pines. Limit use in urban environments. | | | Aug-Oct |  |
| *Pinus taeda* **Loblolly Pine** | 6 to 9 | 70' x 30' | 1 2 **3 4 5 6** | More tolerant of inundation than other pines. | | | Oct-Nov |  |
| *Platanus occidentalis* **American Sycamore** | 4 to 9 | 100' x 80' | 1 2 **3 4 5 6** | Suitable only for large areas. Can frequently drop debris and best used in natural areas. | Late Winter - Early Spring | | Oct-Feb |  |
| *Prunus serotina* **Wild Black Cherry** | 3 to 9 | 60' x 40' | 1 2 3 **4 5** 6 | Fast growing but can be aggressive. | Summer | April-May | Aug-Sept |  |

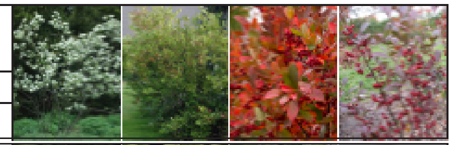
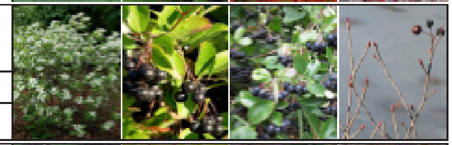
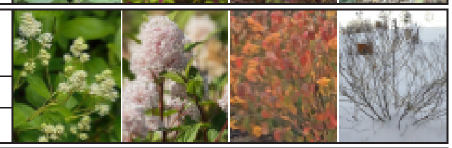
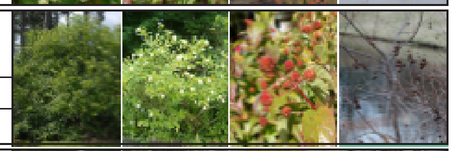
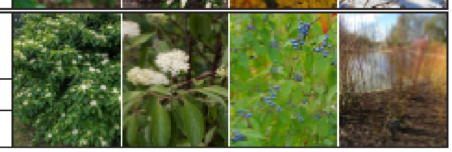
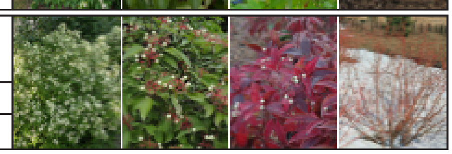
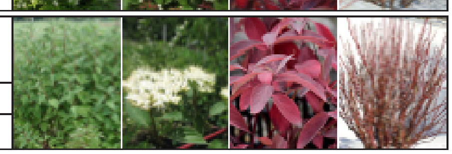
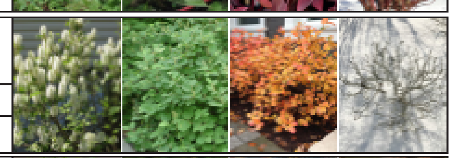
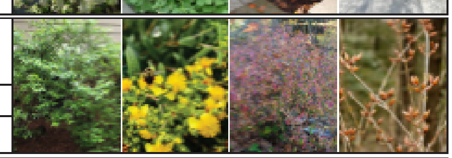
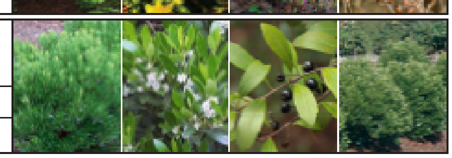
| Species | Zone | Size | Spacing | | Notes | Planting | Fruit/Flower | Photos |
|---|---|---|---|---|---|---|---|---|
| *Quercus bicolor* **Swamp White Oak** | 4 to 8 | 60' x 60' | | 1 2 **3 4 5 6** | Valued by wildlife as a host plant and food source. Suitable as a street tree. | Early Winter | Sept-Nov |  |
| *Quercus michauxii* **Swamp Chestnut Oak** | 5 to 9 | 60' x 50' | | 1 2 **3 4** 5 6 | Adaptable to areas of flooding and inundation. Can handle urban conditions. | Early Winter | Sept-Oct |  |
| *Quercus palustris* **Pin Oak** | 4 to 8 | 60' x 40' | | 1 2 **3 4 5 6** | Popular oak with wide appeal and suitable as a street tree. | Early Winter | Oct-Nov |  |
| *Quercus phellos* **Willow Oak** | 5 to 9 | 60' x 40' | | 1 2 **3 4 5** 6 | Adaptable tree but does best with moisture. Suitable as a street tree. | Early Winter | Sept-Nov |  |
| *Quercus rubra* **Red Oak** | 4 to 8 | 75' x 75' | | 1 2 3 **4 5 6** | Not as successful in hotter/ humid areas. Suitable as a street tree. | Early Winter | Aug-Oct |  |
| *Quercus shumardii* **Shumard Oak** | 5 to 9 | 60' x 40' | Spacing | 1 2 **3 4 5 6** | Adaptable tree that will do better in warmer areas. | Early Winter | Sept-Oct |  |
| *Salix nigra* **Black Willow** | 4 to 9 | 50' x 50' | | 1 **2 3 4** 5 6 | Aggressive roots that may impact pipes/utilities. Weaker wood. | Late Fall - Early Winter | March-May |  |
| *Taxodium distichum* **Baldcypress** | 4 to 9 | 70' x 30' | | 1 **2 3 4 5 6** | Highly adaptable to various hydric conditions. Suitable as a street tree. | Late Winter - Early Spring | Sept-Nov |  |
| *Tilia americana* **Basswood** | 3 to 8 | 70' x 50' | | 1 2 3 **4 5 6** | Fragrant flower. Large-tree which does best in open areas. | Fall - Winter (avoid Summer) | June |  |
| *Tsuga canadensis* **Eastern Hemlock** | 3 to 7 | 60' x 30' | | 1 2 3 **4 5** 6 | Nice evergreen but not tolerant of challenging sites. Use sparingly due to woolly adelgid. | | Oct-Nov |  |
| *Ulmus americana 'Valley Forge/Princeton/Jefferson'* **American Elm** | 3 to 9 | 70' x 50' | | 1 2 **3 4 5 6** | Use only dutch elm resistant cultivars indicated. | Fall | |  |

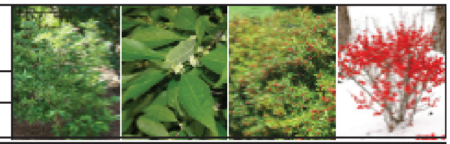
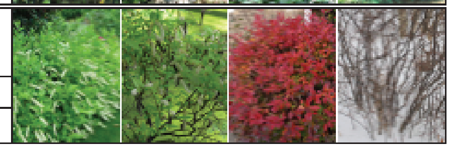
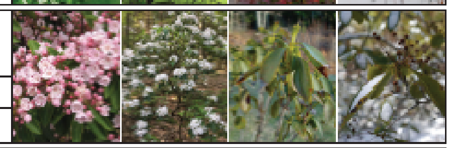
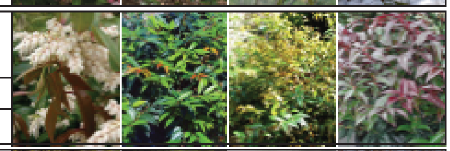
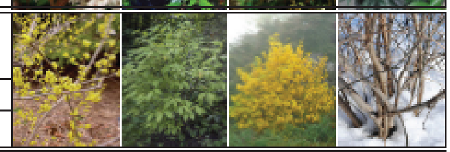
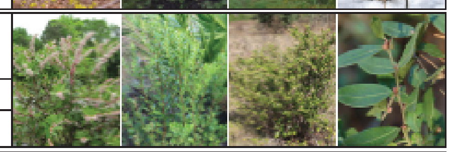
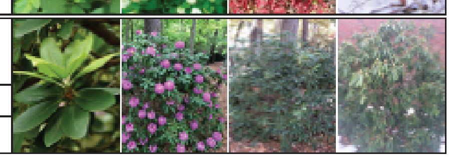
## G.3.2 Understory Trees

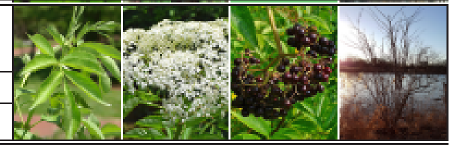
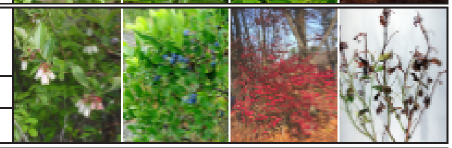
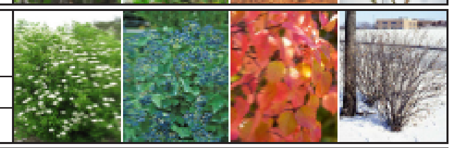
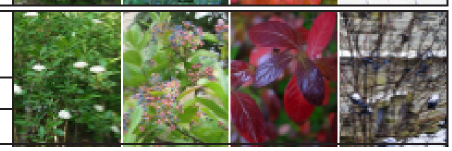
| Species | Zone | Size | Scale | Notes | Pruning | Bloom | Fruit | Photos |
|---|---|---|---|---|---|---|---|---|
| *Acer buergerianum* **Trident Maple** | 5 to 9 | 30' x 25' | 1 2 3 **4 5 6** | Exfoliating bark provides subtle winter interest. Only use cultivars. | Early Winter | April - May | Oct - Nov |  |
| *Amelanchier arborea* **Downy Serviceberry** | 4 to 9 | 25' x 25' | 1 2 **3 4 5 6** | Multi-seasons of interest. Works best in more natural/less urban areas. | Early Summer | March-April | June |  |
| *Amelanchier x grandiflora* **Apple Serviceberry** | 4 to 9 | 25' x 20' | 1 2 **3 4 5 6** | Adaptable and disease-resistant tree with great fall color. Several varieties available. | Early Summer | March-April | June |  |
| *Asimina triloba* **Pawpaw** | 5 to 9 | 20' x 20' | 1 2 **3 4 5** 6 | Interesting understory tree but not highly adapatable. Better fruit production in full sun. | Late Winter - Early Spring | April-May | Sept-Nov |  |
| *Carpinus caroliniana* **American Hornbeam** | 3 to 9 | 30' x 30' | 1 2 **3 4 5** 6 | Variability in fall color. Adaptable to different growing conditions. | Late Winter - Early Spring | | |  |
| *Castanea pumila* **Chinquapin** | 6 to 9 | 15' x 15' | 1 2 3 4 **5 6** | Often grown as a large shrub. Use in natural areas under preferred growing conditions. | Late Winter - Early Spring | May-July | Sept-Nov |  |
| *Cercis canadensis* **Eastern Redbud** | 4 to 9 | 25' x 30' | 1 2 **3 4 5** 6 | Provide ideal growing conditions. Long bloomer. | Late Spring - Early Summer | March-May | Aug-Nov |  |
| *Chionanthus virginicus* **Fringetree** | 4 to 9 | 20' x 15' | 1 2 **3 4 5 6** | Adaptable, especially to urban conditions. Can have emerald ash borer issues; limit in natural areas. | Summer (rarely needed) | May-June | Aug-Sept |  |
| *Cornus alternifolia* **Alternate-leaf Dogwood** | 3 to 7 | 20' x 25' | 1 2 **3 4 5** 6 | Best used in colder climates. More shade in hotter zones. Pronounced horizontal branching. | Summer | May-June | July-Aug |  |
| *Cornus florida* **Dogwood** | 5 to 9 | 25' x 25' | 1 2 **3 4 5** 6 | Classic understory tree with many varieties feature different flower colors. Limit stress. | Summer | March-May | Aug-Oct |  |
| *Cotinus obovatus* **American Smoketree** | 4 to 8 | 30' x 30' | 1 2 3 **4 5 6** | Extraordinary fall color. Tolerant of poor, but dry, soils. | Late Winter - Early Spring | April-May | |  |
| *Crataegus crus-galli* **Cockspur Hawthorn** | 4 to 7 | 25' x 25' | 1 2 3 4 **5 6** | Pushing it in zone 7. Great tolerance for urban conditions. | Summer | April-May | Sept-Nov |  |

| Plant | Hardiness Zone | Size | | Notes | Season | Bloom | Fruit | Photos |
|---|---|---|---|---|---|---|---|---|
| *Crataegus viridis 'Winter King'* **Winter King Hawthorn** | 4 to 7 | 30' x 30' | 1 2 3 **4 5 6** | Use in colder zones. | Summer | May | Sept-Jan |  |
| *Ilex opaca* **American Holly** | 5 to 9 | 30' x 20' | 1 2 **3 4 5 6** | Does not handle high wind exposure. Several cultivars exist. Male needed for fruit set. | Winter | | Oct-Jan |  |
| *Juniperus virginiana* **Eastern Red Cedar** | 3 to 9 | 40' x 10' | 1 2 3 4 **5 6** | Several varieties of different sizes and hues. Adjusts well to adverse conditions. | | | Sept-Feb |  |
| *Magnolia virginiana* **Sweetbay Magnolia** | 5 to 9 | 30' x 20' | 1 2 **3 4 5** 6 | Semi-evergreen with some fall color. 'Moonglow' and 'Green Mile' are worthy cultivars. | After Blooming | May-Sept | Aug-Sept |  |
| *Malus 'Harvest Gold'* **Harvest Gold Crabapple** | 4 to 8 | 25' x 15' | 1 2 3 **4 5 6** | Disease-resistant, low maintenance crabapple that can be used as a street tree. | Spring | April | Sept-Dec |  |
| *Malus 'Prairie Fire'* **Prairie Fire Crabapple** | 4 to 8 | 20' x 20' | 1 2 3 **4 5 6** | Tolerant of urban conditions and demonstrates good disease resistance. | Spring | April-May | Sept-Dec |  |
| *Malus 'Sugar Tyme'* **Sugar Tyme Crabapple** | 4 to 8 | 20' x 15' | 1 2 3 **4 5 6** | Smaller crabapple with good disease resistance. | Spring | April | Sept-Dec |  |
| *Oxydendrum arborea* **Sourwood** | 5 to 9 | 30' x 15' | 1 2 3 **4 5 6** | Great, year-round ornamental tree best used in non-urban areas. | Late Fall - Early Winter | June-July | Sept-Oct |  |
| *Parrotia persica* **Persian Ironwood** | 4 to 8 | 35' x 25' | 1 2 3 **4 5 6** | Adaptable tree. Not overly showy but worthy features throughout the year. | Spring | Feb-April | |  |
| *Prunus virginiana 'Canada Red'* **Common Chokeberry** | 2 to 6 | 25' x 20' | 1 2 3 **4 5 6** | Only use in colder climates such as higher elevation mountains. | Early Summer | April-May | Aug |  |
| *Viburnum prunifolium* **Blackhaw Viburnum** | 3 to 9 | 20' x 15' | 1 2 3 **4 5 6** | Include more than one shrub for better fruiting. Best in more natural areas. | Summer (after blooming) | May | Sept-Nov |  |

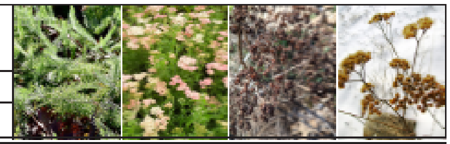
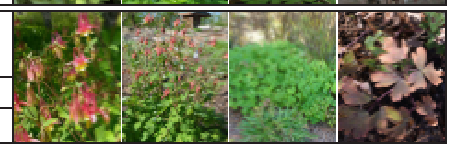
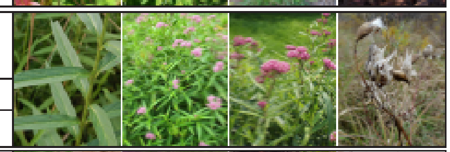
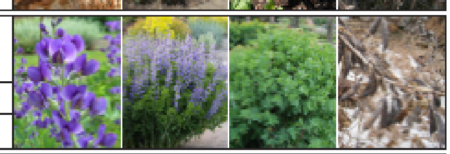
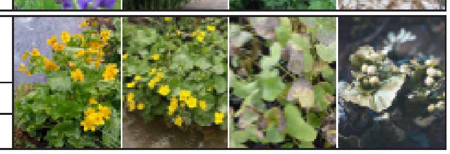
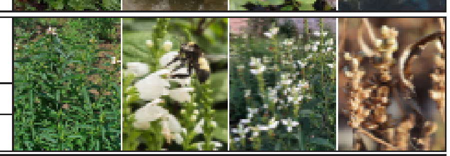
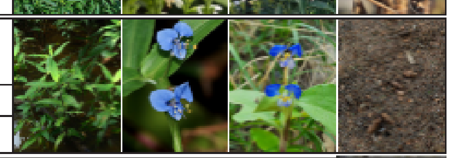
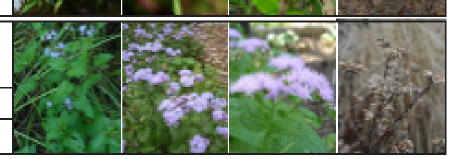
## G.3.3 Shrubs

| Plant | Zones | Size | Spacing | | Notes | Pruning | Bloom | Fruit | Photos |
|---|---|---|---|---|---|---|---|---|---|
| *Aronia arbutifolia 'Brilliantissima'* **Brilliant Red Chokeberry** | 4 to 9 | 6' x 5' | 4'-0" o.c. | 1 2 **3 4 5** 6 | Bested used in masses in soils with good moisture. Can become aggressive. | Summer (after blooming) | May | Sept-Nov |  |
| *Aronia melanocarpa 'Morton'* **Iroquois Beauty Chokeberry** | 3 to 9 | 3' x 5' | 4'-0" o.c. | 1 2 **3 4 5 6** | The cultivar 'Low Scape Mound' (2' x 2') can be used as a groundcover. | Summer (after blooming) | May-June | Aug-Sept |  |
| *Callicarpa americana* **American Beautyberry** | 6 to 10 | 6' x 5' | 4'-0" o.c. | 1 2 **3 4 5** 6 | More natural looking shrub. Does best with consistent soil moisture. | Winter | June-Aug | Aug-Nov |  |
| *Ceanothus americanus* **New Jersey Tea** | 4 to 8 | 3' x 4' | 3'-0" o.c. | 1 2 3 **4 5 6** | Can grow in difficult areas, particularly dry sites. | Late Winter - Early Spring | May-June | June-July |  |
| *Cephalanthus occidentalis* **Buttonbush** | 5 to 10 | 8' x 6' | 5'-0" o.c. | 1 **2 3 4 5** 6 | Best used in wet areas. The cultivar 'Sugar Shack' is more compact (4' x 4') and tidy. | Early Spring | June-Aug | Aug-Sept |  |
| *Clethra alnifolia* **Pepperbush** | 4 to 9 | 6' x 5' | 4'-0" o.c. | 1 2 **3 4 5** 6 | Fruit capsule provides winter interest. 'Hummingbird' is a more compact variety. | Winter | July-Aug | Sept-Oct |  |
| *Cornus amomum* **Silky Dogwood** | 5 to 8 | 8' x 8' | 6'-0" o.c. | 1 2 **3 4 5** 6 | Adaptable large shrub that is more suitable for naturalized areas. | Late Winter - Early Spring | May-June | Aug-Sept |  |
| *Cornus racemosa 'Muszam'* **Muskingum Grey Dogwood** | 4 to 8 | 3' x 5' | 4'-0" o.c. | 1 2 **3 4 5 6** | Tolerates various growing conditions. Effective as a groundcover. | Late Winter - Early Spring | May-June | Aug-Sept |  |
| *Cornus sericea 'Farrow'* **Arctic Fire Dogwood** | 2 to 7 | 5' x 5' | 4'-0" o.c. | 1 **2 3 4 5** 6 | Doesn't tolerate heat and humidity. Only use in cooler areas. | Late Winter - Early Spring | May-June | Aug-Sept |  |
| *Fothergilla gardenii* **Dwarf Fothergilla** | 5 to 8 | 3' x 4' | 3'-0" o.c. | 1 2 **3 4 5** 6 | Does best protected from afternoon shade. Reliable performance. | Summer (after blooming) | April-May | |  |
| *Hypericum prolificum* **Shrubby St. John's Wort** | 4 to 8 | 4' x 4' | 3'-0" o.c. | 1 2 3 **4 5 6** | Several varieties exist. Can handle some moisture but not overly saturated areas. | Late Winter - Early Spring | June-Aug | Aug-Feb |  |
| *Ilex glabra 'Shamrock'* **Dwarf Inkberry** | 4 to 10 | 5' x 5' | 4'-0" o.c. | 1 2 **3 4 5** 6 | Alternate cultivars include the 'Compacta' or 'Nigra' cultivar. | Late Winter | May-June | Sept-May |  |

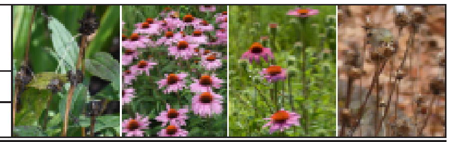
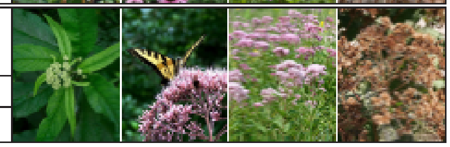
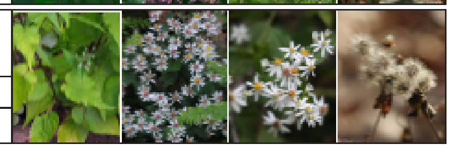
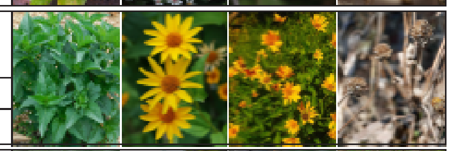
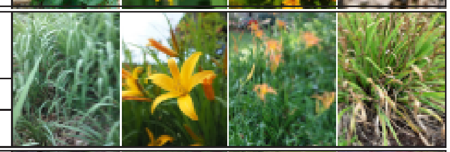
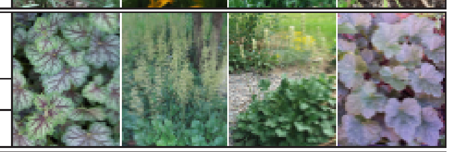
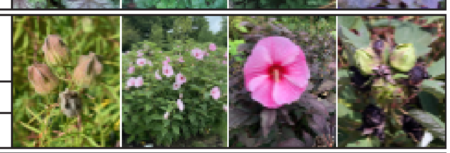
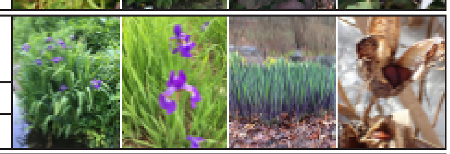
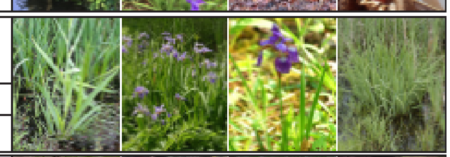
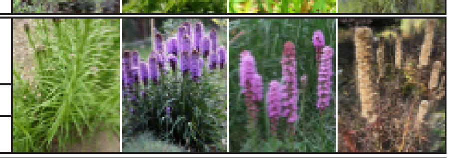
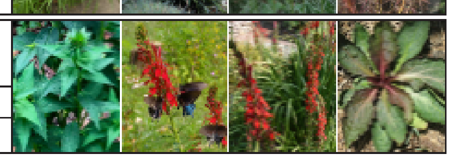
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Ilex verticillata 'Red Sprite'* **Red Sprite Winterberry** | 3 to 9 | 4' x 4' | 3'-0" o.c. | 1 **2 3 4 5** 6 | Use cultivar 'Jim Dandy' as pollinator. Plant 1 male for every 5-8 (max) females. | Early Spring | April-June | Aug-Dec |  |
| *Ilex vomitoria 'Nana'* **Dwarf Yaupon Holly** | 7 to 10 | 5' x 5' | 4'-0" o.c. | 1 2 **3 4 5 6** | Great for borders and hedges. Can also use cultivars 'Taylor's Rudolph' or 'Stokes Dwarf.' | Late Winter | | Oct-March |  |
| *Itea virginica* **Virginia Sweetspire** | 5 to 9 | 5' x 4' | 3'-0" o.c. | 1 2 **3 4 5 6** | Highly adaptable and versatile with several seasons of interest. Several cultivars exist. | Summer (after blooming) | May-June | Aug-Oct |  |
| *Kalmia latifolia* **Mountain Laurel** | 4 to 9 | 10' x 8' | 6'-0" o.c. | 1 2 3 **4 5 6** | Provide ideal conditions for best growth. Several cultivars with various flower colors. | Summer (after blooming) | May-June | Sept-Oct |  |
| *Leucothoe axillaris* **Doghobble** | 6 to 9 | 4' x 5' | 4'-0" o.c. | 1 2 **3 4 5** 6 | Low-growing evergreen shrub. Provide ideal conditions for best growth. | Late Spring (after blooming) | March-May | Sept-Oct |  |
| *Lindera benzoin* **Spicebush** | 4 to 9 | 8' x 8' | 6'-0" o.c. | 1 2 **3 4 5 6** | Good multi-seasonal shrub for rain gardens. Can be difficult to transplant and establish. | Late Spring (after blooming) | March-April | Aug-Sept |  |
| *Lyonia lucida* **Fetterbush** | 7 to 9 | 4' x 4' | 3'-0" o.c. | 1 2 **3 4** 5 6 | Only use in warmer zones. Can form thickets so best in more naturalized applications. | Late Winter - Early Spring | April-June | Sept-Oct |  |
| *Myrica cerifera* **Wax Myrtle** | 7 to 11 | 15' x 10' | 8'-0" o.c. | 1 **2 3 4 5 6** | Highly adaptable and resilient evergreen. Use instead of M. pensylvanica in warm zones. | Late Winter - Early Summer | April | Aug-Oct |  |
| *Myrica pensylvanica 'Morton'* **Morton Northern Bayberry** | 3 to 7 | 5' x 6' | 5'-0" o.c. | 1 **2 3 4 5 6** | Highly adaptable evergreen shrub. Use 1 male ('Morton Male') for every 5 (max) females. | Late Winter - Early Summer | | Sept-March |  |
| *Physocarpus opulifolius* **Ninebark** | 2 to 7 | 6' x 8' | 6'-0" o.c. | 1 2 **3 4 5 6** | Various cultivars exist (including dwarf) with different colored foliage and flowers. | Late Winter | May-July | July-Sept |  |
| *Rhododendron catawbiense* **Catawba Rhododendron** | 4 to 8 | 8' x 6' | 6'-0" o.c. | 1 2 3 **4 5 6** | Evergreen. Ensure adequate moisture in full sun. Protect from afternoon sun. | Summer (after blooming) | April-June | July-Oct |  |
| *Rhus aromatica 'Gro-Low'* **Gro-Low Fragrant Sumac** | 3 to 9 | 2' x 6' | 4'-0" o.c. | 1 2 3 **4 5 6** | Fast growing, low maintenance groundcover with multi-seasonal interest. | Early Winter | March-April | Aug-Sept |  |

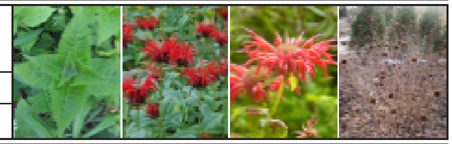
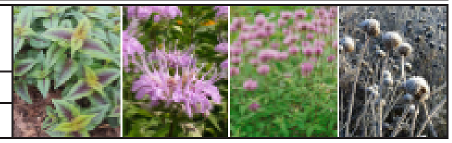
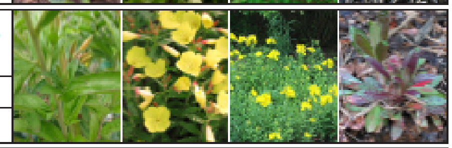
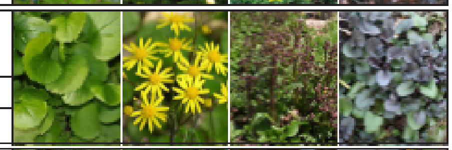
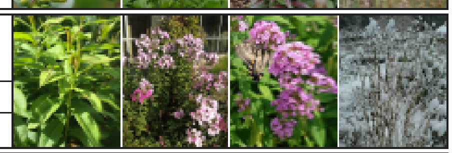
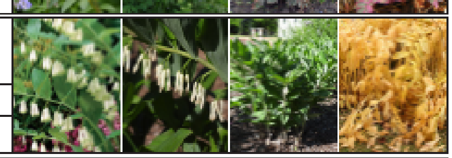
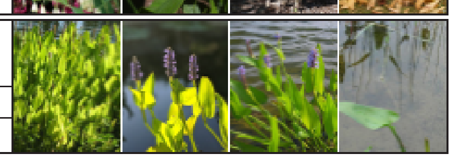
| Plant | Hardiness Zone | Size | Spacing | Zones | Notes | Pruning | Bloom | Fruit | Photos |
|---|---|---|---|---|---|---|---|---|---|
| *Rosa palustris* **Swamp Rose** | 4 to 9 | 5' x 5' | 4'-0" o.c. | 1 **2 3 4** 5 6 | Flowers best in full sun. Better disease resistance than hybrid roses. | Late Winter | June-Aug | Sept-Oct |  |
| *Sambucus canadensis* **Elderberry** | 4 to 9 | 8' x 8' | 6'-0" o.c. | 1 2 **3 4** 5 6 | Root suckering plant that may become aggressive and expand. | Late Winter - Early Spring | June | Aug-Sept |  |
| *Vaccinium corymbosum* **Highbush Blueberry** | 3 to 7 | 8' x 8' | 6'-0" o.c. | 1 2 **3 4 5 6** | Adaptable to different growing conditions. Use multiple varieties to encourage better fruiting. | Late Winter - Early Spring | March-May | July-Aug |  |
| *Viburnum dentatum* **Arrowwood Viburnum** | 3 to 8 | 6' x 6' | 4'-0" o.c. | 1 2 3 **4 5 6** | Durable and reliable with seasonal interest. Smaller cultivars available. | Summer (after blooming) | May-June | Sept-Oct |  |
| *Viburnum nudum* **Possomhaw Viburnum** | 5 to 9 | 8' x 5' | 4'-0" o.c. | 1 2 **3 4** 5 6 | Plant in masses for better pollination and fruit display. | Summer (after blooming) | April-May | Aug-Oct |  |

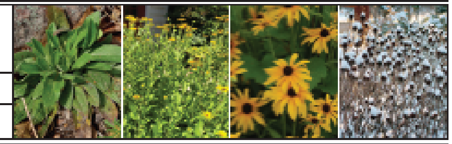
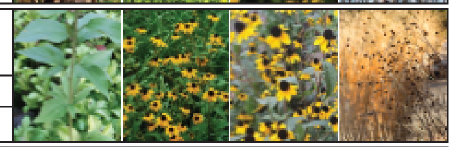
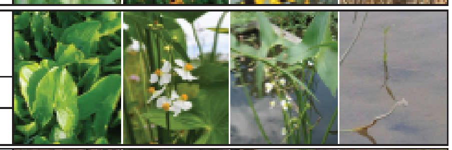
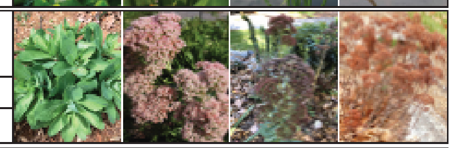
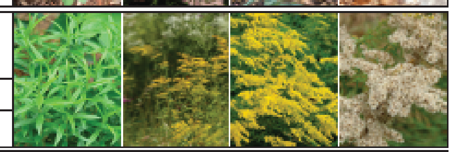
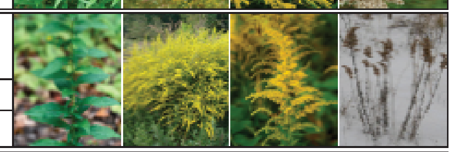
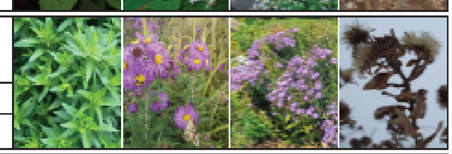
## G.3.4 Flowering Perennials

| Plant | Zones | Size | Spacing | Zones | Notes | Seasonal interest | Bloom | Photos |
|---|---|---|---|---|---|---|---|---|
| *Achillea millefolium* **Common Yarrow** | 3 to 9 | 2' x 2' | 24" o.c. | 1 2 3 **4 5 6** | Various colors available; 'Moon-shine' (yellow), 'Paprika' (red), 'Terra Cotta' (orange). | Summer (rebloom) | June-Sept |  |
| *Agastache spp.* **Giant Hyssop** | 5 to 10 | 3' x 2' | 36" o.c. | 1 2 3 4 **5 6** | Various colors available; Purple/ Lavender, Red/Burgundy, White, Pink, Blue | | June-Sept |  |
| *Amsonia tabernaemontana* **Bluestar** | 3 to 9 | 2' x 2' | 18" o.c. | 1 2 **3 4 5 6** | May require staking if grown in shade or rich soil. Prune after flowering to promote bushy growth. | Summer | April-May |  |
| *Anemone virginiana* **Thimbleweed** | 3 to 8 | 3' x 1' | 12" o.c. | 1 2 3 4 **5 6** | Poisonous if eaten in large quantities. Contact dermititis caused by the plant's fresh sap. | Fall | April-June |  |
| *Aquilegia canadensis* **Wild Columbine** | 3 to 8 | 2' x 1' | 12" o.c. | 1 2 3 **4 5 6** | Additional plant notes | Spring (rebloom) | April-May |  |
| *Asclepias incarnata* **Swamp Milkweed** | 3 to 9 | 4' x 2' | 12" o.c. | 1 **2 3 4** 5 6 | Pink or white blooms attractive to pollinators, particularly butterflies. | | July-Aug |  |
| *Asclepias tuberosa* **Butterfly Milkweed** | 3 to 9 | 2' x 1' | 36" o.c. | 1 2 3 4 **5 6** | Likely to attract aphids, though they do not typically harm the plant. | | June-Aug |  |
| *Baptisia australis* **Blue Wild Indigo** | 3 to 9 | 3' x 3' | 36" o.c. | 1 2 3 4 **5 6** | Grows in tall clumps, though tends to droop when planted in shadier areas. | Spring (rebloom) | May-June |  |
| *Caltha palustris* **Marsh Marigold** | 3 to 7 | 2' x 1' | 18" o.c. | 1 **2 3** 4 5 6 | Low-growing and quick spreading, with yellow blooms and shiny dark green leaves. | | April-June |  |
| *Chelone glabra* **White Turtlehead** | 3 to 8 | 2' x 2' | 24" o.c. | 1 **2 3** 4 5 6 | Flowers form a tight cluster of white blooms. | | Aug-Oct |  |
| *Commelina latifolium* **Virginia Dayflower** | 5 to 8 | 2' x 6' | 48" o.c. | 1 **2 3 4** 5 6 | Spreads low to the ground and has small blue, white, or yellow blooms. | | July-Sept |  |
| *Conoclinium coelestinum* **Blue Mistflower** | 5 to 10 | 2' x 2' | 24" o.c. | 1 **2 3** 4 5 6 | Cut back taller plants in the spring to prevent flopping. | Spring | Aug-Oct |  |

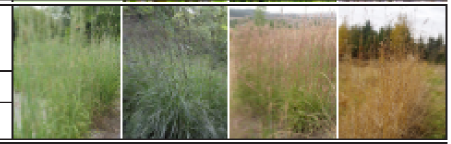
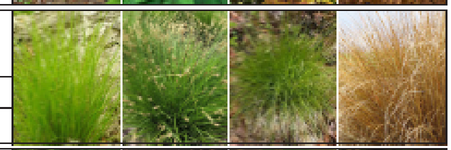
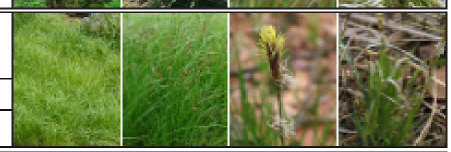
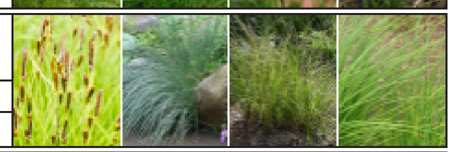
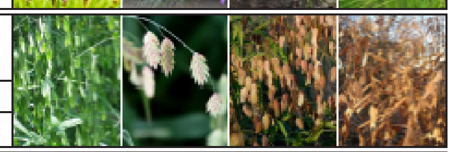
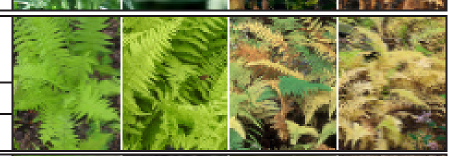
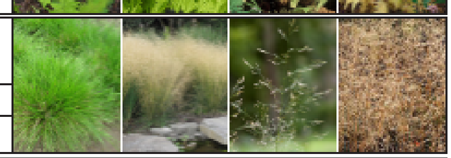
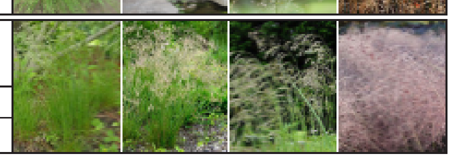
| Plant | Hardiness | Size | Spacing | | Notes | Cut back | Bloom |
|---|---|---|---|---|---|---|---|
| *Coreopsis lanceolata* **Lanceleaf Tickseed** | 4 to 9 | 2' x 2' | 18" o.c. | 1 2 3 **4 5 6** | Deadhead to extend blooming period. | Summer | May-July |
| *Echinacea purpurea* **Purple Coneflower** | 3 to 8 | 3' x 2' | 18" o.c. | 1 2 3 **4 5 6** | Deadhead to extend blooming period. | Summer | June-Aug |
| *Eupatoriadelphus fistulosus* **Joe Pye Weed** | 4 to 8 | 6' x 3' | 36" o.c. | 1 2 3 **4 5 6** | Cut back in early spring to promote bushier growth. | Spring | June-Aug |
| *Eurybia divaricata* **White Wood Aster** | 3 to 8 | 2' x 1' | 18" o.c. | 1 2 3 **4 5 6** | Cut back to 6" in early spring to promote dense growth. | Early Spring | June-Aug |
| *Heliopsis helianthoides* **Heliopsis helianthoides** | 3 to 9 | 4' x 2' | 24" o.c. | 1 2 3 **4 5 6** | Additional plant notes | Summer | June-Aug |
| *Hemerocallis spp.* **Daylily** | 3 to 9 | 2' x 1' | 12" o.c. | 1 2 3 **4 5 6** | Deadheading optional. | | June-July |
| *Heuchera americana* **Alumroot** | 4 to 9 | 2' x 1' | 12" o.c. | 1 2 3 **4 5 6** | Produces tall thin stalks with delicate clustered white blooms. | | June-Aug |
| *Hibiscus moscheutos* **Rosemallow** | 4 to 9 | 5' x 3' | 24" o.c. | 1 2 **3 4 5** 6 | Prune stems in late spring for a bushier growth. | Spring | July-Sept |
| *Iris versicolor* **Blue Flag Iris** | 3 to 9 | 2' x 2' | 18" o.c. | 1 **2 3** 4 5 6 | Thrives in 2"- 4" of standing water with acidic soil high in organic matter. | | May-June |
| *Iris virginica* **Southern Blue Flag Iris** | 5 to 9 | 2' x 1' | 12" o.c. | 1 **2 3** 4 5 6 | Best grown in wet, boggy, acidic, sandy soils in full sun. | | June |
| *Liatris spicata* **Blazing Star** | 3 to 8 | 4' x 1' | 12" o.c. | 1 2 **3 4 5** 6 | Purple-pink flowers bloom in dense clusters atop a tall stalk. | | July-Aug |
| *Lobelia cardinalis* **Cardinal Flower** | 3 to 9 | 4' x 1' | 18" o.c. | 1 2 **3 4 5** 6 | More tolerant of low moisture soil when planted in partial shade. Full moisture in full sun. | | July-Sept |

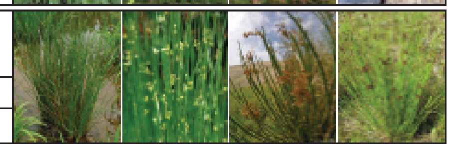
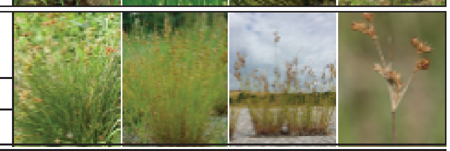
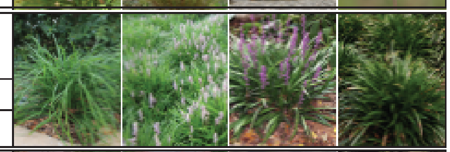
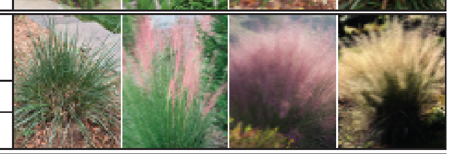
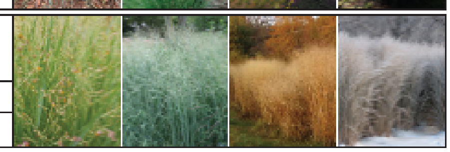
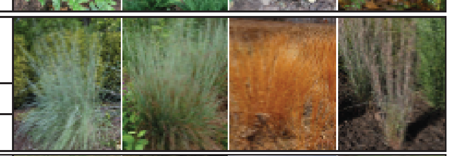
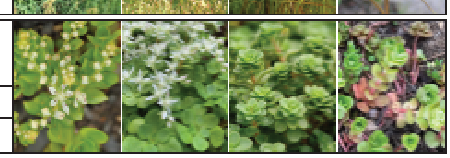













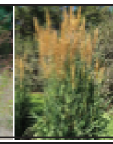
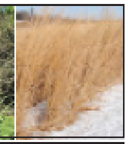
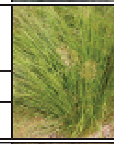
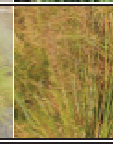
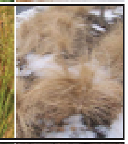
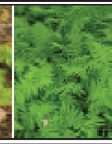
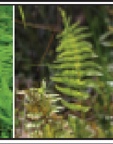
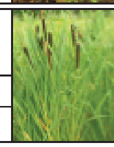
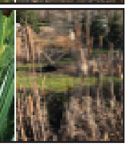
| Plant | Zones | Size | Spacing | Planting Zones | Notes | Season | Bloom | Photos |
|---|---|---|---|---|---|---|---|---|
| *Mimulus ringens* **Monkeyflower** | 3 to 8 | 2' x 1' | 12" o.c. | 1 2 **3 4 5** 6 | Typically found in wet meadows, along streambanks, ponds, and in low woods. | | June-Sept |  |
| *Monarda didyma* **Bee Balm** | 4 to 9 | 3' x 3' | 36" o.c. | 1 2 3 **4 5 6** | Grows vigorously. Should be surrounded with strong-rooted perennials. | | July-Aug |  |
| *Monarda fistulosa* **Wild Bergamot** | 3 to 9 | 3' x 2' | 18" o.c. | 1 2 3 4 **5 6** | Known for its ability to tolerate both wet and dry conditions. | | June-Sept |  |
| *Oenothera fruticosa* **Sundrops** | 4 to 8 | 1' x 2' | 18" o.c. | 1 2 3 4 **5 6** | Evergreen basal rosette becomes green-red during winter. | Summer | July-Sept |  |
| *Packera aurea* **Golden Ragwort** | 3 to 8 | 2' x 2' | 18" o.c. | 1 2 **3 4 5** 6 | Naturalizes into large colonies and has evergreen basal foliage. | Spring | April |  |
| *Peltandra virginica* **Arrow Arum** | 5 to 9 | 2' x 2' | 18" o.c. | 1 **2 3** 4 5 6 | Only use in wet or inundated areas. | | April-June |  |
| *Penstemon digitalis* **Foxglove** | 3 to 8 | 3' x 1' | 18" o.c. | 1 2 3 **4 5 6** | Tolerant of occassional drought and inundation once established. | | April-June |  |
| *Phlox paniculata* **Garden Phlox** | 4 to 8 | 3' x 3' | 18" o.c. | 1 2 3 **4 5** 6 | Cut to ground to reduce powdery mildew in the following season. | Winter | July-Sept |  |
| *Physostegia virginiana* **Obedient Plant** | 2 to 9 | 3' x 2' | 18" o.c. | 1 2 **3 4 5** 6 | Cut back after flowering to reduce height and spread. | Summer | June-Sept |  |
| *Polemonium reptans* **Jacob's Ladder** | 3 to 8 | 1' x 2' | 18" o.c. | 1 2 3 **4 5** 6 | Prefers moist, humusy soil in partial sun. | | April-June |  |
| *Polygonatum biflorum* **Solomon's Seal** | 3 to 9 | 3' x 1' | 18" o.c. | 1 2 **3 4 5** 6 | Spreads slowly to form colonies in optimal moist, shady conditions. | | April-May |  |
| *Pontederia cordata* **Pickerel Weed** | 3 to 10 | 3' x 2' | 24" o.c. | 1 **2 3** 4 5 6 | Thick rhizomes spread to form large colonies in typical depths of 12" freshwater. | | June-Oct |  |

| Plant | Zone | Size | Spacing | | Light | Notes | Pruning | Bloom | Photos |
|---|---|---|---|---|---|---|---|---|---|
| *Pycnanthemum tenuifolium* Narrow Leaf Mountain Mint | 4 to 8 | 3' x 2' | 24" o.c. | 1 2 3 **4 5 6** | ◐ ○ | Spreads generously by rhizome. Tough soil stabilizer | | July-Sept |  |
| *Rudbeckia hirta* Black-eyed Susan | 3 to 8 | 3' x 2' | 18" o.c. | 1 2 3 **4 5 6** | ◐ ○ | Mingles well with coreopsis, echinacea, and asclepias. | | June-Sept |  |
| *Rudbeckia triloba* Three Lobed Coneflower | 4 to 8 | 3' x 2' | 18" o.c. | 1 2 3 4 **5 6** | ◐ ○ | Deadhead in summer to encourage rebloom. Cut to ground after first frost. | Summer (rebloom) | July-Oct |  |
| *Sagittaria latifolia* Duck Potato | 5 to 10 | 3' x 2' | 24" o.c. | 1 **2 3** 4 5 6 | ◐ ○ | Deadhead to prevent self-seeding. Spreads vigorously. | | July-Sept |  |
| *Sedum 'Autumn Joy'* Autumn Joy Stonecrop | 3 to 10 | 2' x 2' | 24" o.c. | 1 2 3 4 **5 6** | ○ | Pinching in spring can encourage thicker, bushier growth. | | Sept-Oct |  |
| *Solidago odora* Sweet Goldenrod | 4 to 9 | 4' x 2' | 24" o.c. | 1 2 3 **4 5 6** | ◐ ○ | Provides habitat and sustenance for many native pollinators, beetles, and birds. | | Aug-Sept |  |
| *Solidago rugosa* Rough Goldenrod | 4 to 8 | 4' x 2' | 24" o.c. | 1 2 3 **4 5 6** | ◐ ○ | Tough and robust; more tolerant of wet soils than other goldenrods. | | Aug-Oct |  |
| *Symphyotrichum cordifolium* Heart Leaved Aster | 3 to 8 | 3' x 2' | 24" o.c. | 1 2 3 4 **5 6** | ◐ ○ | Pinching back in early summer helps control plant height. | Summer | Aug-Sept |  |
| *Symphyotrichum novae-angliae* New England Aster | 4 to 8 | 4' x 3' | 24" o.c. | 1 2 3 4 **5 6** | ◐ ○ | Pinching back in early summer helps control plant height. | Summer | Aug-Sept |  |
| *Tiarella cordifolia* Foamflower | 3 to 8 | 1' x 2' | 12" o.c. | 1 2 3 **4 5 6** | ● ◐ | Prefers moist, humusy soil. Does not tolerate drought. | | May |  |
| *Verbena hastata* Blue Verbena | 3 to 8 | 4' x 2' | 18" o.c. | 1 2 **3 4 5** 6 | ◐ ○ | Spreads slowly by rhizome or seed. | | July-Sept |  |

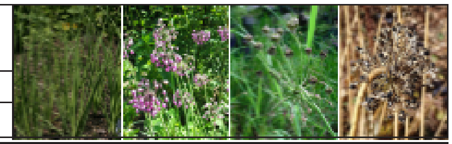
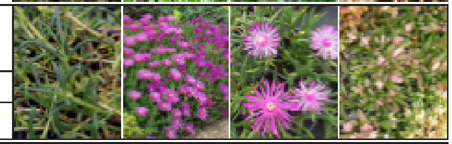
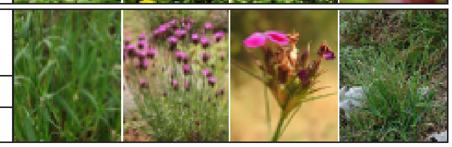
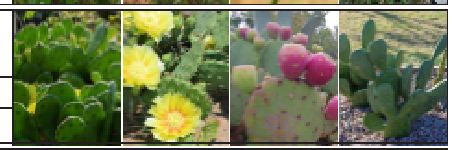
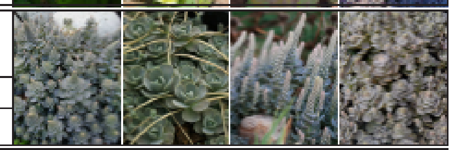
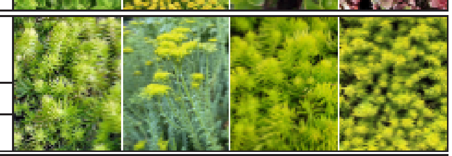
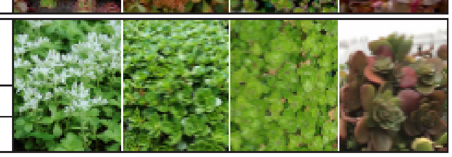
## G.3.5 Grasses and Groundcovers

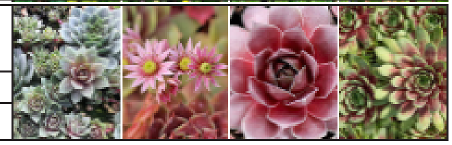
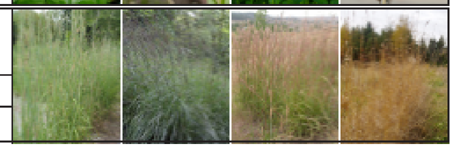
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Acorus calamus* **Sweet Flag** | 3 to 6 | 2' x 2' | 18" o.c. | 1 **2 3** 4 5 6 | Thrives in the wet zone of bioswales and as erosion control species at the edges of ponds. | | |  |
| *Andropogon gerardii* **Big Bluestem** | 4 to 9 | 7' x 3' | 24" o.c. | 1 2 3 **4 5 6** | Cut stems to ground in late winter before new shoots appear. | Late Winter | Sept-Feb |  |
| *Andropogon virginicus* **Broomsedge** | 3 to 9 | 4' x 2' | 18" o.c. | 1 **2 3 4 5 6** | Cut stems to ground in late winter. | Late Winter | Sept-Nov |  |
| *Athyrium aspleniodies* **Southern Ladyfern** | 5 to 9 | 3' x 3' | 24" o.c. | 1 2 3 **4 5 6** | Partners well with hostas and packeras. Nice texture. | | |  |
| *Carex bromoides* **Brome Sedge** | 4 to 8 | 1' x 2' | 18" o.c. | 1 2 **3 4 5** 6 | Prefers moist to wet soils but may not tolerate clay soils. | | May-July |  |
| *Carex cherokeensis* **Cherokee Sedge** | 6 to 9 | 2' x 2' | 12" o.c. | 1 2 **3 4 5** 6 | Native to southeastern US, so best in warmer zones. | Winter | |  |
| *Carex pensylvanica* **Pennsylvania Sedge** | 3 to 8 | 0.5' x 0.5' | 6" o.c. | 1 2 **3 4 5 6** | Typically grows in loose colonies with a creeping habit. Cut to ground in early spring. | Early Spring | |  |
| *Carex stricta* **Tussock Sedge** | 3 to 8 | 2' x 2' | 12" o.c. | 1 2 **3 4 5** 6 | Cut stems to ground in late winter before new shoots appear. | Late Winter | |  |
| *Chasmanthium latifolium* **Northern Sea Oats** | 5 to 8 | 5' x 2' | 12" o.c. | 1 2 **3 4 5 6** | Cut back to basal rosette in early spring. | Early Spring | Aug-Sept |  |
| *Dennstaedtia punctilobula* **Hay Scented Fern** | 3 to 8 | 2' x 4' | 24" o.c. | 1 2 3 **4 5 6** | Tolerates a wide range of soils, including poor rocky soil, and dry soil once established. | | |  |
| *Deschampsia cespitosa* **Tufted Hair Grass** | 4 to 9 | 2' x 2' | 12" o.c. | 1 2 **3 4 5** 6 | Cut back seed stalks in late winter / early spring. | Early Spring | July-Sept |  |
| *Deschampsia flexuosa* **Crinkled Hair Grass** | 3 to 8 | 3' x 2' | 18" o.c. | 1 2 3 **4 5 6** | Cut to ground in late winter. | Late Winter | July-Sept |  |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Dryopteris marginalis*<br>**Marginal Wood Fern** | 4 to 9 | 2' x 3' | 18" o.c. | 1 2 3 **4 5 6** | Fronds remain bluish green year-round. | | |  |
| *Elymus hystrix*<br>**Bottlebrush Grass** | 2 to 9 | 4' x 2' | 18" o.c. | 1 2 3 **4 5 6** | Cut to ground in late winter. | Late Winter | Sept-Oct |  |
| *Eragrostis spectabilis*<br>**Purple Lovegrass** | 5 to 9 | 1' x 1' | 12" o.c. | 1 2 3 **4 5 6** | Widely used grass that can handle tough urban conditions. | | Aug-Oct |  |
| *Juncus effusus*<br>**Soft Rush** | 1 to 11 | 4' x 2' | 18" o.c. | 1 **2 3** 4 5 6 | Thrives in saturated mucky soil or shallow standing water. | | July-Sept |  |
| *Juncus tenuis*<br>**Path Rush** | 2 to 9 | 2' x 1' | 12" o.c. | 1 **2 3** 4 5 6 | Good filler for rain gardens, ground cover, and erosion control. | | May-Sept |  |
| *Liriope muscari*<br>**Big Blue Liriope** | 5 to 10 | 1' x 1' | 12" o.c. | 1 2 3 **4 5 6** | Non-native that can become aggressive. Use sparingly. | | Aug-Sept |  |
| *Muhlenbergia capillaris*<br>**Muhly Grass** | 5 to 9 | 3' x 3' | 24" o.c. | 1 2 3 4 **5 6** | Cut to ground in late winter. | Late Winter | Sept-Nov |  |
| *Panicum virgatum*<br>**Switchgrass** | 5 to 9 | 4' x 3' | 24" o.c. | 1 **2 3 4 5 6** | Undemanding native grass that can be cut to 8" in late winter. Several cultivars exist. | Late Winter | Feb-July |  |
| *Polystichum acrostichoides*<br>**Christmas Fern** | 3 to 9 | 3' x 3' | 18" o.c. | 1 2 3 4 **5 6** | Evergreen fern that provides a nice groundcover in shady areas. | | |  |
| *Schizachyrium scoparium*<br>**Little Bluestem** | 3 to 9 | 4' x 2' | 18" o.c. | 1 2 3 **4 5 6** | Cut to ground in early spring. | Early Spring | Aug-Feb |  |
| *Scirpus cyperinus*<br>**Woolgrass** | 4 to 8 | 5' x 3' | 18" o.c. | 1 **2 3** 4 5 6 | Best used next to ponds and streambeds. Readily self-sows. | | |  |
| *Sedum ternatum*<br>**Stonecrop** | 3 to 9 | 0.5' x 1' | 12" o.c. | 1 2 3 4 **5 6** | Tolerates shade and moist soils better than most sedums. | | May-July |  |

| Plant | Zones | Size | Spacing | Numbers | Notes | Pruning | Bloom | Photos |
|---|---|---|---|---|---|---|---|---|
| *Sorghastrum nutans* **Indiangrass** | 4 to 9 | 6' x 2' | 18" o.c. | 1 2 **3 4** 5 6 | Cut back in late winter. | Late Winter | Feb-Sept |     |
| *Sporobolus heterolepis* **Prairie Dropseed** | 3 to 9 | 3' x 3' | 18" o.c. | 1 2 3 **4 5 6** | Good ground cover for hot, dry areas. | | Aug-Oct |     |
| *Thelypteris palustris* **Marsh Fern** | 3 to 8 | 2' x 3' | 18" o.c. | 1 2 **3 4 5** 6 | Prefers rich, moist soil. Avoid standing water. | | |     |
| *Typha latifolia* **Broadleaf Cattail** | 3 to 9 | 6' x 4' | 24" o.c. | 1 **2 3** 4 5 6 | Can become invasive. | | June-July |     |

## G.3.6 Green Roof Plants

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Allium cernuum* **Nodding Onion** | 4 to 8 | 2' x 1' | 12" o.c. | Creates nice vertical accents for rooftops. Great for tough sites. | May - June | |  |
| *Delosperma cooperi* **Trailing Ice Plant** | 6 to 10 | .25' x 1.5' | 12" o.c. | Can be evergreen in warmer areas. | July - Oct | |  |
| *Delosperma nubigenum* **Hardy Ice Plant** | 6 to 9 | .25' x 1.5' | 12" o.c. | Can be evergreen in warmer areas. | May - June | |  |
| *Dianthus carthusianorum* **Carthusian Pink** | 5 to 9 | 2' x 1' | 12" o.c. | Evergreen. Adds height to rooftop plantings. | June - Aug | |  |
| *Opuntia humifusa* **Eastern Prickly Pear** | 4 to 9 | 1' x 1.5' | 12" o.c. | Has sharp spines and should not be placed near occupiable areas. Interesting texture. | June | Aug-Sept |  |
| *Orostachys boehmer* **Duncecap** | 6 to 10 | .25' x 1' | 9" o.c. | Nice silvery foliage. Mat-forming. | Sept - Oct | |  |
| *Phemeranthus calycinum* **Fame Flower** | 5 to 9 | 1' x .5' | 6" o.c. | Native to the central US. Will reseed and fill in. | Bloom Time | Fruit Time |  |
| *Sedum album* **White Stonecrop** | 3 to 9 | .5' x 1' | 12" o.c. | Highly adaptable and a staple for green roofs. Interesting red winter color. Several cultivars. | June-Aug | |  |
| *Sedum kamtschaticum* **Kamschatka Sedum** | 3 to 9 | .25' x .75' | 9" o.c. | One of the most drought tolerant and durable green roof plants. | June-July | |  |
| *Sedum reflexum* **Blue Spruce Stonecrop** | 4 to 9 | .5' x 1' | 9" o.c. | Mat-forming durable, evergreen. | June-July | |  |
| *Sedum spurium* **Caucasian Stonecrop** | 4 to 8 | .25" x 1' | 12" o.c. | Good spreading habit. Evergreen. Several cultivars with different flower and foliage colors. | July - Sept | |  |
| *Sedum ternatum* **Mountain Stonecrop** | 3 to 9 | .5' x 1' | 9" o.c. | Good green roof plant for more shaded areas. Mat-forming habit. | May-June | |  |

| Plant | Zones | Size | Spacing | | Notes | Bloom | Photos |
|---|---|---|---|---|---|---|---|
| *Sedum tetractinum* **Chinese Stonecrop** | 4 to 8 | .25' x 1' | 9" o.c. | | Establishes itself quickly. Evergreen. | May |  |
| *Sempervivum spp.* **Hen and Chicks** | 3 to 8 | .5' x 1' | 12" o.c. | | Evergreen with several varieties exist with different flower and foliage. | June |  |
| *Mimulus ringens* **Monkeyflower** | 3 to 8 | 2' x 1' | 12" o.c. | 1 2 3 4 5 6 | Typically found in wet meadows, along streambanks, ponds, and in low woods. | June-Sept |  |
| *Andropogon gerardii* **Big Bluestem** | 4 to 9 | 7' x 3' | 24" o.c. | 1 2 3 4 5 6 | Cut stems to ground in late winter before new shoots appear. (Late Winter) | Sept-Feb |  |

## G.4 Additional Resources

The plants listed in the accompanying plant lists are intentionally selected for their beneficial functions and proven performance in stormwater management systems. In addition to the provided appendix, users of this manual are encouraged to use the extensive native plant resources compiled by the Virginia Department of Conservation and Recreation, the Virginia Department of Forestry, The Flora Project of Virginia, and the Virginia Native Plant Society. These additional resources are described in the following sections.

1. **Virginia Department of Conservation and Natural Resources** - The Virginia Department of Conservation and Recreation (DCR) maintains several resources pertaining to physiography, vegetation, native and invasive plant species, pollinators, and natural communities. Note that the Native Plant Finder for Conservation, Restoration, and Landscaping and Virginia Solar Site Native Plant Finder databases will soon be combined into a single database.
    a. **Native Plant Finder for Conservation, Restoration, and Landscaping** - Provides detailed information about plant species and plant families in a searchable online database. https://www.dcr.virginia.gov/natural-heritage/native-plants-finder
    b. **Virginia Solar Site Native Plant Finder** - Assists users in identifying native plant species appropriate for use at solar facilities to match the needs of pollinators and birds. https://www.dcr.virginia.gov/natural-heritage/solar-site-native-plants-finder
    c. **Overview of the Physiology and Vegetation of Virginia** - This PDF is available online and covers topics including climate, geological history, soils, natural history, and contemporary natural communities of Virginia's physiographic provinces. https://www.dcr.virginia.gov/natural-heritage/natural-communities/document/ncoverviewphys-veg.pdf
2. **The Virginia Department of Forestry** - Among its many responsibilities, the Virginia Department of Forestry (DOF) is tasked with preserving and improving water quality through sustainable forest management methods and best practices. The following resources are available on the Virginia DOF website and address aspects of forestry related to stormwater management.
    a. **Stormwater Management** - Discusses the important role of trees in stormwater management systems and provides links to case studies conducted in Lynchburg, Harrisonburg, and Norfolk, VA. https://dof.virginia.gov/urban-community-forestry/urban-forestry-community-assistance/urban- stormwater-management/

b. **Storm Planning and Recovery** - Provides direction and resources for communities responding to extreme weather events and natural disasters. https://dof.virginia.gov/urban-community-forestry/storm-planning-and-recovery/

c. **Seedling Nurseries** - The Virginia DOF grows seedlings of both pine and hardwood tree species. Additional resources provided include planting and identification guides. https://dof.virginia.gov/forest-management-health/seedling-nurseries/

d. **Rain Gardens Technical Guide** - This guide is freely available online and includes detailed instructions for homeowners, gardeners, landowners, and landscape architects on the planning and development of rain gardens. Rain gardens provide an attractive solution for water quality problems and drainage and erosion concerns. https://dof.virginia.gov/water-quality-protection/water-quality-protection-landowner- assistance/stormwater-management-for-landowners/

3. **The Flora Project of Virginia** - The Flora Project of Virginia is a non-profit organization established in 2001 with the purpose of producing a modern Flora Virginica reference text in honor of the original text published by John Clayton in 1739. The book was published in 2012 and includes 3,200 taxa in 200 families and features 1,400 botanical illustrations. Additionally, the organization developed and maintains the Flora App, which is available for purchase and download.

4. **Virginia Native Plant Society** - The Virginia Native Plant Society and its chapters seek to further the appreciation and conservation of Virginia's native plants and habitats. It maintains a Native Plant Site Registry of natural areas containing exemplary plant communities. The society also provides a variety of information on native plant species, including growing advice, plant guides, native plant nurseries, and conservation resources.

## G.5 References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Virginia Department of Environmental Quality (VDEQ). 2011. Stormwater Design Specification, Appendix E, Landscaping, Version 1.0. Available online at: https://swbmpvwrrc.wp.prod.es.cloud.vt.edu/wp-content/uploads/2017/11/Introduction_App-E_Landscaping_03012011.pdf

VDEQ and DCR. 2017. Frequently Asked Questions (FAQ) Native vs. Invasive Plant Species for Erosion & Sediment Control. April. Available online at: https://www.deq.virginia.gov/home/showpublisheddocument?id=2466.

# APPENDIX H CONSTRUCTION AND MAINTENANCE CHECKLISTS

**Contents:**



## H.1 BMP Checklists

Appendix H provides examples of checklists for conducting maintenance for Post-Construction BMPs. Designers, planners, engineers, or owners should maintain their BMPs to meet the specifications of BMPs or the conditions in their maintenance agreements (see 10.2 Inspection and Maintenance Requirements for more information).

# BMP CHECKLISTS

**FACILITY ID:** ______________________

**DATE:** ___/_____/___

**ASSESSED BY:**

**NAME:** ______________________________________

**ADDRESS:** ______________________________________

**PHOTO IDS:** ______________________________________

**HANDHELD/ GPS ID:**

## SECTION 1- BACKGROUND INFORMATION (GIS)

**BMP TYPE:**

- ☐ Dry Detention Pond
- ☐ Extended Detention Pond
- ☐ Wet Pond
- ☐ Filter (specify: ____________)
- ☐ Infiltration (specify:____________)
  - ☐ Check if structure is underground
- ☐ Dry Swale
- ☐ Wet Swale
- ☐ Grass Channel
- ☐ Dry Well
- ☐ Permeable Pavement
- ☐ Bioretention
- ☐ Wetland
- ☐ Level Spreader
- ☐ WQ Inlet
- ☐ Proprietary Device
- ☐ Other ____________

**YEAR CONSTRUCTED:** ________

**OWNERSHIP**
☐ Public ☐ Private ☐ Unknown

### SITE CHARACTERIZATION

**DRAINAGE AREA:** _____(acres) **IMPERVIOUS COVER:** _____(acres) Discerned from: ☐ Plan ☐ County Data ☐ GIS ☐ Field

**CONTRIBUTING DRAINAGE AREA** (% land use): *Note – All percentages should sum up to 100%.*

_____Industrial _____Commercial _____Urban/Residential _____Suburban/Res
_____Forested _____Institutional _____Golf course _____Park
_____Crop _____Pasture _____Other: ____________

**WATER QUALITY VOL (FROM DESIGN PLAN):** _____(ft$^3$)

## SECTION 2- FIELD VISIT

Rain in last 48 hrs? ☐ Yes ☐ No

Evidence of high water table (e.g., excessive soil saturation)? ☐ Yes ☐ No

### DESIGN ELEMENTS

**FACILITY SIZE:**
Length: _____(ft)
Width: _____(ft)
Surface Area: _____(ft$^2$)
Depth of WQ storage _____(ft)

**OBSERVED WQ STORAGE VOL:**
_____(ft$^3$)

**HYDRAULIC CONFIGURATION**
☐ On-line Facility
☐ Off-line Facility

**DESIGN STORM(S):**
☐ Water Quality
☐ Flood Control
☐ Channel Protection
☐ Unknown

**BMP SIGNAGE:** (check all that apply)
☐ None ☐ Flood Warning ☐ Stormwater Education ☐ No Trespassing ☐ Wildlife Habitat
☐ Public Property ☐ Do Not Mow ☐ Other: ____________

### OUTLET CHARACTERISTICS

| | |
|---|---|
| **PRIMARY OUTLET STRUCTURE:** | ☐ N/A – infiltration w/ no outlet ☐ Pipe ☐ Riser ☐ Weir ☐ Large Storm Overflow ☐ Open channel ☐ Large Storm By-pass ☐ Other: ________ |
| **OUTLET FEATURES:** | ☐ N/A ☐ Trash Rack ☐ Pond Drain ☐ Inverted outlet pipe ☐ Hooded outlet ☐ Anti-vortex device ☐ Perforated pipe ☐ Gravel Diaphragm ☐ Micropool outlet ☐ Multiple outlet levels<br>*Outlet includes restrictor?* ☐ Yes ☐ No |
| **OUTLET STRUCTURE CONDITIONS:** | Erosion at Outlet: ☐None ☐Slight ☐Moderate ☐Severe<br>Outlet Clogging: ☐None ☐Slight ☐Moderate ☐Severe<br>Structural Problems: ☐None ☐Slight ☐Moderate ☐Severe |
| **CONDITIONS AT OUTFALL:** | ☐ Stream ☐ Closed storm sewer ☐ Surface channel ☐ Road ditch ☐ Other: ________ ☐Unknown |

Active Erosion: ☐None ☐Slight ☐Moderate ☐Severe
Trash: ☐None ☐Slight ☐Moderate ☐Severe
Sedimentation: ☐None ☐Slight ☐Moderate ☐Severe

Odor: ☐None ☐Slight ☐Moderate ☐Severe
Algae: ☐None ☐Slight ☐Moderate ☐Severe
Other WQ Problems: ☐None ☐Slight ☐Moderate ☐Severe

Emergency Spillway Type: ☐ Channel ☐ Riser Overflow ☐ Weir ☐ Other: ________

## BMP CHECKLISTS

### Soil or Filter Media

**Type of Filter/Infiltration Media:** (check all that apply)
☐ Soil mix ________(in) ☐ Sand ________(in) ☐ Gravel ________(in) ☐ Large Stone ________(in)
☐ Organic material ________(in) ☐ Other________ ☐ N/A ☐ Unknown
Avg. depth of sediment build-up on surface?______(in)

**Soil Media Sample:** *Note – Complete during site investigation, if applicable*
Dominant Soil Type ☐ Clay ☐ Loam ☐ Sand ☐ Sand/Loam
Is the soil homogenous? ☐ Yes ☐ No

Comments:

### Vegetation

**General Observations:**
☐ Landscaped
☐ Aquatic Bench
☐ Invasive Species
☐ Plant Diversity

**Type of ground cover** (% of Surface Area in Plan View up to low Outlet):
*Note – All percentages should sum up to 100 %.*
_____Trees _____Grasses/Perennials _____Ponded water _____Other: _____
_____ Managed Turf _____ Bare Soil _____Shrubs _____N/A
_____ Gravel/stone _____ Mulch _____ Emergent wetland

Depth of mulch, if present: ☐ Hardwood _____(in) ☐ Pine Straw _____ (in) ☐ Other________ (in)
Rate degree of shading of BMP Surface Area by trees: ☐ Well Shaded ☐ Some Shading ☐ No Shading ☐ N/A

### Inlet Characteristics

**Inlet #1:**
Diameter/Width:
_____(in)

**Type of Inlet:** ☐ Open Channel ☐ Closed Pipe
☐ Sheet Flow ☐ Curb Cut ☐ Other: __________

Elevation difference between bottom of inlet and BMP surface:
_____ (in)

**Inlet Submersion:**
☐ Complete
☐ Partial
☐ None

**Inlet Conditions:**
Inlet Erosion ☐None ☐Slight ☐Moderate ☐Severe
Inlet Clogging ☐None ☐Slight ☐Moderate ☐Severe
Structural Problems ☐None ☐Slight ☐Moderate ☐Severe

Comments:

**Inlet #2:**
Diameter/Width:
_____(in)

**Type of Inlet:** ☐ Open Channel ☐ Closed Pipe
☐ Sheet Flow ☐ Curb Cut ☐ Other: __________

Elevation difference between bottom of inlet and BMP surface:
_____ (in)

**Inlet Submersion:**
☐ Complete
☐ Partial
☐ None

**Inlet Conditions:**
Inlet Erosion ☐None ☐Slight ☐Moderate ☐Severe
Inlet Clogging ☐None ☐Slight ☐Moderate ☐Severe
Structural Problems ☐None ☐Slight ☐Moderate ☐Severe

Comments:

### Pretreatment

**Type of Pretreatment** *(check all that apply)*
☐ None ☐ Grass Filter Strip
☐ Sediment Forebay (_____ $ft^3$) ☐ Plunge Pool?
☐ Grass Channel ☐ Stone Diaphragm
☐ Riprap Channel or Apron ☐ Other: __________

**Pretreatment Function** ☐ By design ☐ Incidental
Is pretreatment functioning? ☐ Yes ☐ No
Is sediment removal necessary? ☐ Yes ☐ No
Signs of pretreatment bypass? ☐ Yes ☐ No
Signs of flow of sediment from pretreatment to BMP? ☐ Yes ☐ No
Severity: ☐ Slight ☐Moderate ☐Severe

### General Design

**BMP Features** (check all that apply)
☐ Maintenance Access ☐ Underdrain
☐ Fence ☐ Clean Out ☐ Pond Drain
☐ Multi-cell ☐ Observation Well ☐ Other:____________
☐ Micropool Is water present in observation well?
☐ Impermeable Liner ☐ Yes ☐ No Depth:______ ft

**Conveyance Through BMP**
☐ No Defined Channel
☐ Low Flow Channel
☐ Concrete ☐ Eroded ☐ Earthen ☐ Other __________
Length of Shortest Flow Path: _________(ft)

Is BMP designed with a Permanent Pool? ☐ Yes ☐ No

# BMP CHECKLISTS

## Performance

**General Problems:** (check all that apply)

- ☐ Maintenance Needed
- ☐ Water Bypass of Inlet
- ☐ Water Bypass of Outlet
- ☐ Incorrect Flow Paths
- ☐ Short-circuiting of treatment mechanism
- ☐ No or ineffective treatment
- ☐ Ineffective pretreatment
- ☐ Others
- ☐ Erosion at Embankments
- ☐ Erosion within Facility
- ☐ Deposition within Facility
- ☐ Inappropriate Ponding of Water
- ☐ Clogged Pond Drain/Underdrain
- ☐ Clogged Media
- ☐ Inappropriate media material
- ☐ Inappropriate underlying soil (infiltration)
- ☐ Permanent Pools not stable
- ☐ Inadequate vegetation
- ☐ Dead or Diseased Vegetation
- ☐ Too many invasive plants
- ☐ Trees on Embankment
- ☐ Failing structural components
- ☐ Safety issue (Note:________________)

**Water Quality in Facility:** ☐N/A

| | | | | |
|---|---|---|---|---|
| Algae | ☐None | ☐Slight | ☐Moderate | ☐Severe |
| Odor | ☐None | ☐Slight | ☐Moderate | ☐Severe |
| Turbidity | ☐None | ☐Slight | ☐Moderate | ☐Severe |
| Color | ☐Normal | ☐Abnormal: __________ | | |

**Evidence of:**

- ☐ Geese
- ☐ Animal Burrows
- ☐ Mosquitoes
- ☐ BMP Alteration

| Problem | | 1=None | 2 - Few | 3 – Several | 4-Severe |
|---|---|---|---|---|---|
| Trash | | No evidence of trash | A few pieces of trash throughout BMP | Trash accumulation near inlet/outlet | Lots of trash in BMP or BMP used for storage |
| BMP Bank Erosion | | No noticeable erosion | Slight erosion < 5% of bank affected | Moderate erosion ~15% of bank affected | Banks severely eroded, >25% of bank affected |
| Sediment Deposition | | No sediment deposition | Areas of minor sediment deposition | Areas of some deposition, may be severe near inlet/outlets | Lots of deposition resulting in pond bottom clogging |
| Surface Slope | | 0-1% BMP surface slope | 1-3% BMP surface slope or steeper slopes with check dams. | 3-5% BMP surface slope with no check dams. | >5% surface slope; |
| Side Slopes | | BMP side slopes 3:1 or flatter | BMP side slopes 2:1 | Steep BMP side slopes | Risk of side slope failure |
| Structural | | No evidence of structural damage | Minor problems (e.g., bank slump, eroded channels) | Moderate structural problems –failure pending | Structural failures (e.g., bank failure, blowout) |
| Visibility | | High visibility, near high-traffic areas | Some visibility, near traffic areas | Limited visibility, near low traffic areas | No visibility, behind buildings or fences |
| Accessibility | | Maintained access area for vehicles | Access area designated, but not maintained | Access for vehicles not designated | Access for vehicles not possible |
| Veg Cover | | No mowing in/around BMP | Mowing along BMP edges but areas of no mow in BMP bottom | Mowed turf vegetation | BMP bottom has large areas of bare soil |
| | | Dense plant cover (>75%) | Plant cover, 50-75% | Some plant cover, 25-50% | Sparse vegetative cover (<25%). |
| Veg Health | Trees | Healthy and established | Slightly stressed | Stressed | Dead |
| | Ground Cover | Healthy and established | Slightly stressed | Stressed | Dead |
| | Shrubs | Healthy and established | Slightly stressed | Stressed | Dead |
| | Emergent Wetland | Healthy and established | Slightly stressed | Stressed | Dead |

**Overall Performance Score** (circle one number)

| Excellent design and function, no general problems with performance | | BMP is well designed, but is undersized or has a few performance problems | | | BMP is adequately designed, several problems with performance are noted | | Poor BMP design, severe performance problems or failure | | |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

## FIELD NOTES

GOOD OR INTERESTING DESIGN FEATURES:

PHOTO #'S:

POOR OR PROBLEMATIC DESIGN FEATURES:

PHOTO #'S:

## SECTION 3 – DESIGN PLAN VERIFICATION

PLAN AVAILABLE: ☐ As-built ☐ Other: _____

Do field observations match design plans/as-builts? Describe any differences.

| | | | | |
|---|---|---|---|---|
| Soil type in facility | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Pretreatment type and size | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Signage | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Low-flow channel | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Dimensions/volume | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Inlet type, #, and sizing | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Outlet type, #, and sizing | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Vegetation composition | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |
| Other features | ☐ N/A | ☐ Yes | ☐ No | If no, describe: |

## P-BAS-01 CONSTRUCTED WETLANDS: O&M CHECKLIST

**Inspection Date**____________
**Project**____________________________ **Site Plan/Permit Number**______________
**Location**____________________________ **Date BMP Placed in Service**______________
**Date of Last Inspection**____________ **Inspector**____________________________
**Owner/Owner's Representative**__________________________________
**As-Built Plans available:** Y / N

**Facility Type:** Level 1 ________________________ Level 2 ________________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Type of wetland
- ☐ Emergent
- ☐ Forested

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Vegetated buffer area
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: __________________

*During the first 6 months following construction, the wetland should be inspected twice after storm events that exceed 1/2 inch of rainfall. Bare or eroding areas in the CDA or around the wetland buffer should be stabilized immediately with grass cover. Trees planted in the buffer and on wetland islands and peninsulas need to be watered every 3 days for the first month, and then weekly during the remainder of the first growing season (April-October), depending on rainfall. Due to typical vegetation survival problems, it is typical to plan and budget for a round of reinforcement planting after one or two growing seasons. Constructed wetlands should be inspected and cleaned up annually. A wetland professional should inspect the facility every 5 years, especially to determine if there is any significant negative change in the wetland species composition from the design or an otherwise healthy wetland.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | Adequate vegetation | | | | Supplement as needed | Owner | |
| | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion and/or bare or exposed soil | | | | Stabilize immediately. | Owner or professional | |
| | There are excessive landscape waste and yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| Pre-Treatment | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion and/or exposed soil. | | | | Immediately identify and correct the cause of the erosion and stabilize the eroded or bare area. | Owner or professional | |
| | Sediment deposits are 50% or more of forebay capacity. | | | | Dredge the sediment to restore the design capacity; sediment should be dredged from forebays at least every 5 years. | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Pre-Treatment (continued)** | The sediment marker is not vertical. | | | | Adjust the sediment depth marker to a vertical alignment | Professional | |
| | There is dead vegetation | | | | Revegetate, as needed | Owner or professional | |
| **Inlets** | The inlet provides a stable conveyance. | | | | Stabilize immediately, as needed; clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion/undercutting at or around the inlet | | | | Repair erosion damage and reseed | Owner or professional | |
| | There is cracking, bulging, erosion or sloughing of the forebay dam. | | | | Repair and restabilize immediately. | Professional | |
| | There is woody growth on the forebay dam. | | | | Remove within 2 weeks of discovery. | Professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed frm area | Professional | |
| **Vegetation** (trees, shrubs, aquatic plants) | Plant composition is consistent with the approved plans | | | | Determine if existing plant materials are at least consistent with the general Constructed Wetland design criteria, and replace inconsistent species. | Professional | |
| | Invasive species are present. | | | | Remove invasive species immediately and replace vegetation as needed. As a general rule, control of undesirable invasive species (e.g., cattail and Phragmites) should commence when their coverage exceeds more than 15% of a wetland cell area. Although the application of herbicides is not recommended, some types, such as Glyphosate, have been used to control cattails with some success. Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. | Professional | |
| | Vegetation is dead or reinforcement planting is needed. | | | | Remove and replace dead or dying vegetation. | Professional | |
| | Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season | | | | Consider watering every 3 days for first month, and then weekly during first year (April – October), depending on rainfall. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Vegetation** (trees, shrubs, aquatic plants) **(continued)** | Practice has become overgrown and is not developing into a mature wetland. | | | | Harvest vegetation periodically if the wetland becomes overgrown or to guide maturing of forested wetlands (typically 5 and 10 years after constr.). | Owner or professional | |
| **Wetland Cells and Pools** | Sediment accumulation is 50% or more of capacity. | | | | Dredge the sediment to restore the design capacity | Professional | |
| | There is evidence of floating debris, sparse vegetative cover, erosion or slumping of side slopes. | | | | Remove debris. Repair and stabilize. | Owner or professional | |
| | Open water is becoming overgrown. | | | | Harvest the unwanted vegetation. | Professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed from the area. | | |
| **Riser/Principle Spillway and Low-Flow Orifice(s)** | There is adequate access to riser for maintenance. | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | Pieces of the riser are deteriorating, misaligned, broken or missing. | | | | Repair immediately. | Professional | |
| | Adjustable control valves are accessible and operational. | | | | Repair, as needed. | Professional | |
| | Reverse-slope pipes and flashboard risers are in good condition. | | | | Repair, as needed. | Professional | |
| | There is excessive trash, debris, or other obstructions in the trash rack. | | | | Remove immediately. | Owner or professional | |
| | Seepage into conduit | | | | Seal the conduit | Professional | |
| **Berm/Dam/ Embankment and Abutments** | There is sparse veg. cover, settlement, cracking, bulging, misalignment, erosion rills deeper than 2 inches, or sloughing of the dam. | | | | Repair and restabilize immediately. | Professional | |
| | There are soft spots, boggy areas, seepage or sinkholes present. | | | | Reinforce, fill and stabilize immediately. | Professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed frm area. | Professional | |
| | There is woody vegetation on the embankment. | | | | Removal of woody species near or on the embankment and maintenance access areas should be done when discovered, but at least every 2 years. | | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Emergency Spillway | There is woody growth on the spillway. | | | | Removal of woody species near or on the emergency spillway should be done when discovered, but at least every 2 years. | Owner or professional | |
| | There is excessive trash, debris, or other obstructions. | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion/back-cutting | | | | Repair erosion damage and reseed | Owner or professional | |
| | There are soft spots, seepage or sinkholes. | | | | Reinforce, fill and stabilize immediately. | Owner or professional | |
| Outlet | The outlet provides stable conveyance from the wetland. | | | | Stabilize as needed. | Professional | |
| | There are excessive sediment deposits. | | | | Remove sediment. | Professional | |
| | Released water is causing undercutting, erosion or displaced rip-rap at or around the outlet | | | | Repair, reinforce or replace rip rap as needed, and restabilize. | Professional | |
| | Woody growth within 5 feet of the outlet pipe barrel. | | | | Prune vegetation back to leave a clear discharge area. | Owner or Professional | |
| | There is excessive trash, debris, or other obstructions. | | | | Remove immediately. | Owner or professional | |
| Overall | Access to the facility or its components is adequate. | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | Water levels in one or more cells are abnormally high or low. | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specifications. | Professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Mosquito proliferation | | | | Eliminate stagnant pools if feasible, and treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. Can also stock the basin with mosquito fish to provide natural mosquito & midge control. | Owner or professional | |
| | Encroachment on the wetland or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall (continued) | Safety signage is not adequate. | | | | Provide sufficient, legible safety signage. | Owner or professional | |

## P-BAS-02 WET PONDS: O&M CHECKLIST

**Inspection Date**____________
**Project**________________________ **Site Plan/Permit Number**____________
**Location**________________________ **Date BMP Placed in Service**____________
**Date of Last Inspection**____________ **Inspector**________________________
**Owner/Owner's Representative**________________________
**As-Built Plans available: Y / N**

**Facility Type:** Level 1 __________________ Level 2 __________________

Pond characteristics and functions (check all that apply)

- ☐ Water quality treatment
- ☐ Extended detention included
- ☐ Channel protection
- ☐ Ties into groundwater
- ☐ Single cell pond
- ☐ Multiple-cell pond system
- ☐ Pond with one or more wetland cells

Hydraulic Configuration:

- ☐ On-line facility
- ☐ Off-line facility

Type of Pre-Treatment Facility:

- ☐ Sediment forebay (above ground)
- ☐ Vegetated buffer area
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: __________________

*During the first 6 months following construction, the pond should be inspected twice after storm events that exceed 1/2 inch of rainfall. The aquatic benches shuld be planted with emergent wetland species, consistent with the Wet Pond design specifications. Bare or eroding areas in the CDA or around the pond buffer should be stabilized immediately with grass cover. Trees planted in the buffer need to be watered every 3 days for the first month, and then weekly during the remainder of the first growing season (April-October), depending on rainfall. Due to typical vegetation survival problems, it is typical to plan and budget for a round of reinforcement planting during the second growing season after construction. Wet Ponds should be inspected and cleaned up annually.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | Adequate vegetation | | | | Supplement as needed | Owner | |
| | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion and/or bare or exposed soil | | | | Stabilize immediately. | Owner or professional | |
| | There are excessive landscape waste and yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| Pre-Treatment | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion and/or exposed soil. | | | | Immediately identify and correct the cause of the erosion and stabilize the eroded or bare area. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Pre-Treatment (continued)** | Sediment deposits are 50% or more of forebay capacity. | | | | Dredge the sediment to restore the design capacity; sediment should be dredged from forebays at least every 5-7 years, and earlier if performance is being affected. | Professional | |
| | The sediment marker is not vertical. | | | | Adjust the sediment depth marker to a vertical alignment | Professional | |
| | There is evidence of clogging | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specifications | Professional | |
| | There is dead vegetation | | | | Revegetate, as needed | Owner or professional | |
| **Inlet** | The inlet provides a stable conveyance into the pond | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion/undercutting at or around the inlet | | | | Repair erosion damage and restabilize | Owner or professional | |
| | There is cracking, bulging, erosion or sloughing of the forebay dam. | | | | Repair and restabilize immediately. | Professional | |
| | There is woody growth on the forebay dam. | | | | Remove within 2 weeks of discovery. | Professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed from the area. | Professional | |
| | There is more than 1 inch of settlement. | | | | Add fill material and compact the soil to the design grade | Owner or Professional | |
| | The inlet alignment is incorrect. | | | | Correct immediately. | Owner or Professional | |
| **Vegetation** | Plant composition is consistent with the approved plans | | | | Determine if existing plant materials are consistent with the general Wet Pond design criteria, and replace inconsistent species. | Professional | |
| | Invasive species are present. | | | | Remove invasive species immediately and replace vegetation as needed. | Professional | |
| | Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season | | | | Consider watering every 3 days for first month, and then weekly during first year (April – October), depending on rainfall. | Owner or professional | |
| | Grass around the facility is overgrown | | | | Mow (at least twice a year) to a height of 4"-9" high and remove grass clippings | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Vegetation (continued)** | Vegetation is dead or reinforcement planting is needed. | | | | Remove and replace dead or dying vegetation. | Professional | |
| **Permanent Pool and Side Slopes** | There is excessive trash and/or debris. | | | | Remove immediately | Owner or professional | |
| | There is evidence of sparse vegetative cover, erosion or slumping side slopes. | | | | Repair and stabilize physical damage, and reseed or plant additional vegetation. | Owner or professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Remove burrowing animals humanely from the area. | | |
| | There is significant sediment accumulation. | | | | Conduct a bathymetric study to determine the impact to design volumes, and dredge if necessary. | Professional | |
| **Riser/Principle Spillway and Low-Flow Orifice(s)** | There is adequate access to the riser for maintenance. | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | Pieces of the riser are deteriorating, misaligned, broken or missing. | | | | Repair immediately. | Professional | |
| | Adjustable control valves are accessible and operational. | | | | Repair, as needed. | Professional | |
| | Reverse-slope pipes and flashboard risers are in good condition. | | | | Repair, as needed. | Professional | |
| | There is evidence of clogging | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specs. | Professional | |
| | Seepage into conduit | | | | Seal the conduit | Professional | |
| | There is excessive trash, debris, or other obstructions in the trash rack. | | | | Remove immediately. | Owner or professional | |
| **Dam/ Embankment and Abutments** | There is sparse veg. cover, settlement, cracking, bulging, misalignment, erosion rills deeper than 2 inches, or sloughing of the dam. | | | | Repair and restabilize immediately, especially after major storms. | Professional | |
| | There are soft spots, seepage, boggy areas or sinkholes present. | | | | Reinforce, fill and stabilize immediately. | | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed frm area. | | |
| | There is woody vegetation on the embankment. | | | | Removal of woody species near or on the embankment and maintenance access areas should be done when discovered, but at least every 2 years. | | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overflow/ Emergency Spillway | There is woody growth on the spillway. | | | | Removal of woody species near or on the emergency spillway should be done when discovered, but at least every 2 years. | Owner or professional | |
| | There is excessive trash, debris, or other obstructions. | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion/backcutting | | | | Repair erosion damage and reseed | Owner or professional | |
| | There are soft spots, seepage or sinkholes. | | | | Reinforce, fill and stabilize immediately. | Owner or professional | |
| | Only one layer of stone armoring exists above the native soil. | | | | Reinforce rip-rap or other armoring materials. | Professional | |
| Outlet | The outlet provides a stable conveyance from the pond. | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is woody growth within 5 feet of the outlet pipe barrel. | | | | Prune vegetation back to leave a clear discharge area. | Owner or Professional | |
| | There is excessive trash, debris, or other obstructions. | | | | Remove immediately. | Owner or professional | |
| | There are excessive sediment deposits at the outlet. | | | | Remove sediment. | Professional | |
| | Discharge is causing undercutting, erosion or displaced rip-rap at or around the outlet. | | | | Repair, reinforce or replace rip rap as needed, and restabilize. | Professional | |
| Overall | Access to the facility or its components is adequate. | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | Fences are inadequate | | | | Collapsed fences must be restored to an upright position. Jagged edges and damaged fences must be repaired or replaced. | Professional | |
| | Water levels in one or more cells are abnormally high or low. | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specifications. | Professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Mosquito proliferation | | | | Eliminate stagnant pools and stock the basin with mosquito fish to provide natural mosquito & midge control. Treat for mosquitoes as needed. If spraying, then use mosquito larvicide, (e.g., Bacillus thurendensis or Altoside formulations) *only if absolutely necessary*. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall (continued) | Encroachment on the pond or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |
| | Safety signage is not adequate. | | | | Provide sufficient, legible safety signage. | Owner or professional | |

## P-BAS-03 EXTENDED DETENTION POND: O&M CHECKLIST

### P-BAS-03 EXTENDED DETENTION PONDS: O&M CHECKLIST

**Inspection Date**____________
**Project**______________________________ **Site Plan/Permit Number**________________
**Location**______________________________ **Date BMP Placed in Service**______________
**Date of Last Inspection**____________ **Inspector**______________________________
**Owner/Owner's Representative**____________________________________________
**As-Built Plans available: Y / N**

**Facility Type:** Level 1 ________________________ Level 2 ________________________

Pond characteristics and functions (check all that apply)
- ☐ Water quality treatment
- ☐ Channel protection
- ☐ Ties into groundwater

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Vegetated buffer area
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: __________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

*Ideally, Extended Detention Ponds should be inspected annually. ED Ponds are prone to a high clogging risk at the ED low-flow orifice. Ideally, the orifice should be inspected at least twice a year after initial construction. The constantly changing water levels in ED Ponds make it difficult to mow or manage vegetative growth. The bottom of ED Ponds often become soggy, and water-loving tees such as willows may invade and will need to be managed. Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer may be managed as a meadow (mowing every other year) or forest. Frequent removal of sediment from the forebay (every 5-7 years, or when 50% of the forebay capacity is filled) is essential to maintain the function and performance of the ED Pond. Sediments excavated from ED Ponds are usually not considered toxic or hazardous, so they can be safely disposed of either by land application of land filling.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | Adequate vegetation | | | | Supplement as needed. | Owner | |
| | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosino and/or bare or exposed soil | | | | Stabilize immediately. | Owner or professional | |
| | There is excessive landscape waste and yard clippings | | | | Remove immediately. | Owner or professional | |
| Pre-Treatment | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion and/or exposed soil. | | | | Immediately identify and correct the cause of the erosion and stabilize the eroded or bare area. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Pre-Treatment (continued) | Sediment deposits are 50% or more of forebay capacity. | | | | Dredge the sediment to restore the design capacity; sediment should be dredged from forebays at least every 5-7 years, and earlier, as needed. | Professional | |
| | The sediment marker is not vertical. | | | | Adjust the sediment depth marker to a vertical alignment | Professional | |
| | There is evidence of clogging | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specifications | Professional | |
| | There is dead vegetation | | | | Revegetate, as needed | Owner or professional | |
| Inlet | The inlet provides a stable conveyance into the pond | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion/undercutting at or around the inlet | | | | Repair erosion damage and restabilize | Owner or professional | |
| | There is cracking, bulging, erosion or sloughing of the forebay dam. | | | | Repair and restabilize immediately. | Professional | |
| | There is woody growth on the forebay dam. | | | | Remove within 2 weeks of discovery. | Professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed from the area. | Professional | |
| | There is more than 1 inch of settlement. | | | | Add fill material and compact the soil to the design grade | Owner or Professional | |
| | The inlet alignment is incorrect. | | | | Correct immediately. | Owner or Professional | |
| Vegetation | Plant composition is consistent with the approved plans | | | | Determine if existing plant materials are consistent with the general Wet Pond design criteria, and replace inconsistent species. | Professional | |
| | Invasive species are present. | | | | Remove invasive species immediately and replace vegetation as needed. | Professional | |
| | Trees planted in the buffer and on wetland islands and peninsulas need watering during the first growing season | | | | Consider watering every 3 days for first month, and then weekly during first year (April – October), depending on rainfall. | Owner or professional | |
| | Grass around the facility is overgrown | | | | Mow (at least twice a year) to a height of 4"-9" high and remove grass clippings. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Vegetation (continued)** | Vegetation is dead or reinforcement planting is needed. | | | | Remove and replace dead or dying vegetation. | Professional | |
| **Permanent Pool and Side Slopes** | There is excessive trash and/or debris. | | | | Remove immediately | Owner or professional | |
| | There is evidence of sparse vegetative cover, erosion or slumping side slopes. | | | | Repair and stabilize physical damage, and reseed or plant additional vegetation. | Owner or professional | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed frm area. | Owner or professional | |
| | There is significant sediment accumulation. | | | | Conduct a bathymetric study to determine the impact to design volumes, and dredge if necessary. | Professional | |
| **Riser/Principle Spillway and Low-Flow Orifice(s)** | There is adequate access to the riser for maintenance. | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | Pieces of the riser are deteriorating, misaligned, broken or missing. | | | | Repair immediately. | Professional | |
| | Adjustable control valves are accessible and operational. | | | | Repair, as needed. | Professional | |
| | Reverse-slope pipes and flashboard risers are in good condition. | | | | Repair, as needed. | Professional | |
| | Seepage into conduit | | | | Seal conduit | Professional | |
| | There is evidence of clogging | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specs. | Professional | |
| | There is excessive trash, debris, or other obstructions in the trash rack. | | | | Remove immediately. | Owner or professional | |
| **Dam/ Embankment and Abutments** | There is sparse veg. cover, settlement, cracking, bulging, misalignment, erosion rills deeper than 2 inches, or sloughing. | | | | Repair and restabilize immediately, especially after major storms. | Professional | |
| | There are soft spots, seepage, boggy areas or sinkholes. | | | | Reinforce, fill and stabilize immediately. | | |
| | There is evidence of nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed from the area. | | |
| | There is woody vegetation on the embankment. | | | | Removal of woody species near or on the embankment and maintenance access areas should be done when discovered, but at least every 2 years. | | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overflow/Emergency Spillway | There is woody growth on the spillway. | | | | Removal of woody species near or on the emergency spillway should be done when discovered, but at least every 2 years. | Owner or professional | |
| | There is excessive trash, debris, or other obstructions. | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosion/backcutting | | | | Repair erosion damage and reseed | Owner or professional | |
| | There are soft spots, seepage or sinkholes. | | | | Reinforce, fill and stabilize immediately. | Owner or professional | |
| | Only one layer of stone armoring exists above the native soil. | | | | Reinforce rip-rap or other armoring materials. | Professional | |
| Outlet | The outlet provides a stable conveyance from the pond. | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is woody growth within 5 feet of the outlet pipe barrel. | | | | Prune vegetation back to leave a clear discharge area. | Owner or Professional | |
| | There is excessive trash, debris, or other obstructions. | | | | Remove immediately. | Owner or professional | |
| | There are excessive sediment deposits at the outlet. | | | | Remove sediment. | Professional | |
| | Discharge is causing undercutting, erosion or displaced rip-rap at or around the outlet. | | | | Repair, reinforce or replace rip rap as needed, and restabilize. | Professional | |
| Overall | Access to the facility or its components is adequate. | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | Fences are inadequate | | | | Collapsed fences must be restored to an upright position. Jagged edges and damaged fences must be repaired or replaced. | Professional | |
| | Water levels in one or more cells are abnormally high or low. | | | | Clear blockages of the riser or orifice(s) and make other adjustments needed to meet the approved design specifications. | Professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Mosquito proliferation | | | | Eliminate stagnant pools and stock the basin with mosquito fish to provide natural mosquito & midge control. Treat for mosquitoes as needed. If spraying, then use mosquito larvicide, (e.g., Bacillus thurendensis or Altoside formulations) *only if absolutely necessary*. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Overall (continued)** | Encroachment on the pond or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |
| | Safety signage is not adequate. | | | | Provide sufficient, legible safety signage. | Owner or professional | |

# P-BAS-04 RAINWATER HARVESTING: O&M CHECKLIST

## P-BAS-01 RAINWATER HARVESTING: O&M CHECKLIST

**Inspection Date**____________

**Project**__________________________________ **Site Plan/Permit Number**_________________

**Location**_________________________________ **Date BMP Placed in Service**_______________

**Date of Last Inspection**____________ **Inspector**_____________________________________

**Owner/Owner's Representative**___________________________________________________

**As-Built Plans available:** **Y / N**

Ideally, this practice should be inspected each Spring and Fall by the owner, with an extensive inspection every three years by a qualified third party inspector.

| Element of BMP | Potential Problems | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall (*Every third year*) | A component of the system is leaking or damaged | | | | Make necessary repairs or replace damaged components | Professional | |
| | Water is flowing out of the overflow pipe during the design rainfall or smaller storm (1-1.5 inch) | | | | Check for clogging or damage and ensure the pump is operating correctly. Ensure water is being used at the volume for which the system was designed. | Owner or professional | |
| | Electric system is flawed | | | | Make any necessary repairs/adjustments | Professional | |
| | Sediment accumulation in cistern exceeds 5% of the design volume | | | | Remove sediment | Professional | |
| | Excessive overhanging vegetation/trees present | | | | Trim branches back to meet standards | Professional | |
| Captured roof area (*Twice a year*) | Excess debris/sediment on the rooftop | | | | Remove debris immediately | Owner or professional | |
| Gutter system (*Twice a year*) | Gutters are clogged and water is backed up | | | | Unclog/remove leaves and debris. May need to install gutter screens. | Owner or professional | |
| | Rooftop runoff is not reaching the gutter system | | | | Correct the positioning or installation of gutters. May need to replace the system | Owner or professional | |
| | Algae growth | | | | Do not allow sunlight to penetrate cistern. Treat the water to remove/prevent algae | Owner or professional | |
| | Mosquitoes are present in the cistern | | | | Check screens for damage and repair/ replace. Treat with mosquito dunks if necessary | Owner or professional | |
| | Lids are damaged. Be sure to check vents and screens on inflow and outflow spigots and mosquito screens | | | | Repair immediately. Ensure that lid damage has not led to any of the aforementioned problems with the cistern | Owner or professional | |

## P-BAS-04 RAINWATER HARVESTING: O&M CHECKLIST

| Element of BMP | Potential Problems | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Screens and filters** (*Twice a year*) | Debris/sediment accumulation. Screens are clogged | | | | Find the source of debris and sediment and remedy. Clear the screen/filter. Replace if necessary | Professional | |
| **Pump** (*Twice a year*) | Not operating properly | | | | Check for clogging. Flush if needed. May need to be replaced | Professional | |
| **Pre-screening devices and first flush devices** (*Every 3 months*) | Dirty/clogged | | | | Have a professional ensure screens have not caused bacterial growth within the gutters or downspouts. The owner may remove the clean out plug from the first flush device and manually wipe it clean. | Owner or Professional | |
| **Backflow preventer** (*Every third year*) | Pressure is uneven and is causing backpressure or back-siphonage | | | | Immediately stop use of the indoor water supplied by the tank and call a professional. | Professional | |
| **Secondary water supply** (*Every third year*) | Not operating properly | | | | Consult an expert only | Professional | |
| **Overflow pipe** (*Annually*) | Erosion is evident at overflow discharge point, along the filter path/secondary runoff reduction practices | | | | Stabilize immediately. It may be necessary to refer to inspection checklists for other BMPs. | Professional | |
| | Overflow pipe in poor condition | | | | Repair or replace pipe | Professional | |

## P-CNV-01 GRASS CHANNELS: O&M CHECKLIST

**Inspection Date**_____________
**Project**_________________________________ **Site Plan/Permit Number**________________
**Location**_________________________________ **Date BMP Placed in Service**______________
**Date of Last Inspection**_____________ **Inspector**______________________________________
**Owner/Owner's Representative**____________________________________________________
**As-Built Plans available: Y / N**

Type of pretreatment facility:

- ☐ Sediment Forebay
- ☐ Check Dam
- ☐ Grass Filter Strip
- ☐ Stone Diaphragm
- ☐ Other: ___________________________
- ☐ None

*Ideally, these BMP areas should be inspected annually, with the inspection conducted spring when the health of the grass channel lining should be evident. Once established, Grass Channels have minimal maintenance needs outside of the Spring clean up: regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the channel and a dense, healthy grass cover.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| Pre-treatment | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash / debris / sediment in the facility | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is evidence of diaphragm or other clogging | | | | Identify and eliminate the source of the problem; . If necessary, remove and clean or replace the stone. | Professional | |
| | There is dead vegetation and evidence of erosion and / or exposed soil | | | | Repair erosion damage, and reseed or otherwise restabilize with vegetation | Owner or professional | |
| Inlets | The inlet is not maintaining a calm flow of water entering the channel or the conveyance capacity is blocked | | | | Remove trash and sediment accumulated at the inflow. Sources of sediment and debris must be identified and corrected. Stone splash pads must be replenished to prevent erosion. | Owner or professional | |

## P-CNV-01 GRASS CHANNELS: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| | There is evidence of erosion at / around inlet | | | | Repair erosion damage, and reseed or otherwise restabilize with vegetation. | Owner or professional | |
| Vegetation | Native soil is exposed or erosion channels are forming | | | | If sediment deposits are thick enough to damage or kill vegetation, remove the sediment by hand, while protecting the vegetation. | Owner or Professional | |
| | Grass height does not reach standards | | | | Grass channels must be mowed to keep grass at a height of 4" to 9". Remove grass clippings after mowing. | Owner or Professional | |
| | Vegetation requires fertilizer or pest control | | | | Fertilize according to specifications. Use organic rather than chemical fertilizer. If feasible, use compost. Use integrated pest management (IPM) techniques to minimize the use of pesticides and herbicides. | Owner or Professional | |
| | The plant composition is consistent with the approved plans | | | | Make a judgment regarding whether plants need to be replaced, and replace if necessary | Professional | |
| | Invasive species or weeds are present | | | | Correctly destroy and/or remove the invasive species; make a judgment regarding whether other weeds need to be removed, and remove if necessary | Owner or professional | |
| | There is dead vegetation and/or exposed soil | | | | Reseed or replace dead vegetation and exposed soil areas | Owner or professional | |
| Side Slopes | Evidence of erosion on side slopes, introducing sediment into the swale. | | | | Repair erosion damage immediately. Stabilize slopes using appropriate erosion control measures and plant appropriate vegetation. | Owner or Professional | |
| Check Dams | Dam is not functioning properly. | | | | Check upstream and downstream sides of check dams for evidence of undercutting, side cutting or erosion and repair immediately. | Professional | |
| | There is a large accumulation of sediment or trash/debris behind the check dam. | | | | Remove sediment when the accumulation exceeds 25% of the original Tv. Remove trash/debris and clear blockages of weep holes. | Professional | |
| Channel Bottom | Undesirable plant species, accumulations of fallen leaves, and other debris from deciduous plant foliage are present. | | | | Remove woody vegetation from the channel. Prune adjacent trees and shrubs to keep the channel clear. Remove/replace invasive veg. or weeds if they cover < 25% of the channel area. Remove accumulated organic matter and debris immediately. | Owner or Professional | |

## P-CNV-01 GRASS CHANNELS: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Channel Bottom (continued) | Base soils are compacted. The practice does not draw down within 48 hours after a storm. | | | | De-thatch and aerate the channel. Remove sediment when the accumulation exceeds 25% of channel volume. Restore the original cross section and revegetate the channel. | Owner or Professional | |
| | There is unhealthy or dead grass cover or evidence of erosion, braiding, or excessive ponding in the channel bottom | | | | Fill in low spots, repair erosion, and add reinforcement planting to maintain 90% turf cover. Reseed any salt killed vegetation and stabilize immediately. Keep the grass in a healthy, vigorous condition at all times, since it is the primary erosion protection for the channel. | Owner or Professional | |
| Channel Outlet | The outlet does not maintain sheet flow of water exiting the channel (unless a collection drain is used). | | | | The source of erosion damage must be identified and controlled when native soil is exposed or erosion channels are forming. Check the channel outlet and all road crossings for bank stability and evidence of piping or scour holes. | Owner or professional | |
| | The outlet provides stable conveyance out of the channel | | | | Stabilize immediately, as needed. | Professional | |
| | There is excessive trash, debris or sediment accumulation at outlet | | | | Check inflow points for cogging and remove any trash and sediment deposits | Owner or professional | |
| | There is dead vegetation and/or exposed soil | | | | Reseed or replace dead vegetation and exposed soil areas | Owner or professional | |
| Pest Control | There is evidence of standing water and mosquito habitat or rodent damage | | | | Pest control measures must be taken when mosquitoes and/or rodents are found to be present. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. Holes in the ground located in and around the swale must be filled and stabilized with vegetation. | Professional | |
| Overall | Access to the Grass Channel is adequate | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | Complaints from local residents | | | | Correct real problems | Owner or professional | |

## P-CNV-01 GRASS CHANNELS: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall (continued) | Encroachment by buildings or other structures | | | | Clearly mark BMP and inform those involved of the BMPs. | Owner, pro (and perhaps the locality) | |

## P-CNV-02 DRY SWALES: O&M CHECKLIST

**Inspection Date**____________
**Project**______________________________ **Site Plan/Permit Number**________________
**Location**______________________________ **Date BMP Placed in Service**______________
**Date of Last Inspection**____________ **Inspector**__________________________________
**Owner/Owner's Representative**________________________________________________
**As-Built Plans available: Y / N**

**Facility Type:** Level 1 ________________________ Level 2 ________________________

Facility Location:
- G Surface
- G Underground

Filtration Media:
- ☐ No filtration (e.g., dry well, permeable pavement, infiltration facility, etc.
- ☐ Sand
- ☐ Bioretention Soil
- ☐ Peat
- ☐ Other: __________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: __________________

*Ideally, Dry Swales should be inspected annually in the Spring, triggering such maintenance activities as sediment removal, spot revegetation, inlet stabilization, and repairs to check dams, underdrains and outlets.*

| Element of BMP | Potential Problem | Problem? Y / N | | | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There are excessive landscape waste or yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| Pre-Treatment and Flow Spreaders | There is adequate access to the pre-treatment facility. | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is evidence of clogging (standing water, noticeable odors, water stains, algae or floating aquatic vegetation) | | | | Identify and eliminate the source of the problem. If necessary, remove and clean or replace the clogged material. | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | | | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Pre-Treatment and Flow Spreaders (continued)** | There is dead vegetation or exposed soil in the grass filter | | | | Restabilize and revegetate as necessary | Owner or professional | |
| | The pea gravel diaphragm is at the correct level | | | | Correct the installation, as needed | Professional | |
| **Inlet and Swale Sides and Base** | The inlet provides a stable conveyance into the swale | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion at or around the inlet | | | | Repair erosion damage and reseed | Owner or professional | |
| **Check Dams** | A check dam is not functioning properly. | | | | Check upstream and downstream sides of check dams for evidence of undercutting, side cutting or erosion and repair immediately. | Professional | |
| | There is a large accumulation of sediment or trash/debris behind the check dam. | | | | Remove sediment when the accumulation exceeds 25% of the original Tv. Remove trash/debris and clear blockages of weep holes. | Professional | |
| **Vegetation** | Invasive species or weeds make up at least 10% of the facility's vegetation | | | | Remove invasive species and excessive weeds immediately and replace vegetation as needed. | Owner or professional | |
| | Trees form an overhead canopy that may drop leaf litter, fruit and other vegetative materials that may cause clogging. | | | | Prune or remove vegetation and organic litter as necessary. | Owner or professional | |
| | Grass height is not consistent with standards. | | | | Dry Swales must be mowed to keep grass at a height of 4" to 9". Remove grass clippings after mowing. | Owner or professional | |
| | The grass cover is not dense enough or is dead or dying | | | | Increase watering and reseed, if necessary, to maintain 95% turf cover, but avoid using chemical fertilizers unless absolutely necessary. Replace salt-killed vegetation with salt-tolerant species. | Professional | |
| **Filter Media/ Soil** | There is evidence that chemicals, fertilizers, and/or oil are present | | | | Remove undesirable chemicals from media and facility immediately, and replace mulch or media as needed | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | | | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Filter Media/ Soil (continued)** | There is excessive trash, debris, or sediment. | | | | Remove trash and debris immediately. Check plant health and, without damaging plants, manually remove the sediment, especially if the depth exceeds 20% of the facility's design depth. | Owner or professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is evidence that chemicals, fertilizers, and/or oil are present | | | | Remove undesirable chemicals from media immediately, and replace mulch or media as needed | Professional | |
| **Underdrain** | The perforated pipe is not conveying water as designed | | | | Determine if the pipe is clogged with debris or if woody roots have pierced the pipe. Immediately clean out or replace the pipe, as necessary. | Professional | |
| | The underlying soil interface is clogged (there is evidence on the surface of soil crusting, standing water, the facility does not dewater between storms, or water ponds on the surface of basin for more than 48 hours after an event). | | | | Measure the draw-down rate of the observation well for three days following a storm event in excess of 1/2 inches in depth. .After three days, if there is standing water on top but not in the underdrain, this indicates a clogged soil layer. If standing water is both on the surface and in the underdrain, then the underdrain is probably clogged. This should be promptly investigated and remediated to restore proper filtration. Grading changes may be needed or underdrain repairs made. | Professional | |
| **Outlet** | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |
| | There is excessive trash, debris, or sediment at the outlet | | | | Remove immediately, and keep the contributing area free of trash and debris. | Owner or professional | |
| **Overall** | Access to the Infiltration facility or its components is adequate | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |

| Element of BMP | Potential Problem | Problem? Y / N | | | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Overall (continued)** | Mosquito proliferation | | | | Eliminate stangant pools and establish vegetation; treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Encroachment on the swale or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

# P-CNV-03 WET SWALES: O&M CHECKLIST

P-CNV-03 WET SWALES: O&M CHECKLIST

**Inspection Date**____________
**Project**____________ **Site Plan/Permit Number**____________
**Location**____________ **Date BMP Placed in Service**____________
**Date of Last Inspection**____________ **Inspector**____________
**Owner/Owner's Representative**____________
**As-Built Plans available: Y / N**

**Facility Type:** Level 1 ____________ Level 2 ____________

Facility Location:
- G Surface
- G Underground

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Filtration Media:
- ☐ No filtration (e.g., dry well, permeable pavement, infiltration facility, etc.
- ☐ Sand
- ☐ Bioretention Soil
- ☐ Peat
- ☐ Other: ____________

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ____________

Wet Swales have maintenance needs similar to Dry Swales, although woody wetland vegetation may need to be removed periodically.

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There are excessive landscape waste or yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| Pre-Treatment | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is evidence of clogging (standing water, noticeable odors, water stains, algae or floating aquatic vegetation) | | | | Identify and eliminate the source of the problem. If necessary, remove and clean or replace the clogged material. | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Pre-Treatment (continued)** | There is dead vegetation. | | | | Replace dead vegetation as necessary | Professional | |
| **Inlets** | The inlet provides a stable conveyance into the swale | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion at or around the inlet | | | | Repair erosion damage and reseed | Owner or professional | |
| **Check Dams** | A check dam is not functioning properly. | | | | Check upstream and downstream sides of check dams for evidence of undercutting, side cutting or erosion and repair immediately. | Professional | |
| | There is a large accumulation of sediment or trash/debris behind the check dam. | | | | Remove sediment when the accumulation exceeds 25% of the original Tv. Remove trash/debris and clear blockages of weep holes. | Professional | |
| **Vegetation** (*monthly*) | Plant composition is consistent with the approved plans | | | | Replace inconsistent species | Professional | |
| | Invasive species (e.g., phragmites) are present. | | | | Remove invasive species immediately and replace vegetation as needed. | Professional | |
| | Vegetation is dead or dying | | | | Replace dead vegetation as needed. | Professional | |
| **Outlet** | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |
| | There is excessive trash, debris, or sediment at the outlet | | | | Remove immediately, and keep the contributing area free of trash and debris. | Owner or professional | |
| **Overall** | Access to the Infiltration facility or its components is adequate. | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | Mosquito proliferation | | | | Eliminate stagnant pools if feasible, and treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Encroachment on the swale or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

## P-CNV-04 REGENERATIVE STORMWATER CONVEYANCE: O&M CHECKLIST

**Inspection Date**_____________
**Project**_____________________________________ **Site Plan/Permit Number**________________
**Location**____________________________________ **Date BMP Placed in Service**________________
**Date of Last Inspection**____________ **Inspector**__________________________________________
**Owner/Owner's Representative**__________________________________________________________
**As-Built Plans available:** Y / N

**Facility Type:** Level 1 __________________________ Level 2 ____________________________

Facility Location:
- ☐ Surface
- ☐ Underground

Filtration Media:
- ☐ No filtration (e.g., dry well, permeable pavement, infiltration facility, etc.
- ☐ Sand
- ☐ Bioretention Soil
- ☐ Peat
- ☐ Other: ____________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ____________________

RSCs have maintenance needs similar to Wet and Dry Swales, although woody wetland vegetation may need to be removed periodically, and boulder steps and riffles must be inspected for erosive conditions.

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There are excessive landscape waste or yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| Pre-Treatment | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is evidence of clogging (standing water, noticeable odors, water stains, algae or floating aquatic vegetation) | | | | Identify and eliminate the source of the problem. If necessary, remove and clean or replace the clogged material. | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Pre-Treatment (continued)** | There is dead vegetation. | | | | Replace dead vegetation as necessary | Professional | |
| **Inlets** | The inlet provides a stable conveyance into the swale | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion at or around the inlet | | | | Repair erosion damage and reseed | Owner or professional | |
| **Boulder Steps & Pools** | A boulder step is not functioning properly. | | | | Check upstream and downstream sides of check dams for evidence of undercutting, side cutting or erosion and repair immediately. | Professional | |
| | There is a large accumulation of sediment or trash/debris behind the step / pool. | | | | Remove sediment when the accumulation exceeds 25% of the original Tv. within pools | Professional | |
| **Vegetation** (*monthly*) | Plant composition is consistent with the approved plans | | | | Replace inconsistent species | Professional | |
| | Invasive species (e.g., phragmites) are present. | | | | Remove invasive species immediately and replace vegetation as needed. | Professional | |
| | Vegetation is dead or dying | | | | Replace dead vegetation as needed. | Professional | |
| **Outlet** | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |
| | There is excessive trash, debris, or sediment at the outlet | | | | Remove immediately, and keep the contributing area free of trash and debris. | Owner or professional | |
| **Overall** | Access to the Infiltration facility or its components is adequate. | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | Mosquito proliferation | | | | Eliminate stagnant pools if feasible, and treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Encroachment on the swale or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

## P-FIL-01 ROOFTOP DISCONNECTION: O&M CHECKLIST

P-FIL-01 ROOFTOP DISCONNECTION: O&M CHECKLIST

**Inspection Date**______________
**Project**________________________________________ **Site Plan/Permit Number**_________________
**Location**_______________________________________ **Date BMP Placed in Service**_________________
**Date of Last Inspection**______________ **Inspector**_______________________________________
**Owner/Owner's Representative**_______________________________________________
**As-Built Plans available: Y / N**

Compensatory device type (include if the pervious area flow path is less than the required minimum length):
***(NOTE: See the separate plan review checklist for the compensatory device)***

- ☐ Dry Well
- ☐ French Drain
- ☐ Rain Garden
- ☐ Other: ______________________________

| Element of BMP | Potential Problem | Problem? Y/N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Piping, Gutters, Drains and Pre-Treatment Sumps** | Fluid from a different practice is being piped near pervious areas | | | | Prevent adjacent uses from piping through or around pervious area. | Professional | |
| | Sediment and debris accumulation | | | | Correct the source of sediment and debris and remove it immediately | Owner or professional | |
| | Mosquito proliferation | | | | Correct gutter flow to eliminate standing water; treat for mosquitoes, as needed | Owner or professional | |
| | Runoff is not entering the receiving pervious area | | | | Check to see if connection spout or overflow pipe is clogged. Remove the sediment. | Owner or professional | |
| | The downspouts remain disconnected | | | | Restore disconnection | Owner or professional | |
| **Manufactured Products** | Product or component is broken or not functioning correctly. | | | | Follow the manufacturer's maintenance recommendations, and repair or replace as needed. | Owner or professional | |
| **Downstream Treatment** | The compensatory treatment units have not been maintained | | | | Correct identifiedd problems, according to the maintenance guidelines for the specific supplementary BMP. | Owner or professional | |
| | Stormwater discharge is ponding at point of disconnection | | | | Dry wells or french drains may be needed, if not already present. Clean out manually, and reconstruct or replace when no longer functioning. | Professional | |

## P-FIL-01 ROOFTOP DISCONNECTION: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Downstream Treatment (continued) | Erosion is evident at the simple disconnection, bioretention/rain gardens, filter paths, or foundation planter | | | | Remove the sediment and debris build-up at the points where runoff enters the pervious area. Then re-stabilize. | Owner or professional | |
| | Practices to which the disconnection discharges are not functioning | | | | Reference that practice's checklist for instructions to fix problems. | Professiona l | |
| | Practices to which the disconnection discharges are disturbed or have been converted | | | | Correct identified problems and stabilize as needed | Owner or professional | |
| | The receiving pervious area(s) retain dimensions as shown on plans and are in good condition | | | | Restore dimensions and make needed repairs | Owner or professional | |
| | There is encroachment on the receiving pervious area(s) or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

## P-FIL-02 VEGETATED ROOFS: O&M CHECKLIST

**Inspection Date**______________
**Project**________________________________________ **Site Plan/Permit Number**__________________
**Location**_______________________________________ **Date BMP Placed in Service**________________
**Date of Last Inspection**______________ **Inspector**________________________________________
**Owner/Owner's Representative**_________________________________________________
**As-Built Plans available:** Y / N

**Facility Type:** Level 1 ______________________________ Level 2 ______________________________

*Ideally, following construction, this practice should be inspected monthly during the vegetation establishment period, and then every six months thereafter to assess the state of vegetative cover and to look for leaks, drainage problems and other functional or structural concerns. Maintenance may include watering, hand-weeding to remove invasive or volunteer plants, and to add plant materials to repair bare areas. The use of herbicides, insecticides, fungicides, and fertilizers should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Vegetation | Plant cover is less 90% plant cover | | | | During establishment period, replace dead plants as needed. During the long-term period, dead plants must generally be replaced once per year in the fall. | Owner or professional | |
| | Plants are wilting | | | | Water more frequently to promote growth and survival. Annual application of slow-release fertilizer is recommended in the fall during the first five years following installation. After that, fertilizer is generally not necessary and should not be applied. | Owner or professional | |
| | Plants are choking on excess vegetation | | | | Fallen leaves and debris from deciduous plant foliage must be removed and should be recycled or composted. | Owner or professional | |
| | Invasive and nuisance plant species are present | | | | Completely remove invasive plant species. Weeding must be done by hand, without the use of herbicides or pesticides. Remov weeds regularly and do not allow them to accumulate. | Owner or professional | |

## P-FIL-02 VEGETATED ROOFS: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Vegetation (continued) | Drought conditions are present | | | | Mulch or shade cloth may be applied to prevent excess solar damage and water loss | Professional | |
| | There is troublesome pest infestation | | | | Use integrated pest management (IPM) techniques to minimize the use of pesticides and herbicides. Minimize use of organic (not chemical) fertilizer, as needed. | Owner or professional | |
| | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | Grass has become unruly | | | | Grass should be mowed as needed. Clippings must be removed and should be recycled or composted. | Owner or professional | |
| Vegetation Irrigation | During the establishment period (initial 1-3 years) | | | | Water sufficiently to assure plant establishment, but do not exceed 1/4-inch of water once every 3 days | Owner or professional | |
| | During the long-term period (3+ years) | | | | Water sufficiently to maintain plant cover, but do not exceed 1/4-inch of water once every 14 days. For automatic sprinklers, use manufacturers' instructions for operation and maintenance. | Owner or professional | |
| Structural Components | Waterproof membrane is leaking or cracked | | | | Make necessary repairs immediately | Professional | |
| | Root barrier is perforated | | | | Replace swatch | Professional | |
| Drainage Layer/Inlet Pipes | Soil substrate, vegetation, debris, litter or other materials clog the roof drain inlet, scuppers or gutters | | | | Sources of organic matter, debris, litter, and other sediment must be identified and materials removed to prevent clogging drainage structures | Professional | |
| | Drain inlet pipe is in poor condition | | | | Repair as needed | Professional | |
| Soil Substrate/ Growing Medium | Evidence of erosion from wind or water | | | | If erosion channels are evident, they must be stabilized with additional soil substrate/growth medium and covered with additional plants | Professional | |
| | Growth media has become clogged with sediment | | | | Manually remove sediment so as not to damage plant materials. | Professional | |

## P-FIL-02 VEGETATED ROOFS: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall | Access to the vegetated roof is adequate. | | | | Egress and ingress routes must be restored to design standards. Walkways must be clear of obstructions and maintained to design standards. | Professional | |
| | There is evidence of damage or vandalism | | | | Maintain the vegetated roof's aesthetics as an asset to the property owner and community. | Owner or professional | |
| | Mosquitoes or other insects are breeding/ abundant at the practice | | | | Standing water creating an environment for development of insect larvae must be eliminated manually. Chemical sprays must not be used. | Owner or professional | |
| | Threat of a spill is imminent | | | | Spill prevention measures must be exercised for mechanical systems located on roofs when substances that can contaminate stormwater are used. Releases of pollutants must be corrected as soon as they are identified. | Owner or professional | |

## P-FIL-08 PERMEABLE PAVEMENT: O&M CHECKLIST

**Inspection Date**_____________
**Project**______________________________________ **Site Plan/Permit**
**Number**______________________________________
**Location**______________________________________ **Date BMP Placed in**
**Service**______________________________________
**Date of Last**
**Inspection**__________________________ **Inspector**

___________________________________
**Owner/Owner's**
**Representative**

**As-Built Plans available:** **Y / N**

**Facility Type:** Level 1 ______________________________ Level 2

Ideally, each permeable pavement installation should be inspected in the Spring of each year, especially at large-scale installations.

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosino and/or bare or exposed soil | | | | Stabilize immediately. | Owner or professional | |
| | There is excessive landscape waste and yard clippings | | | | Remove immediately. | Owner or professional | |
| Adjacent Vegetation | Trees and shrubs are within 5 feet of the pavement surface | | | | Check that tree roots have not penetrated the pavement and leaf residue has not clogged the pavement. Vegetation that limits access or interferes with the permeable pavement operation must be pruned or removed. | Owner or Professional | |
| Inlets, Pre-Treatment Cells and Flow Diversion Structures | There is excessive trash, debris or sediment accumulation | | | | Remove immediately | Owner or Professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | Evidence of clogging | | | | Clean out sediment or debris. Remove and wash or replace stone, as needed | Professional | |
| Pavement Surface | Mosquito proliferation | | | | Eliminate standing water and establish vegetation; treat for | Owner or professional | |

# P-FIL-03 PERMEABLE PAVEMENT: O&M CHECKLIST

| Elamant of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| | | | | | mosquitoes as needed. If sprays are considered, then use a licensed pest controller to apply an approved mosquito larvicide *(only if absolutely necessary)*. | | |
| Pavement Surface | There is evidence of erosion and / or bare or exposed soil in grid paver areas | | | | Stabilize immediately. Mow, irrigate and apply organic (not chemical) fertilizer, as needed to keep grass healthy and dense enough to provide filtering while protecting the underlying soil. Remove any grass clippings. | Owner or professional | |
| | There is loose material (e.g., bark, sand, etc.) stored on the pavement surface | | | | Remove immediately and vacuum sweep the area to prevent clogging the pavement pores. | Professional | |
| | Pavement is stained and/or clogged or water is ponded, indicating the pavement is not draining properly. Measure the drawdown rate in the observation well for three (3) days following a storm event that exceeds 1/2-inch of rain. If standing water is still observed in the well after three days, this is a clear sign that the pavement is clogged. There are significant amounts of sediment have accumulated between the pavers. | | | | The surface must be kept clean and free of leaves, debris, and sediment by vacuum sweeping (without brooms or water spray) immediately and, otherwise, at a frequency consistent with the use and loadings encountered (at a minimum, annual dry-weather sweeping in the Spring). Where paving blocks are installed, the sweeper must be calibrated so it does *not* pick up the stones between the paver blocks. Following the vacuum sweeping, test pavement sections by pouring water from 5 gallon buckets, to ensure proper drainage. | Professional | |
| Structural Integrity | There is evidence of surface deteriortation, such as slumping, cracking, spalling or broken pavers. | | | | Repair or replace affected areas, as necessary. | Professional | |
| Observation Wells | Is each observation well still capped? | | | | Repair, as necessary. | Professional | |
| Outlet | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |

## P-FIL-04 INFILTRATION PRACTICES: O&M CHECKLIST

**Inspection Date**____________
**Project**________________________________ **Site Plan/Permit Number**________________
**Location**_______________________________ **Date BMP Placed in Service**______________
**Date of Last Inspection**____________ **Inspector**____________________________________
**Owner/Owner's Representative**__________________________________________________
**As-Built Plans available: Y / N**

**Facility Type:** Level 1 _________________________ Level 2 __________________________

Facility Location:
- G Surface
- G Underground

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Filtration Media:
- ☐ No filtration (e.g., dry well, permeable pavement, infiltration facility, etc.
- ☐ Sand
- ☐ Bioretention Soil
- ☐ Peat
- ☐ Other: ____________________

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ____________________

*Ideally, infiltration facilities should be inspected annually. Spill Prevention measures should be used around infiltration facilities when handling substances that contaminate stormwater. Releases of pollutants should be corrected as soon as identified.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | Vegetative cover is adequate | | | | Supplement as needed | Owner or professional | |
| | There are excessive landscape waste or yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| Pre-Treatment Facility | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |

# P-FIL-04 INFILTRATION PRACTICES: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Pre-Treatment Facility (continued) | There is evidence of erosion and/or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is evidence of clogging (standing water, noticeable odors, water stains, algae or floating aquatic vegetation) | | | | Identify and eliminate the source of the problem. If necessary, remove and clean or replace the clogged material. | Professional | |
| | There is dead vegetation or exposed soil in the grass filter | | | | Restabilize and revegetate as necessary | Owner or professional | |
| Inlets | Inlets provide a stable conveyance into facility | | | | Stabilize immediately, as needed. | Owner or professional | |
| | There is excessive trash/debris/sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion at or around the inlet | | | | Repair erosion damage and reseed or otherwise restabilize with vegetation | Owner or professional | |
| Embankment, Flow Diversion Structures (e.g., Dikes, Berms, etc.) and Side Slopes | There is evidence of erosion or bare soil | | | | Identify the source of erosion damage and prevent it from recurring. Repair erosion damage and reseed or otherwise restabilize with vegetation | Owner or professional | |
| | There is excess sediment accumulation | | | | Remove immediately | Owner or professional | |
| | Water is not detained in the infiltration basin | | | | Check for a breach in the containment structure and repair immediately. | Professional | |
| | Side slopes support nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed frm area. | Professional | |
| Maintaining Facility Capacity and Proper Drainage | Look for weedy growth on the stone surface indicating sediment accumulation and potential clogging | | | | Identify and control sources of sediment and debris. Remove sediment and debris in excess of 4" in depth every 2-5 years (or sooner if performance is affected). | Professional | |
| | Measure the draw-down rate of the observation well for three days following a storm event in excess of 1/2 inches in depth. If standing water is still observed after three days, this is a clear sign that clogging is a problem. | | | | Immediately clear debris from the underdrain. Replace the underdrain if necessary. If needed, regrade and till to restore infiltration capacity (the need for this can be prevented by preventing upstream erosion and subsequent sediment transport to the facility). | Professional | |
| | There is excessive trash/debris | | | | Remove immediately | Owner or professional | |

## P-FIL-04 INFILTRATION PRACTICES: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Vegetation | Grass within the practice is overgrown | | | | Grass must be mowed to a height of 4"-9" and grass clippings removed (ideally recycled or composted). | Owner or professional | |
| | Pioneer trees are sprouting in the base of the facility | | | | Remove trees to prevent roots from puncturing the filter fabric, allowing sediment to enter | | |
| | Vegetation forms an overhead canopy that may drop leaf litter, fruit and other vegetative materials that may cause clogging. | | | | Prune or remove vegetation as necessary | Owner or professional | |
| Observation Well | Is each observation well still capped? | | | | Repair, as necessary. | Professional | |
| Outlet | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |
| | Evidence of flow bypassing facility | | | | Repair immediately | Professional | |
| | There is excessive trash, debris, or sediment at the outlet | | | | Remove immediately | Owner or professional | |
| Overflow or Emergency Spillway | The pipe or spillway is not effectively conveying excess water to an adequate receiving system | | | | Clear sediment and debris whenever 25% or more of the conveyance capacity is blocked. When damaged pipe is discovered, it must be repaired or replaced immediately. Identify and control sources of erosion damage. Replace or reinforce stone armament whenever only one layer of stone remains. | Professional | |
| Structural Components | Evidence of structural deterioration | | | | Repair as necessary | Professional | |
| | Evidence of spalling or cracking of structural components | | | | Repair or replace, as necessary | Professional | |
| | Grates are in good condition | | | | Repair or replace, as necessary | Owner or professional | |
| Overall | Access to the Infiltration facility or its components is adequate | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that manholes, valves and/or locks can be opened and operated. | Professional and, perhaps, the locality | |
| | There is evidence of standing water | | | | Fill in low spots and stabilize; correct flow problems causing ponding | Owner or professional | |

## P-FIL-04 INFILTRATION PRACTICES: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall (continued) | Mosquito proliferation | | | | Eliminate standing water and establish vegetation; treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |
| | Complaints from local residents | | | | Correct real problems | Owner or professional | |
| | Encroachment on the infiltration area or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

# P-FIL-05 BIORETENTION PRACTICES: O&M CHECKLIST

## P-FIL-05 BIORETENTION PRACTICES: O&M CHECKLIST

**Inspection Date**_____________
**Project**_____________________________________ **Site Plan/Permit Number**________________
**Location**____________________________________ **Date BMP Placed in Service**______________
**Date of Last Inspection**_____________ **Inspector**________________________________
**Owner/Owner's Representative**______________________________________________
**As-Built Plans available:** Y / N

**Facility Type:** Level 1 ______________________________ Level 2 ______________________________

Facility Location:
- G Surface
- G Underground

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Filtration Media:
- ☐ No filtration (e.g., dry well, permeable pavement, infiltration facility, etc.
- ☐ Sand
- ☐ Bioretention Soil
- ☐ Peat
- ☐ Other: ______________________

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ______________________

*Ideally, Bioretention facilities should be inspected and cleaned up annually, peferably during the Spring. During the first 6 months following construction of a bioretention facility, the site should be inspected at least twice after storm events that exceed 1/2-inch of rainfall. Watering is needed once a week during the first 2 months following installation, and then as needed during the first growing season (April-October), depending upon rainfall. If vegetation needs to be replaced, one-time spot fertilization may be needed, preferably using an organic rather than a chemical fertilizer. Each facility should have a customized routine maintenance schedule addressing issues such as the following: grass mowing, weeding, trash removal, .mulch raking and maintenance, erosion repair, reinforcement plantings, tree and shrub pruing, and sediment removal.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | Adequate vegetation | | | | Supplement as necessary | Owner or professional | |
| | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There are excessive landscape waste or yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| | Oil, grease or other unauthorized substances are entering the facility | | | | Identify and control the source of this pollution. It may be necessary to erect fences, signs, etc | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Pre-Treatment** | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | Excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| **Pre-Treatment (continued)** | There is evidence of clogging (standing water, noticeable odors, water stains, algae or floating aquatic vegetation, or oil/grease) | | | | Identify and eliminate the source of the problem. If necessary, remove and clean or replace the clogged material. | Professional | |
| | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is dead vegetation or exposed soil in the grass filter | | | | Restabilize and revegetate as necessary | Owner or professional | |
| **Inlets** | Check for sediment build-up at curb cuts, gravel diaphragms or pavement edges that prevent flow from getting into the bed, and check for bypassing. | | | | Remove sediment and correct any other problems that block inflow. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion at or around the inlet | | | | Repair erosion damage and reseed or otherwise restabilize with vegetation | Owner or professional | |
| | Inflow is hindered by trees and/or shrubs. | | | | Remove woody vegetation from points of inflow and directly above underdrains. (Trees and shrubs may be located closer to the perimeter.) | Owner or professional | |
| **Side Slopes** (*Annually, after major storms*) | There is evidence of rill or gully erosion or bare soil | | | | Identify the source of erosion damage and prevent it from recurring. Repair erosion damage and reseed or otherwise restabilize with vegetation | Owner or professional | |
| | There is excess sediment accumulation | | | | Remove immediately | Owner or professional | |
| | Side slopes support nuisance animals. | | | | Animal burrows must be backfilled and compacted. Burrowing animals should be humanely removed from the area. | Professional | |
| **Vegetation** (*monthly*) | Plant composition is consistent with the approved plans and any stakes or wires are in good condition. | | | | Determine if existing plant materials are at least consistent with general Bioretention design criteria and replace inconsistent species. | Professional | |
| | There should be 75-90% cover (mulch plus vegetation), and the mulch cover | | | | Supplement vegetation and mulch as needed. | | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| | should be 2-3 inches deep. | | | | | | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Vegetation** (*monthly*) **(continued)** | There is evidence of hydrocarbons or other deleterious materials, resulting in unsatisfactory plant growth or mortality, | | | | Replace contaminated mulch. If problem persists, test soils for hydrocarbons and other toxic substances. If excess levels are found, the soils, plants and mulch may all need to be replaced in accordance with the approved construction plans. | Professional | |
| | Invasive species or weeds make up at least 10% of the facility's vegetation | | | | Remove invasive species and excessive weeds immediately and replace vegetation as needed. | Owner or professional | |
| | The grass is too high | | | | Mow within a week. Grass species should be selected that have dense cover, are relatively slow growing, and require the least mowing and chemical inputs. Grass should be from 6-10 inches high. | Owner or professional | |
| | Vegetation is diseased, dying or dead | | | | Remove and replace. Increase watering, but avoid using chemical fertilizers, unless absolutely necessary. | Professional | |
| | Winter-killed or salt-killed vegetation is present. | | | | Replace with hardier species. | Owner or professional | |
| **Filter Media** (*Annually*) | The filter media is too low, too compacted, or the composition is inconsistent with design specifications | | | | Raise the level, loosen and amend or replace the media, as needed, to be consistent with the state design criteria for Bioretention (85-88% sand 8-12% soil fines 3-5% organic matter in form of leaf compost). Other remediation options are described in the maintenance section of the state design criteria for Bioretention | Professional | |
| | The mulch is older than 3 years or is otherwise in poor condition | | | | The mulch must be replaced every 2-3 years | Professional | |
| | There is evidence that chemicals, fertilizers, and/or oil/grease are present | | | | Remove undesirable chemicals from media and facility immediately, and replace mulch or media as needed | Professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove trash and debris immediately. Check plant health and, without damaging plants, manually remove the sediment, especially if the depth exceeds 20% of the facility's design depth. | Owner or professional | |
| | There is evidence of concentrated flows, erosion or exposed soil | | | | Identify the source of erosion damage and prevent it from recurring. Repair the erosion damage and reseed or otherwise restabilize with vegetation. | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Filter Media** (*Annually*) (continued) | The filter bed is clogged and/or filled inappropriately | | | | Redistribute the soil substrate and remove sediment within 2 weeks. | Professional | |
| | The topsoil is in poor condition (e.g., the pH level is not 6-7, the composition is inappropriate, etc.) | | | | Ensure a 3-inch surface depth of topsoil consistent with the state design criteria for Bioretention (loamy sand or sandy loam texture, with less than 5% clay content, and organic matter content of at least 2%). If the pH is less than 6.5, spread limestone. | Professional | |
| **Underdrain/ Proper Drainage** | The perforated pipe is not conveying water as designed | | | | Determine if the pipe is clogged with debris or if woody roots have pierced the pipe. Immediately clean out or replace the pipe, as necessary. | Professional | |
| | The underlying soil interface is clogged (there is evidence on the surface of soil crusting, standing water, the facility does not dewater between storms, or water ponds on the surface of basin for more than 48 hours after an event). | | | | Measure the draw-down rate of the observation well for three days following a storm event in excess of 1/2 inches in depth. .After three days, if there is standing water on top but not in the underdrain, this indicates a clogged soil layer. If standing water is both on the surface and in the underdrain, then the underdrain is probably clogged. This should be promptly investigated and remediated to restore proper filtration. Grading changes may be needed or underdrain repairs made. The filter media may need to be raked, excavated and cleaned or replaced to correct the problem. Holes that are not consistent with the design and allow water to flow directly through a planter to the ground must be plugged. | Professional | |
| **Planters** | The planter is unable to receive or detain stormwater prior to infiltration. Water does not drain from the reservoir within 3-4 hours of after a storm event. | | | | Identify and correct sources of clogging. Topsoil and sand/peat layer may need to be amended with sand or replaced all together. | Owner or professional | |
| | The planter has structural deficiencies, including rot, cracks, and failure, or the planter is unable to contain the filter media or vegetation | | | | Make needed repairs immediately. | Owner or professional | |
| **Outlet/ Overflow Spillway** | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to fix problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **Outlet/ Overflow Spillway (continued)** | There is excessive trash, debris, or sediment at the outlet | | | | Remove immediately, and keep the contributing area free of trash and debris. | Owner or professional | |
| | Any grates present are in good condition | | | | Repair or replace as necessary | Owner or professional | |
| **Observation Well** | Is the observation well still capped? | | | | Repair, as necessary. | Professional | |
| Overall | Access to the Infiltration facility or its components is adequate | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | There is evidence of standing water | | | | Fill in low spots and stabilize; correct flow problems causing ponding. | Owner or professional | |
| | Mosquito proliferation | | | | Eliminate stangant pools and establish vegetation; treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |
| | Complaints from local residents | | | | Correct real problems | Owner or professional | |
| | Encroachment on the bioretention area or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

## P-FIL-06 FILTERING PRACTICES: O&M CHECKLIST

**Inspection Date**_____________
**Project**_____________________________________ **Site Plan/Permit**
**Number**_____________________________________
**Location**____________________________________ **Date BMP Placed in**
**Service**_____________________________________
**Date of Last**
**Inspection**_________________________ **Inspector**
_________________________
**Owner/Owner's**
**Representative**

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**As-Built Plans available:** **Y / N**

**Facility Type:** Level 1 ___________________________ Level 2

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Facility Location:
- G Surface
- G Underground

Filtration Media:
- ☐ No filtration (e.g., dry well, permeable pavement, infiltration facility, etc.
- ☐ Sand
- ☐ Bioretention Soil
- ☐ Peat
- ☐ Other: _________________

Hydraulic Configuration:
- ☐ On-line facility
- ☐ Off-line facility

Type of Pre-Treatment Facility:
- ☐ Sediment forebay (above ground)
- ☐ Sedimentation chamber
- ☐ Plunge pool
- ☐ Stone diaphragm
- ☐ Grass filter strip
- ☐ Grass channel
- ☐ Other: ___________________

*An inspection and clean-up should be scheduled annually to remove trash and floatables that accumulate in the pre-treatment celss and filter bed. Frequent sediment cleanouts in the dry and wet sedimentation chambers are recommended every 2-3 years to maintain the function and performance of the filter. If the filter treats runoff from a hotspot, crews may need to test the filter bed media before disposing of the media and trapped pollutants. If the filter does not treat runoff from a hotspot, the media can be safely disposed by either land application or land filling, without prior testing.*
***Warning:*** *If the filtering facility has a watertight cover; be careful regarding the possibility of flammable gases within the facility. Care should be taken lighting a match or smoking while inspecting facilities that are not vented. If the filtering facility is in a completely enclosed vault, the* ***OSHA Confined Space Entry*** *procedures must be followed.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | Adequate vegetation | | | | Supplement as necessary | Owner | |
| | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| **and Side Slopes** | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There are excessive landscape waste or yard clippings | | | | Remove immediately and recycle or compost | Owner or professional | |
| **Pre-Treatment** | There is adequate access to the pre-treatment facility | | | | Establish adequate access | Professional and, perhaps, the locality | |
| | Excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| **Pre-Treatment (continued)** | There is evidence of erosion and / or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | There is dead vegetation. | | | | Replace dead vegetation as necessary | Professional | |
| | Perimeter turf (or a grass filter strip) is too high. | | | | Mow at least 4 times a year to keep the grass at a height of 4" to 9". Remove grass clippings after mowing. | Owner or professional | |
| | There is evidence of oil, grease,clogging (standing water, noticeable odors, water stains, algae) | | | | Identify and eliminate the source of the problem. If necessary, remove and clean or replace the clogged material. | Professional | |
| **Inlets** | The inlet provides a stable conveyance into the swale | | | | Stabilize immediately, as needed, and clear blockages. | Owner or professional | |
| | There is excessive trash, debris, or sediment. | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion at or around the inlet | | | | Repair erosion damage and reseed | Owner or professional | |
| **Sedimentation Chambers** | Sediment or debris accumulations are excessive | | | | Clean out the wet and dry sedimentation chambers | Professional | |
| **Filter Media** | If facility takes longer than 48 hours to drain or filter media is discolored, the media is probably clogged | | | | Replace the top sand layer of an enclosed filter (typically done every 5 years). Till or aerate the surface to improve infiltration and grass cover of an open filter (also typically done every 5 years. | | |
| **Oil and Grease** | Evidence of filter surface clogging | | | | Clean or replace filter media, as necessary. | Professional | |
| **Underdrain** | The underdrain is not conveying water as designed | | | | To determine if the pipe is clogged, measure the draw-down rate of the observation well for three days following a storm event in excess of 1/2 inches in depth. .After three days, if there is standing water on top but not in the underdrain, this indicates a clogged sand layer that must be replaced. If standing water is both on the surface and in the | Professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| | | | | | underdrain, then the underdrain is probably clogged. Immediately clean out the pipe manually or, if needed, use a high-pressure hose. Replace the underdrain if it is structurally damaged. | | |
| **Observation Well** *(every 2 years)* | Is the observation well still capped? | | | | Repair, as necessary. | Professional | |
| **Outlet** | The outlet provides stable conveyance | | | | Remove blockages and stabilize, as needed. | Professional | |
| | Evidence of flow bypassing facility | | | | Repair immediately | Professional | |
| | Outlets are obstructed or erosion and soil exposure is evident below the outlet. | | | | Remove obstructions and stabilize eroded or exposed areas. | Owner or Professional | |
| **Structural Components** | Evidence of structural deterioration | | | | Repair as necessary | Professional | |
| | Evidence of spalling or cracking of structural components | | | | Repair or replace, as necessary | Professional | |
| | Grates are in good condition | | | | Repair or replace, as necessary | Owner or professional | |
| **Pump** (where applicable) | Catalog cuts and wiring diagram for pump available | | | | If missing, obtain replacements | Owner | |
| | Waterproff conduits for wiring appear to be intact | | | | Repair as necessary | Professional | |
| | Panel box is well marked | | | | If not, mark it correctly | Professional | |
| | No evidence of pump failure (excess water in pump well, etc.) | | | | Repair as necessary | Professional | |
| **Overall** | Access to the facility or its components is adequate. | | | | Establish adequate access. Remove woody vegetation and debris that may block access. Ensure that hardware can be opened and operated. | Professional and, perhaps, the locality | |
| | Condition of hydraulic control components | | | | Repair, as necessary. | Professional | |
| | Complaints from local residents | | | | Correct real problems. | Owner or professional | |
| | Noticeable odors outside facility | | | | Determine source and eliminate it. | Professional | |
| | Mosquito proliferation | | | | Eliminate stagnant pools if feasible, and treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| | Encroachment on the filter or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

# P-FIL-07 SHEET FLOW TO VEGETATED FILTER STRIP OR CONSERVED OPEN SPACE: O&M CHECKLIST

## P-FIL-07 SHEET FLOW TO VEGETATED FILTER AREAS AND CONSERVED OPEN SPACE: O&M CHECKLIST

**Inspection Date**_____________
**Project**_________________________________ **Site Plan/Permit Number**________________
**Location**_________________________________ **Date BMP Placed in Service**_______________
**Date of Last Inspection**_____________ **Inspector**_______________________________
**Owner/Owner's Representative**_______________________________________________
**As-Built Plans available:** **Y / N**

**Facility Type:** Level 1 ___________________________ Level 2 ___________________________

*Ideally, these BMP areas should be inspected annually, with the inspection conducted during the non-growing season when it is easier to observe the flow path. Once established, vegetated filter strips have minimal maintenance needs outside of the Spring clean up: regular mowing, repair of check dams and other measures to maintain the hydraulic efficiency of the filter strip and a dense, healthy grass cover. Grass filter strips and boundary zones must be mowed at least twice a year to prevent woody growth. A conservation easement may be required to ensure that the vegetated filter strip area and any newly established or restored forest cover may not be cleared. Also, a responsible party should ensure that routine forest improvements are made over time (i.e., thinning, invasive plant removal, etc.).*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Contributing Drainage Area | There is excessive trash and debris | | | | Remove immediately. | Owner or professional | |
| | There is evidence of erosino and/or bare or exposed soil | | | | Stabilize immediately. | Owner or professional | |
| Inlet | Inlets provide stable conveyance into facility | | | | Stabilize immediately, as needed. | Owner or professional | |
| | Excessive trash / debris / sediment accumulation at the inlet | | | | Remove trash and debris immediately | Owner | |
| | Evidence of erosion at / around the inlet | | | | Correct the source problem and stabilize immediately | Owner or professional | |
| Channel | Scour and erosion are present within the vegetated filter area | | | | Sediments are to be cleaned out of Level Spreader forebays and flow splitters | Owner or professional | |
| | Debris and sediment build-up is present at the top of the vegetated filter area | | | | Check conveyance(s) to the filter area for trouble spots and correct any problems immediately. Manually remove the deposited sediment. | Owner or professional | |
| Gravel Diaphragm | Foot or vehicular traffic is compromising the gravel diaphragm. | | | | Block foot and vehicular traffic. Re-stabilize the area immediately. | Professiona l | |

# P-FIL-07 SHEET FLOW TO VEGETATED FILTER STRIP OR CONSERVED OPEN SPACE: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Level Spreader | The level spreader is performing properly. Flows are not concentrating on the down-gradient side of the element | | | | Search the spreader for chips, cracks, or any other fundamental compromise of the structure. Repair immediately. | Professional | |
| | There is excessive landscape waste and yard clippings | | | | Remove immediately. | Owner or professional | |
| Vegetation | Vegetative density is less than 90% cover in the boundary zone or grass filter | | | | Reseed and fertilize (if necessary) the exposed soil | Owner or professional | |
| | The plant composition is consistent with the approved plans | | | | Make a judgment regarding whether plants need to be replaced, and replace if necessary | Professional | |
| | Invasive species or weeds are present | | | | Correctly destroy and/or remove the invasive species; make a judgment regarding whether other weeds need to be removed, and remove if necessary | Owner or professional | |
| | There is troublesome pest infestation | | | | Use integrated pest management (IPM) techniques to minimize the use of pesticides and herbicides. Minimize use of organic (not chemical) fertilizer, as needed. | Owner or professional | |
| | There is dead vegetation and/or exposed soil | | | | Reseed or replace dead vegetation on exposed soil areas | Owner or professional | |
| Overflow Area | Flows through the filter area short-circuit the overflow control section | | | | Check that the structure is not clogged. If so, manually clean out debris immediately. | Owner or professional | |
| Outlet | The outlet provides stable conveyance away from the filter area | | | | Stabilize immediately, as needed. | Professional | |
| Overall | There is adequate access to the level spreader and filter area | | | | Establish adequate access | Professional | |
| | There is evidence of standing water | | | | Fill in low spots and stabilize; correct flow problems causing ponding | Owner or professional | |
| | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |

## P-FIL-07 SHEET FLOW TO VEGETATED FILTER STRIP OR CONSERVED OPEN SPACE: O&M CHECKLIST

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| Overall (continued) | Mosquito proliferation | | | | Eliminate stagnant pools and establish vegetation; treat for mosquitoes as needed. If sprays are considered, then a mosquito larvicide, such as Bacillus thurendensis or Altoside formulations can be applied *only if absolutely necessary*. | Owner or professional | |
| | Complaints from local residents | | | | Correct real problems | Owner or professional | |
| | Encroachment on the filter area or easement by buildings/structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |

## P-FIL-08 SOIL COMPOST AMENDMENT: O&M CHECKLIST

### P-FIL-08 SOIL COMPOST AMENDMENTS: O&M CHECKLIST

**Inspection Date**_____________
**Project**______________________________________ **Site Plan/Permit Number**___________________
**Location**_____________________________________ **Date BMP Placed in Service**________________
**Date of Last Inspection**_____________ **Inspector**____________________________________________
**Owner/Owner's Representative**____________________________________________________________
**As-Built Plans available: Y / N**

*Ideally, the amended soil area should be watered once every 3 days for the first month, and then weekly during the first growing season (April-October), depending upon rainfall. The area should be inspected at least after each storm event that exceeds 1/2-inch of rainfall during the first six months following the incorporation of soil amendments. Depending on the results of a soil test for the amended area, a one-time spot fertilization may be needed in the fall after the first growing season to increase plant vigor. The area should be de-thatched every few years to increase permeability.*

| Element of BMP | Potential Problem | Problem? Y / N | Investigate? Y / N | Repaired? Y / N | How to Fix Problem | Who Will Address Problem | Comments |
|---|---|---|---|---|---|---|---|
| | There is excessive trash and debris | | | | Remove immediately | Owner or professional | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately with grass cover | Owner or professional | |
| | Evidence of excessive use of fertilizer or lawn chemicals | | | | Develop and implement a nutrient and pest control management plan | Owner or professional | |
| | Runoff is ponding, creating rills, and/or causing erosion | | | | Dethatch or aerate the soil. Introduce more compost amendments and/or lime. Restabilize eroded areas by replanting vegetation. | Owner or professional | |
| | Access to the amended soil area for maintenance is adequate. | | | | Establish adequate access | Professional | |
| | Absence of signs designating the area as a Conservation Area | | | | Obtain or create and post appropriate signage | Owner (and perhaps the locality) | |
| | There is evidence of erosion and / or bare or exposed soil | | | | Stabilize immediately | Owner or professional | |
| | Encroachment on the amended area or easement by buildings or other structures | | | | Inform involved property owners of BMPs status ; clearly mark the boundaries of the receiving pervious area, as needed | Owner or professional (and perhaps the locality) | |
| NOTE: Soil compost amendments do not need to be addressed in a maintenance agreement if they are incorporated to reduce lawn runoff volume or improve a residential rooftop disconnection. They probably should be addressed in a simple maintenance agreement if the soil restoration/improvement is associated with more than 10,000 square feet of reforestation. Soil compost amendments within a vegetated filter strip or grass channel should be located in a public right of way or within a dedicated stormwater or drainage easement. | | | | | | | |

# H.2 References

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# APPENDIX I STANDARD WORKSHEETS FOR EROSION AND SEDIMENT CONTROL

**Contents:**

# I.1 Compost Filter Sock

## STANDARD WORKSHEETS FOR EROSION AND SEDIMENT CONTROL

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________

Location: ______________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

**COMPOST FILTER SOCK**

| Sock No. | Sock Diameter (in) | Location of Compost Filter Sock Segment | Slope Percent (%) | Slope Length Above Barrier (ft) |
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# I.2 Standard Silt Fence

## STANDARD SILT FENCE

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________

Location: ______________________________

Prepared By: ____________________ Date: ____________

Checked By: ____________________ Date: ____________

| STANDARD SILT FENCE | | | |
|---|---|---|---|
| Fence No. | Location of Fence Segment | Slope Percent (%) | Slope Length Above Barrier (ft) |
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# I.3 Reinforced Silt Fence

## REINFORCED SILT FENCE

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________________________

Location: ______________________________________________

Prepared By: ____________________________ Date: ________________

Checked By: ____________________________ Date: ________________

| REINFORCED SILT FENCE | | | |
|---|---|---|---|
| Fence No. | Location of Fence Segment | Slope Percent (%) | Slope Length Above Barrier (ft) |
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# I.4 Super Silt Fence

## SUPER SILT FENCE

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________

Location: ______________________________

Prepared By: ______________________ Date: ____________

Checked By: ______________________ Date: ____________

| SUPER SILT FENCE | | | |
|---|---|---|---|
| Fence No. | Location of Fence Segment | Slope Percent (%) | Slope Length Above Barrier (ft) |
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# I.5 Straw Bale Barrier

## STRAW BALE BARRIER

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________

Location: ______________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

| STRAW BALE BARRIER | | | |
|---|---|---|---|
| Barrier No. | Location of Barrier Segment | Slope Percent (%) | Slope Length Above Barrier (ft) |
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# I.6 Wood Chip Filter Berm

**WOOD CHIP FILTER BERM**

**APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL**

Project Name: ______________________________________________

Location: ______________________________________________

Prepared By: ____________________________ Date: ________________

Checked By: ____________________________ Date: ________________

| WOOD CHIP FILTER BERM | | | |
|---|---|---|---|
| **Berm No.** | **Location of Berm Segment** | **Slope Percent (%)** | **Slope Length Above Barrier (ft)** |
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# I.7 Rock Check Dam

## ROCK CHECK DAM

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________________________

Location: ______________________________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

| ROCK CHECK DAM | | | | | |
|---|---|---|---|---|---|
| Rock Check Dam No. | Drainage Area (ac) | Location of Rock Check Dam | Channel Depth (ft) | Riprap Size $D_{50}$ (in) | Spacing Between Check Dams (ft) |
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# I.8 Stormwater Conveyance Channel

## STORMWATER CONVEYANCE CHANNEL

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ____________________________________________

Location: ____________________________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

| STORMWATER CONVEYANCE CHANNEL | | | | | | |
|---|---|---|---|---|---|---|
| **Channel No.** | | | | | | |
| Drainage Area | (ac) | | | | | |
| Design Storm Event | | | | | | |
| Required Capacity | (cfs) | | | | | |
| **CHANNEL DESIGN DATA** | | | | | | |
| Bottom Width | (ft) | | | | | |
| Sideslopes | (H:V) | | | | | |
| Total Depth | (ft) | | | | | |
| Top Width | (ft) | | | | | |
| Bed Slope | (ft/ft) | | | | | |
| Cross-Sectional Area | (sf) | | | | | |
| Hydraulic Radius | (ft) | | | | | |
| Manning's n Coefficient | | | | | | |
| **CALCULATED CHANNEL DATA** | | | | | | |
| Flow Depth | (ft) | | | | | |
| Velocity at Flow Depth | (fps) | | | | | |
| Capacity at Flow Depth | (cfs) | | | | | |
| Top Width at Flow Depth | (ft) | | | | | |
| Freeboard at Flow Depth | (ft) | | | | | |
| **MAXIMUM ALLOWABLE PROPERTIES** | | | | | | |
| Velocity at Flow Depth | (fps) | | | | | |
| Shear Stress at Flow Depth | (pcf) | | | | | |
| **CHANNEL PROTECTION DATA** | | | | | | |
| Median Stone Size $D_{50}$ | (in) | | | | | |
| Protective Lining Type | | | | | | |

# I.9 Sediment Basin

## SEDIMENT BASIN

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________________________

Location: ______________________________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

| SEDIMENT BASIN | | | | |
|---|---|---|---|---|
| **Sediment Basin No.** | | | | |
| Total Area Draining to Basin | (ac) | | | |
| **WET STORAGE DESIGN DATA** | | | | |
| Minimum Required Volume (67 cy/ac) | (cy) | | | |
| Basin Volume at Dewatering Orifice Invert Elevation | (cy) | | | |
| Excavation Volume to Obtain Required Volume | (cy) | | | |
| Available Volume before Cleanout Required (33 cy/ac) | (cy) | | | |
| Dewatering Orifice Invert to Cleanout Level Distance | (ft) | | | |
| **DRY STORAGE DESIGN DATA** | | | | |
| Minimum Required Volume (67 cy/ac) | (cy) | | | |
| Basin Volume at Crest of Riser Elevation (134 cy/ac) | (cy) | | | |
| Diameter of Dewatering Orifice | (in) | | | |
| Diameter of Flexible Tubing | (in) | | | |
| **PRELIMINARY DESIGN ELEVATIONS** | | | | |
| Crest of Riser | (ft) | | | |
| Dewatering Orifice Invert | (ft) | | | |
| Cleanout Level | (ft) | | | |
| Top of Dam | (ft) | | | |
| Design High Water (25-year Storm Elevation) | (ft) | | | |
| Upstream Toe of Dam | (ft) | | | |
| **BASIN SHAPE** | | | | |
| Surface Area of the Normal Pool (A) | (sf) | | | |
| Flow Path Length from Inflow to Outflow (L) | (ft) | | | |
| Effective Width ($W_e$ = A/L) | (ft) | | | |
| Length of Flow to Effective Width Ratio (L/$W_e$) | (L:W) | | | |
| Number of Baffles | | | | |
| Baffle Spacing | (ft) | | | |
| **RUNOFF** | | | | |
| 2-Year Peak Rate of Runoff ($Q_2$) | (cfs) | | | |
| 25-Year Peak Rate of Runoff ($Q_{25}$) | (cfs) | | | |
| **PRINCIPAL SPILLWAY DESIGN – WITHOUT EMERGENCY SPILLWAY** | | | | |
| Required Spillway Capacity ($Q_p = Q_{25}$) | (cfs) | | | |
| Assumed Available Head (using $Q_{25}$) | (cfs) | | | |
| **PRINCIPAL SPILLWAY DESIGN – WITH EMERGENCY SPILLWAY** | | | | |
| Required Spillway Capacity ($Q_p = Q_2$) | (ft) | | | |
| Assumed Available Head (using $Q_2$) | (ft) | | | |
| **PRINCIPAL SPILLWAY DESIGN** | | | | |
| Riser Diameter | (in) | | | |

## APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ____________________

Location: ____________________

Prepared By: ____________________ Date: ____________

Checked By: ____________________ Date: ____________

| SEDIMENT BASIN | | | | |
|---|---|---|---|---|
| Actual Head | (ft) | | | |
| Barrel Length | (ft) | | | |
| Head on Barrel Through Embankment | (ft) | | | |
| Barrel Diameter | (in) | | | |
| Trash Rack and Anti-Vortex Device Diameter | (in) | | | |
| Trash Rack and Anti-Vortex Device Height | (in) | | | |
| **EMERGENCY SPILLWAY DESIGN** | | | | |
| Required Spillway Capacity ($Q_e = Q_{25} - Q_p$) | (cfs) | | | |
| Bottom Width | (ft) | | | |
| Slope of the Exit Channel | (ft/ft) | | | |
| Minimum Length of the Exit Channel | (ft) | | | |
| **ANTI-SEEP COLLAR DESIGN** | | | | |
| Depth of Water at Principal Spillway Crest (Y) | (ft) | | | |
| Slope of Upstream Face of Embankment (Z) | (Z:1) | | | |
| Slope of Principal Spillway Barrel ($S_b$) | (ft) | | | |
| Length of Barrel in Saturated Zone ($L_s$) | (%) | | | |
| Number of Collars Required | (ft) | | | |
| Collar Dimensions | | | | |
| **FINAL DESIGN ELEVATIONS** | | | | |
| Top of Dam | (ft) | | | |
| Design High Water | (ft) | | | |
| Emergency Spillway Crest | (ft) | | | |
| Principal Spillway Crest | (ft) | | | |
| Dewatering Orifice Invert | (ft) | | | |
| Barrel Inlet Invert | (ft) | | | |
| Barrel Outlet Invert | (ft) | | | |
| Cleanout | (ft) | | | |
| Upstream Toe of Dam | (ft) | | | |

# I.10 Sediment Trap

**SEDIMENT TRAP**

**APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL**

Project Name: ____________________

Location: ____________________

Prepared By: ____________________ Date: __________

Checked By: ____________________ Date: __________

| SEDIMENT TRAP | | | | |
|---|---|---|---|---|
| **Sediment Trap No.** | | | | |
| Total Area Draining to Trap | (ac) | | | |
| **WET STORAGE DESIGN DATA** | | | | |
| Minimum Required Volume (67 cy/ac) | (cy) | | | |
| Surface Area of Flooded Area at Base of Outlet | (sf) | | | |
| Maximum Depth from Trap Low Point and Base of Outlet | (ft) | | | |
| Available Wet Storage Volume | (cy) | | | |
| **DRY STORAGE DESIGN DATA** | | | | |
| Minimum Required Volume (67 cy/ac) | (cy) | | | |
| Surface Area of Flooded Area at Base of Outlet | (sf) | | | |
| Surface Area of Flooded Area at Crest of Outlet | (sf) | | | |
| Available Dry Storage Volume | (cy) | | | |
| **TRAP SHAPE** | | | | |
| Length of Flow to Effective Width Ratio | (L:W) | | | |
| **EMBANKMENT** | | | | |
| Embankment Height | (ft) | | | |
| Outlet Height | (ft) | | | |
| Minimum Top Width | (ft) | | | |
| **STONE OUTLET** | | | | |
| Minimum Outlet Length (6 x Drainage Area) | (ft) | | | |
| Riprap Size | | | | |
| Coarse Aggregate Size | | | | |
| **COMPOST FILTER SOCK OUTLET** | | | | |
| Effective Height | (ft) | | | |
| Effective Base Width | (ft) | | | |
| Base Layer Sock Diameter | (in) | | | |
| Intermediate Layer Sock Diameter | (in) | | | |
| Top Layer Sock Diameter | (in) | | | |
| **PIPE OUTLET** | | | | |
| Riser Diameter | (in) | | | |
| Riser Crest Elevation | (ft) | | | |
| Barrel Diameter | (in) | | | |
| Barrel Length | (ft) | | | |
| Barrel Inlet Invert Elevations | (ft) | | | |
| Barrel Outlet Invert Elevations | (ft) | | | |
| Surface Skimmer Diameter | (in) | | | |
| Surface Skimmer Elevation | (ft) | | | |
| Dewatering Orifice Invert Elevations | (ft) | | | |

# I.11 Riprap Apron at Pipe Outlet to Flat Area with No Defined Channel

**RIPRAP APRON AT PIPE OUTLET TO FLAT AREA WITH NO DEFINED CHANNEL**

**APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL**

Project Name: ______________________________

Location: ______________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

**RIPRAP APRON AT PIPE OUTLET TO FLAT AREA WITH NO DEFINED CHANNEL**

| Apron No. | do (in) | Tailwater Cond. (min/max) | Pipe n | Pipe Slope (ft/ft) | Q (cfs) | V (fps) | Riprap Size $D_{50}$ (in) | d (in) | Apron Dimensions (ft) | | |
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Notes:
1. Q = Discharge
2. V = Velocity
3. do = pipe diameter
4. d = Riprap Thickness
5. La = Apron Length
6. Aiw = Apron Initial Width
7. Atw = Apron Terminal Width

# I.12 Riprap Apron at Pipe Outlet to an Existing Channel

## RIPRAP APRON AT PIPE OUTLET TO AN EXISTING CHANNEL

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________________________

Location: ______________________________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

**RIPRAP APRON AT PIPE OUTLET TO AN EXISTING CHANNEL**

| Apron No. | do (in) | Tailwater Cond. (min/max) | Pipe n | Pipe Slope (ft/ft) | Q (cfs) | V (fps) | Riprap Size $D_{50}$ (in) | d (in) | Apron Dimensions (ft) | | | | | Side Slopes (H:V) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | La | Ibw | Tbw | Itw | Ttw | |
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Notes:

1. Q = Discharge
2. V = Velocity
3. d = Riprap Thickness
4. La = Apron Length
5. Ibw = Initial Bottom Width
6. Tbw = Terminal Bottom Width
7. Itw = Initial Top Width
8. Ttw = Terminal Top Width

# I.13 Plunge Pool

## PLUNGE POOL

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________________________

Location: ______________________________________________

Prepared By: ______________________________ Date: ______________

Checked By: ______________________________ Date: ______________

**PLUNGE POOL**

| Outlet No. | Type (I or II) | Pipe Outlet | | Plunge Pool | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Q (cfs) | do (in) | D (ft) | L (ft) | W (ft) | BL (ft) | BW (ft) | Riprap Size $D_{50}$ (in) | d (ft) |
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Notes:

1. Q = Discharge
2. do = Pipe Diameter
3. D = Depth
4. L = Length
5. W = Width
6. BL = Bottom Length
7. BW = Bottom Width
8. d = Riprap Thickness

# I.14 Subsurface Drain

## SUBSURFACE DRAIN

### APPENDIX I STANDARD WORSKEETS FOR EROSION AND SEDIMENT CONTROL

Project Name: ______________________________

Location: ______________________________

Prepared By: ______________________ Date: ______________

Checked By: ______________________ Date: ______________

| SUBSURFACE DRAIN | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Type (Relief or Interceptor) | Pattern (Random or Uniform) | Drain Pipe Type | Pipe n | Dia. (in) | Grade (%) | Length (ft) | Required Capacity (cfs) | Relief Drain Spacing (ft) | Interceptor Drain Spacing (ft) |
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# APPENDIX J STANDARDS AND SPECIFICATIONS

**Contents:**



Virginia Department of Environmental Quality

**Standards and Specifications #** ___________ (Note: to be entered by the Department)

**Standards and Specifications Agreement**

**For**

**[ENTITY NAME]**

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## J.1 Standards and Specifications Entity

Entity Name: ______________________________

Entity Address: ______________________________

City, State, and Zip Code: ______________________________

Contact Name: ______________________________

Contact Phone: ______________________________

Contact Email: ______________________________

Alt. Contact Name: ______________________________

Alt. Contact Phone: ______________________________

Alt. Contact Email: ______________________________

## J.2 Standards and Specifications Entity Type

☐ State
☐ Federal
☐ Linear Utility
☐ Public Service Authority
☐ Wetland/Stream

# J.3 Standards and Specifications Agreement Information

Agreement Date: ______________________________

Date of previously approved agreement: ______________________________

Have there been any updates to your previously approved agreement? ☐ Yes ☐ No

# J.4 Certification

"I certify under penalty of law that this agreement and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

Printed Name: ______________________________
Title: ______________________________
Signature: ______________________________
Date: ______________________________

**Standards and Specifications Agreement**

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# J.5 Administration

Per § 62.1-44.15:31 of the Code of Virginia, the Virginia Department of Transportation shall; any other state agency or federal entity may; and electric, natural gas, and telephone utility companies; interstate and intrastate natural gas pipeline companies; railroad companies; and authorities created pursuant to § 15.2-5102 of the Code of Virginia may submit standards and specifications, for approval by the Virginia Department of Environmental Quality (Department), who serves as the Virginia Erosion and Stormwater Management Program (VESMP) authority for all land-disturbing activities subject to approved standards and specifications. The Standards and Specifications Program is designed to provide a single set of standards and specifications, the Virginia Stormwater Management Handbook, Version 1.0, that describes how entities with approved standards and specifications conduct land-disturbing activities in a manner that will be consistent with the requirements of the Virginia Erosion and Stormwater Management Act (VESMA), Virginia Erosion and Stormwater Management Regulation, and the General Virginia Pollutant Discharge Elimination System (VPDES) Permit for Discharges of Stormwater from Construction Activities (Construction General Permit).

**[ENTITY NAME], hereinafter the "S&S Entity,"** is responsible for administering, implementing, and complying with the standards and specifications for Erosion and Sediment Control (ESC) and Stormwater Management (SWM) set out in this agreement by following the design criteria in the Virginia Stormwater Management Handbook, Version 1.0, for **[SPECIFY THE ACTIVITIES THAT WILL BE COVERED UNDER THIS AGREEMENT].**

## J.6 Regulated Land-Disturbing Activities

A. Land-disturbing activities that meet one of the criteria below are regulated as follows:

1. Land-disturbing activity that disturbs 10,000 square feet or more, is less than one acre, not in an area of a locality designated as a Chesapeake Bay Preservation Area, and not part of a common plan of development or sale, is subject to criteria defined in Article 2 (9VAC25-875-540 et seq.) of Part V of the Virginia Erosion and Stormwater Management Regulation (Regulation).
2. Land-disturbing activity that disturbs 2,500 square feet or more, is less than one acre, and in an area of a locality designated as a Chesapeake Bay Preservation Area is subject to criteria defined in Article 2 (9VAC25-875-540 et seq.) and Article 3 (9VAC25-875-570 et seq.) of Part V of the Regulation unless Article 4 (9VAC25-875-670 et seq) of Part V is applicable, as determined in accordance with 9VAC25-875-480 and 9VAC25-875-490.
3. Land-disturbing activity that disturbs less than one acre, but is part of a larger common plan of development or sale that disturbs one acre or more, is subject to criteria defined in Article 2 (9VAC25-875-540 et seq.) and Article 3 (9VAC25-875-570 et seq.) of Part V of the Regulation unless Article 4 (9VAC25-875-670 et seq) of Part V is applicable, as determined in accordance with 9VAC25-875-480 and 9VAC25-875-490.
4. Land-disturbing activity that disturbs one acre or more is subject to criteria defined in Article 2 (9VAC25-875-540 et seq.) and Article 3 (9VAC25-875-570 et seq.) of Part V of the Regulation unless Article 4 (9VAC25-875-670 et seq.) of Part V is applicable, as determined in accordance with 9VAC25- 875-480 and 9VAC25-875-490.

B. Land-disturbing activities exempt per 9VAC25-875-90 are not required to comply with the requirements of the VESMA unless otherwise required by federal law.

## J.7 Certified Personnel

A. The S&S Entity's administrator shall be responsible for the management and coordination of this standards and specifications agreement and shall be certified as a Dual Combined Administrator as outlined in 9VAC25- 875-400.

B. Plan Reviewers shall review all ESC and SWM plans for compliance with this standards and specifications agreement and all applicable laws and regulations. Plan reviewers shall be certified as a Plan Reviewer for ESC and a Plan Reviewer for SWM or as a Dual Plan Reviewer, as outlined in 9VAC25-875-400.

C. Compliance inspectors shall be responsible for the inspection and compliance of ESC, SWM, and stormwater pollution prevention plan practices. They shall be certified as an Inspector for ESC and an Inspector for SWM or as a Dual Inspector, as outlined in 9VAC25-875-400.

## J.8 Review and Approval of Plans

A. The S&S Entity has the authority to approve soil erosion control and stormwater management (ESM) plans, except for activities not required to comply with the requirements of the Virginia Erosion and Stormwater Management Act (VESMA), under § 62.1-44.15:34 of the Code of Virginia. The ESM plan is a document describing methods for controlling soil erosion and managing stormwater in accordance with the requirements adopted pursuant to the VESMA. The ESM plan may consist of aspects of the erosion and sediment control plan and the stormwater management plan as each is described in the Virginia Erosion and Stormwater Management Regulation. (9VAC25-875-20)

B. ESM plans must be approved in writing. If a third party is used to fulfill the certification of the plan reviewer, the third-party reviewer may recommend approval to the S&S Entity; however, the S&S Entity formally approves the plan in writing. The date of the approvable plan should be noted in the approval letter signed by the S&S Entity's certified plan reviewer.

C. Plans must be reviewed and approved by Department-certified personnel, as outlined in 9VAC25-875-400, to ensure compliance with these Standards and Specifications for ESC and SWM and reviewed by the S&S Entity for consistency with the Virginia Stormwater Management Handbook, Version 1.0, and applicable permit and regulatory requirements.

D. The Department may require changes to an approved ESM plan in the following cases:

   1. Where inspection has revealed that the plan is inadequate to satisfy applicable regulations or ordinances; or

   2. Where the S&S Entity finds that because of changed circumstances, or for other reasons, the plan cannot be effectively carried out and proposed amendments to the plan, consistent with the requirements of the VESMA, are agreed to by the department, as the VESMP authority, and the S&S Entity.

## J.9 Erosion and Sediment Control Plan – Contents of Plans

A. The S&S Entity shall prepare an erosion and sediment control plan for its land-disturbing activities. The erosion and sediment control plan shall contain all major conservation decisions to ensure that the entire unit or units of land will be treated to achieve the conservation objectives in 9VAC25-875-560. The erosion and sediment control plan shall be prepared in accordance with 9 VAC25-875-550 and be consistent with design criteria in the Virginia Stormwater Management Handbook, Version 1.0.

B. The person responsible for carrying out the plan shall provide the name of an individual holding a certificate who will be in charge of and responsible for carrying out the land-disturbing activity to the Department.

## J.10 Erosion and Sediment Control Variances and Exceptions

A. The Department may waive or modify any of the standards that are deemed to be inappropriate or too restrictive for site conditions, by granting a variance. A variance may be granted under these conditions:

   1. Prior to construction, the S&S Entity may request a variance to become part of the approved erosion and sediment control plan. The S&S Entity shall explain the reasons for requesting variances in writing. Specific variances which are allowed by the department shall be documented in the plan.

   2. During construction, the person responsible for implementing the approved plan may request a variance in writing from the Department. The Department shall respond in writing either approving or disapproving such a request. If the department does not approve a variance within 10 days of receipt of the request, the request shall be considered disapproved. Following disapproval, the applicant may resubmit a variance request with additional documentation.

## J.11 Stormwater Pollution Prevention Plan Contents

A. A stormwater pollution prevention plan shall include, but not be limited to, an approved erosion and sediment control plan, an approved stormwater management plan, a pollution prevention plan for regulated land- disturbing activities, and a description of any additional control measures necessary to address a total maximum daily load (TMDL) pursuant to 9VAC25-875-500 E.

B. An erosion and sediment control plan consistent with the requirements of 9VAC25-875-550 must be designed and implemented during construction activities. Prior to land disturbance, this plan must be approved by a Plan Reviewer for ESC or a Dual Plan Reviewer.

C. A stormwater management plan consistent with the requirements of 9VAC25-875-510 and the design criteria in the Virginia Stormwater Management Handbook, Version 1.0, must be designed and implemented during construction activities. Prior to land disturbance, this plan must be approved by a Plan Reviewer for SWM or a Dual Plan Reviewer.

D. A pollution prevention plan that complies with 9VAC25-875-520 and identifies potential sources of pollutants that may reasonably be expected to affect the quality of stormwater discharges from the construction site and describes control measures that will be used to minimize pollutants in stormwater discharges from the construction site must be developed before land disturbance commences.

E. In addition to the requirements of subsections A through D of this section, if a specific wasteload allocation for a pollutant has been established in an approved TMDL and is assigned to stormwater discharges from a construction activity, additional control measures that are consistent with the Virginia Stormwater Management Handbook, Version 1.0, must be identified and implemented by the operator so that discharges are consistent with the assumptions and requirements of the wasteload allocation.

F. The stormwater pollution prevention plan must address the requirements specified in 40 CFR 450.21, to the extent otherwise required by state law or regulations and any applicable provisions of a state permit:

1. Control stormwater volume and velocity within the site to minimize soil erosion;
2. Control stormwater discharges, including both peak flow rates and total stormwater volume, to minimize erosion at outlets and to minimize downstream channel and stream bank erosion;
3. Minimize the amount of soil exposed during construction activity;
4. Minimize the disturbance of steep slopes;
5. Minimize sediment discharges from the site. The design, installation, and maintenance of erosion and sediment controls must address factors such as the amount, frequency, intensity, and duration of precipitation, the nature of resulting stormwater runoff, and soil characteristics, including the range of soil particle sizes expected to be present on the site;
6. Provide and maintain natural buffers around surface waters, direct stormwater to vegetated areas to increase sediment removal and maximize stormwater infiltration, unless infeasible;
7. Minimize soil compaction and, unless infeasible, preserve topsoil;
8. Stabilization of disturbed areas must, at a minimum, be initiated immediately whenever any clearing, grading, excavating, or other earth-disturbing activities have permanently ceased on any portion of the site, or temporarily ceased on any portion of the site and will not resume for a period exceeding 14 calendar days. Stabilization must be completed within a reasonable period of time or as otherwise determined by the department. In arid, semiarid, and drought-stricken areas where initiating vegetative stabilization measures immediately is infeasible, alternative stabilization measures must be employed as specified by the Department; and
9. Utilize outlet structures that withdraw water from the surface, unless infeasible, when discharging from basins and impoundments.

G. The stormwater pollution prevention plan shall be amended whenever there is a change in design, construction, operation, or maintenance that has a significant effect on the discharge of pollutants to state waters and that has not been previously addressed in the plan. The stormwater pollution prevention plan must be maintained at a central onsite location. If an onsite location is unavailable, notice of the stormwater pollution prevention plan's location must be posted near the main entrance at the construction site.

## J.12 Stormwater Management Plan Contents

A. A stormwater management plan shall be developed and implemented as approved or modified by the Department-certified plan reviewer and shall be developed in accordance with the following:

   1. A stormwater management plan for a land-disturbing activity shall apply the stormwater management technical criteria outlined in Article 3 (9VAC25-875-570 et seq.) of Part V of the Regulation to the entire land-disturbing activity.
   2. A stormwater management plan shall consider all sources of surface runoff and all sources of subsurface and groundwater flows converted to surface runoff; and
   3. Best management practices in the stormwater management plan are consistent with design criteria in the Virginia Stormwater Management Handbook, Version 1.0.

B. A complete stormwater management plan shall address all requirements of 9VAC25-875-510.

C. All final plan elements, specifications, or calculations of the stormwater management plans whose preparation requires a license under Chapter 4 (§ 54.1-400 et seq.) or 22 (§ 54.1- 2200 et seq.) of Title 54.1 of the Code of Virginia shall be appropriately signed and sealed by a professional who is licensed to engage in practice in the Commonwealth of Virginia. Nothing in this subsection shall authorize any person to engage in practice outside his area of professional competence.

## J.13 Pollution Prevention Plan Contents

A. A plan for implementing pollution prevention measures during construction activities shall be developed, implemented, and updated as necessary. The pollution prevention plan shall detail the design, installation, implementation, and maintenance of effective pollution prevention measures as specified in 40 CFR 450.21(d) to minimize the discharge of pollutants. At a minimum, such measures must be designed, installed, implemented, and maintained to:

   1. Minimize the discharge of pollutants from equipment and vehicle washing, wheel wash water, and other wash waters. Wash waters must be treated in a sediment basin or alternative control that provides equivalent or better treatment prior to discharge;
   2. Minimize the exposure of building materials, building products, construction wastes, trash, landscape materials, fertilizers, pesticides, herbicides, detergents, sanitary waste, and other materials present on the site to precipitation and to stormwater; and
   3. Minimize the discharge of pollutants from spills and leaks and implement chemical spill and leak prevention and response procedures.

B. The pollution prevention plan shall include effective best management practices to prohibit the following discharges in accordance with 40 CFR 450.21(e):

   1. Wastewater from washout of concrete, unless managed by an appropriate control;
   2. Wastewater from washout and cleanout of stucco, paint, form release oils, curing compounds, and other construction materials;
   3. Fuels, oils, or other pollutants used in vehicle and equipment operation and maintenance; and
   4. Soaps or solvents used in vehicle and equipment washing.

C. Discharges from dewatering activities, including discharges from dewatering of trenches and excavations, are prohibited unless managed by appropriate controls in accordance with 40 CFR 450.21(c).

## J.14 Technical Criteria for Regulated Land-Disturbing Activities

A. To protect the quality and quantity of state water from the potential harm of unmanaged stormwater runoff resulting from land-disturbing activities, the S&S Entity shall adhere to the technical criteria for regulated land-disturbing activities set forth in Part V of the Regulation expressly to include 9VAC25-

875-580 [water quality design criteria requirements]; 9VAC25-875-590 [water quality compliance]; 9VAC25-875-600 [water quantity]; 9VAC25-875-610 [offsite compliance options]; 9VAC25-875-620 [design storms and hydrologic methods]; 9VAC25-875-630 [stormwater harvesting]; 9VAC25-875-640 [linear development project]; and, 9VAC25-875-650 [stormwater management impoundment structures or facilities], which shall apply to all land-disturbing activities, except as expressly set forth in 9VAC25-875-490.

B. The S&S Entity shall submit documentation that offsite options, approved by the Department or applicable state board, that are required to achieve the necessary phosphorous water quality reductions have been obtained prior to the commencement of the land-disturbing activity (i.e., prior to issuance of the permit). In the case of a phased project, the land disturber may acquire or achieve the offsite nutrient reductions prior to the commencement of each phase of the land-disturbing activity in an amount sufficient for each such phase.

# J.15 Long-Term Maintenance of Permanent Stormwater Facilities

A. The S&S Entity shall submit a construction record drawing for permanent stormwater management facilities to the VESMP authority based on the locality where the land-disturbing activity will occur. The record drawing shall contain a statement signed by a professional registered in the Commonwealth of Virginia pursuant to Chapter 4 (§ 54.1-400 et seq.) of Title 54.1 of the Code of Virginia, stating that to the best of the professional's knowledge, the construction record drawing shows all adjustments and revisions to the stormwater management plan made during construction and serve as a permanent record of the actual location of all constructed elements.

B. The provision of long-term responsibility for and maintenance of stormwater management facilities and other techniques specified to manage the quality or quantity of runoff is required. Such requirements shall be set forth in a maintenance agreement which is recorded in the local land records prior to permit termination or earlier and shall at a minimum:

1. Be submitted to the VESMP authority for review and approval prior to the approval of the stormwater management plan;

2. Be stated to run with the land;

3. Provide for all necessary access to the property for purposes of maintenance and regulatory inspections;

4. Provide for inspections and maintenance and the submission of inspection and maintenance reports to the VESCP, or VESMP authority; and

5. Be enforceable by all appropriate governmental parties.

(Note: the Department has approved a model stormwater management facility maintenance agreement for use on projects where it is the permitting authority. The model agreement is in Section 10.2.1.1 of the Handbook.)

# J.16 Project Tracking and Reporting

A. The S&S Entity is responsible for providing project tracking and electronic notifications to the Department of all regulated land-disturbing activities subject to this standards and specifications agreement to comply with the applicable ESC and SWM requirements pursuant to 9VAC25-875-830 D 6.

B. The S&S Entity must electronically notify the Department of any land- disturbing activities subject to approved standards and specifications that the S&S Entity intends to construct in Virginia prior to initiating land disturbance. The following information is required to be included in the electronic notification two weeks prior to initiating the regulated land-disturbing activity:

1. Project name and any associated Construction General Permit number;
2. Project location (including nearest intersection, latitude and longitude, or access point);
3. On-site project manager name and contact information;
4. Responsible Land Disturber (RLD) name and contact information;
5. Project description;
6. Acreage of disturbance for the project;
7. Anticipated project start and finish date; and
8. Any deviations/variances/exemptions/waivers associated with the project.

C. In addition to the prior land disturbance notification described above, the S&S Entity shall submit to the Department bi-annual linear project tracking of all active projects covered under this standards and specifications agreement from the last six months (including those previously reported). This bi-annual linear project tracking must include the acreage for all listed projects and shall be submitted by January 15th and July 15th of each year to the Department.

## J.17 Monitoring, Inspections, and Enforcement

A. The S&S Entity or its designated inspector shall perform periodic inspections of the land-disturbing activity during construction for:

1. Compliance with the approved erosion and sediment control plan;
2. Compliance with the approved stormwater management plan;
3. Development, updating, and implementation of a pollution prevention plan;
4. Compliance with these Standards and Specifications.;
5. Compliance with the permit, if applicable; and
6. Development and implementation of additional control measures necessary to address a TMDL.

B. Periodic inspections are the responsibility of the S&S Entity and shall be conducted by an Inspector for ESC and Inspector for SWM or a Dual Inspector, as outlined in 9VAC25-875-400.

C. The Department will conduct periodic inspections on all projects during construction, including random inspections and inspections in response to complaints. Where inspections by Department personnel reveal deficiencies in carrying out an approved plan, the Department may take enforcement actions in accordance with the VESMA and related regulations.