

Chapter 8: Virginia Stormwater Management Handbook (version 1.1)

Design Specifications for Post-Construction BMPs

The Virginia Stormwater Management Handbook (Handbook) is intended to be a web-based living document that can be updated in a timely manner to reflect changes in laws, regulations, technology, and best management practices.

The Virginia Department of Environmental Quality (DEQ) will utilize a public notice and engagement process when making substantive updates to BMP specifications and other technical content in the Handbook.

- The most current version of the Handbook can always be found online at <https://online.encodeplus.com/regs/deq-va/index.aspx>

Version 1.1
August 2024



CHAPTER 8 DESIGN SPECIFICATIONS FOR POST-CONSTRUCTION BMPs

Contents:

- 8.1 Introduction to the New Virginia Post-Construction Stormwater Best Management Practices
- 8.2 Significant Updates
 - 8.2.1 Post-Construction Stormwater BMP Framework
 - 8.2.2 Post-Construction Stormwater BMP Numbering and Nomenclature
- 8.3 Overview of Best Management Practices
 - 8.3.1 Basins – P-BAS
 - 8.3.2 Conveyance – P-CNV
 - 8.3.3 Filtration and Infiltration – P-FIL
 - 8.3.4 Support Components – P- SUP
- 8.4 Overview of Manufactured Treatment Devices
 - 8.4.1 Hydrodynamic Devices – MTD-H
 - 8.4.1.1 General Overview
 - 8.4.1.2 Hydrodynamic Devices in Virginia
 - 8.4.2 Filtering Devices – MTD-F
 - 8.4.2.1 General Overview
 - 8.4.2.2 Filtering Devices in Virginia
 - 8.4.3 Biofilter Devices – MTD-B
 - 8.4.3.1 General Overview
 - 8.4.3.2 Biofilter Devices in Virginia
 - 8.4.4 MTD Approval Process
 - 8.4.4.1 MTD Evaluation Process
 - 8.4.4.2 VDEQ Evaluations
 - 8.4.4.3 Sizing Information
- 8.5 Standards and Specifications for Post-Construction BMPs
 - List of BMPs
 - P-BAS-01 Constructed Wetlands
 - 1.0 Definition
 - 2.0 Purpose and Applicability of Best Management Practice
 - 3.0 Planning and Considerations
 - 4.0 Stormwater Performance Summary
 - 5.0 Design Criteria
 - 6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-BAS-02 Wet Pond

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

9.0 Appendix A Sample Construction Inspection Checklist for Wet Ponds

P-BAS-03 Extended Detention Pond

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-BAS-04 Rainwater Harvesting

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-CNV-01 Grass Channels

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-CNV-02 Dry Swales

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-CNV-03 Wet Swales

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-CNV-04 Regenerative Stormwater Conveyance

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-01 Rooftop Disconnection

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-02 Vegetated Roof

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice

- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-03 Permeable Pavement

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-04 Infiltration Practices

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-05 Bioretention

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References
- 9.0 Appendix A Micro-bioretention
- 10.0 Appendix B Ultra-Urban Bioretention

P-FIL-06 Filtering Practices

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations

- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-07 Sheet Flow to Vegetated Filter Strip or Conserved Open Space

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-08 Soil Compost Amendment

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 Construction Specifications
- 7.0 Operations and Maintenance Considerations
- 8.0 References

P-FIL-09 Tree Planting

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practice
- 3.0 Planning and Considerations
- 4.0 Stormwater Performance Summary
- 5.0 Design Criteria
- 6.0 References
- 7.0 Appendix A Runoff Reduction Computation Methodology for Tree Planting Over Turf

P-SUP-01 Earthen Embankment

- 1.0 Definition
- 2.0 Purpose and Applicability of Best Management Practices
- 3.0 Design Criteria
- 4.0 Construction Specifications
- 5.0 Operations and Maintenance Considerations
- 6.0 Typical Details

7.0 References

P-SUP-02 Principal Spillways

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-SUP-03 Vegetated Emergency Spillway

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-SUP-06 Pre-Treatment

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References

P-SUP-07 Quantity Only Approach to BMPs

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 Underground Detention Basin

9.0 References

P-SUP-08 Permanent Level Spreader

1.0 Definition

2.0 Purpose and Applicability of Best Management Practice

3.0 Planning and Considerations

4.0 Stormwater Performance Summary

5.0 Design Criteria

6.0 Construction Specifications

7.0 Operations and Maintenance Considerations

8.0 References



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 Erosion and 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.
- [P-SUP-08](#) Permanent Level Spreader

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 MTRF 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 MTRF 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 MTRF.

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/ft² = 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/ft ²	40%	NJDEP
BayFilter using Enhanced Media Cartridges (EMC)	MTD-F-02	0.50 gpm/ft ² * 0.33 gpm/ft ² **	64%	TAPE TP GULD
StormTech Isolator Row Plus	MTD-F-03	4.13 gpm/ft ²	40%	NJCAT
HydroFilter	MTD-F-04	2.0 gpm/ft ²	40%	NJDEP

Table 8-2 Filtering MTDs Approved by VDEQ

MTD Name	BMP #	Hydraulic Loading Rate	Approved TP Removal Efficiency	Basis for VDEQ Approval
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	<i>4.00 gpm/ft²</i>	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
Filtterra HC Biofiltration	MTD-B-05	3.12 gpm/ft ²	40%	NJDEP
Filtterra Biofiltration	MTD-B-06	1.00 gpm/ft ²	65%	TAPE TP GULD
Filtterra 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

Table 8-3 Biofiltering MTDs Approved by VDEQ

MTD Name	BMP #	Hydraulic Loading Rate*	Approved TP Removal Efficiency	The Basis for VDEQ approval

*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.
- 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.

Unless a higher efficiency is provided by another state, regional, or national verification or certification program, the VDEQ will assign a percent TP removal efficiency as follows:

Certification	Assigned TP Removal Efficiency ¹
TAPE TP Removal: ≥50%	50%
TAPE TSS Removal: ≥80%	40%
NJDEP TSS Removal: 80%	40%
NJDEP TSS Removal: 50%	20%

When a higher efficiency is provided, the VDEQ will use the higher efficiency. These assignments of removal efficiencies are not an endorsement of any product by the VDEQ.

¹Defined as the change in the average event mean concentration (EMC)

"TAPE" means Washington State's Technology Assessment Protocol - Ecology program

"NJDEP" means New Jersey Department of Environmental Protection

"TP" means Total Phosphorus

"TSS" means Total Suspended Solids

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 ($qpTv \leq MTFR$).
 - 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 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 <i>P-BAS-01-1</i> .
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. 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).
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.

Table P-BAS-01-1 Feasibility Criteria

Parameter	Discussion
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	
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. 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%

Table P-BAS-01-4 Summary of Stormwater Functions Provided by Constructed Wetlands

Stormwater Function	Level 1 Design	Level 2 Design
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. and 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. 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. 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	$TvBMP = [(Rv)(A)] / 12 + \text{the volume remaining from any upstream BMPs}$	$TvBMP = [1.5(Rv)(A)] / 12 + \text{the volume remaining from any upstream BMPs}$
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. • 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)

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)
Pre-treatment ¹	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. Length of shortest flow path/overall length = 0.5 or more ³	Length/Width ratio OR Flow path = 3:1 or more. 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 - Multi-cell Wetland: Emergent and upland wetland design - Pond/Wetland Combination: Pond and emergent wetland design

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

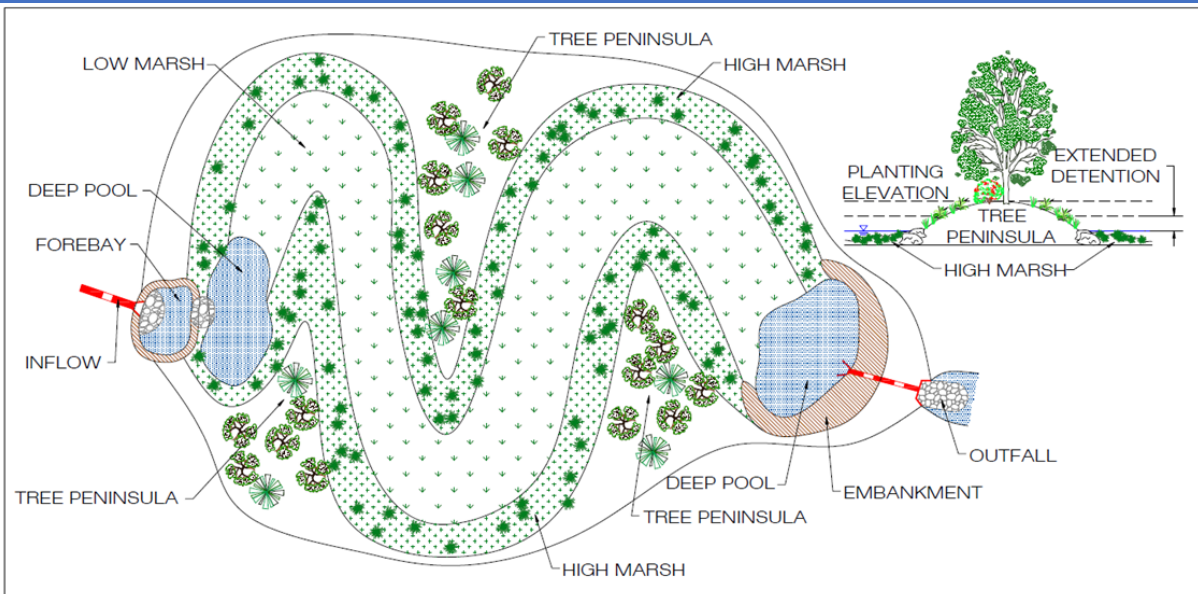


Figure P-BAS-01-3 Constructed Wetland Level 1 Plan and Cross Section

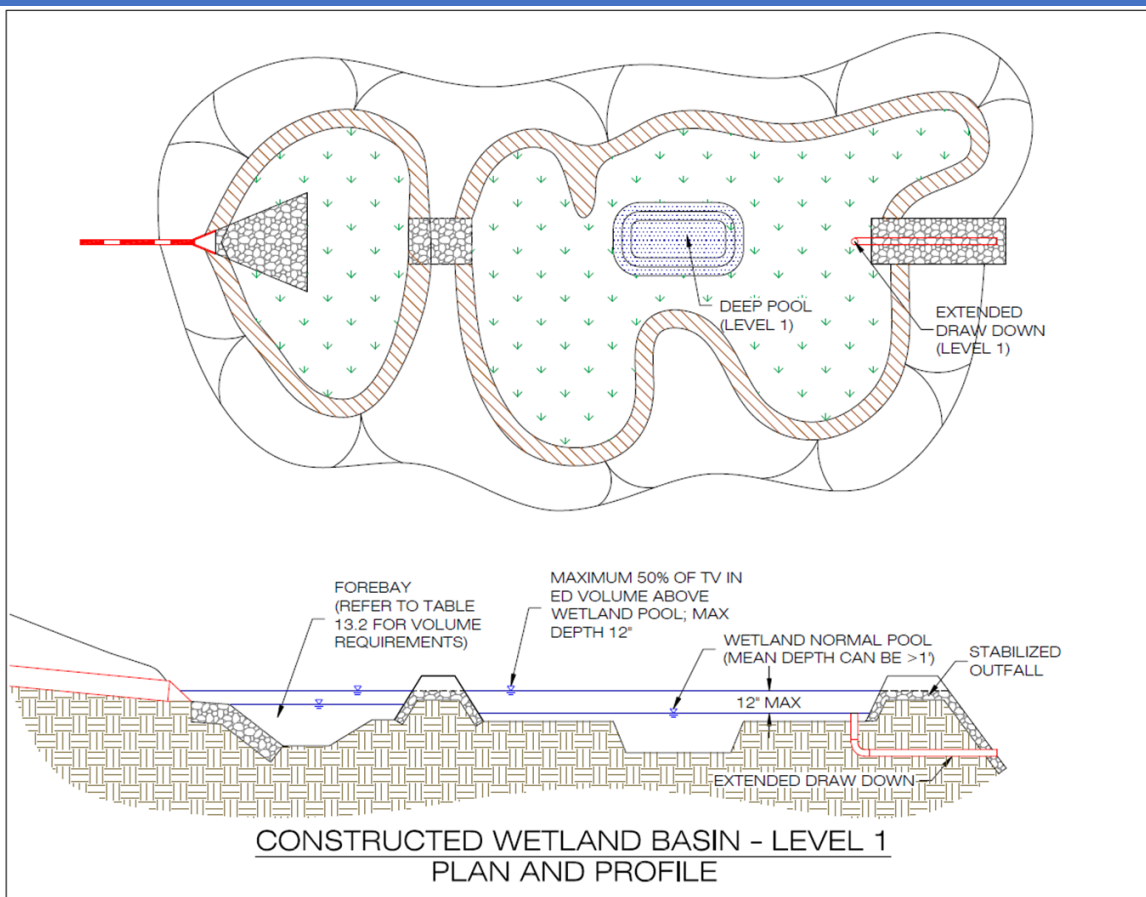


Figure P-BAS-01-4 Constructed Wetland Level 2 Plan and Cross Section

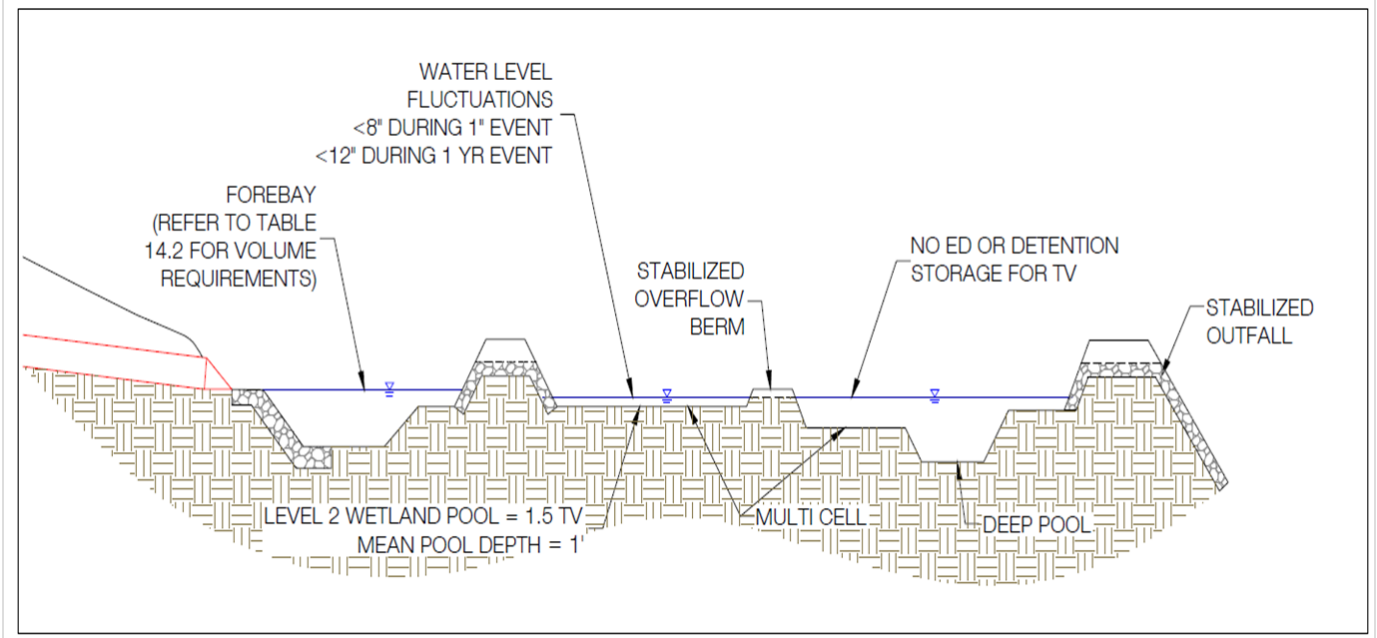
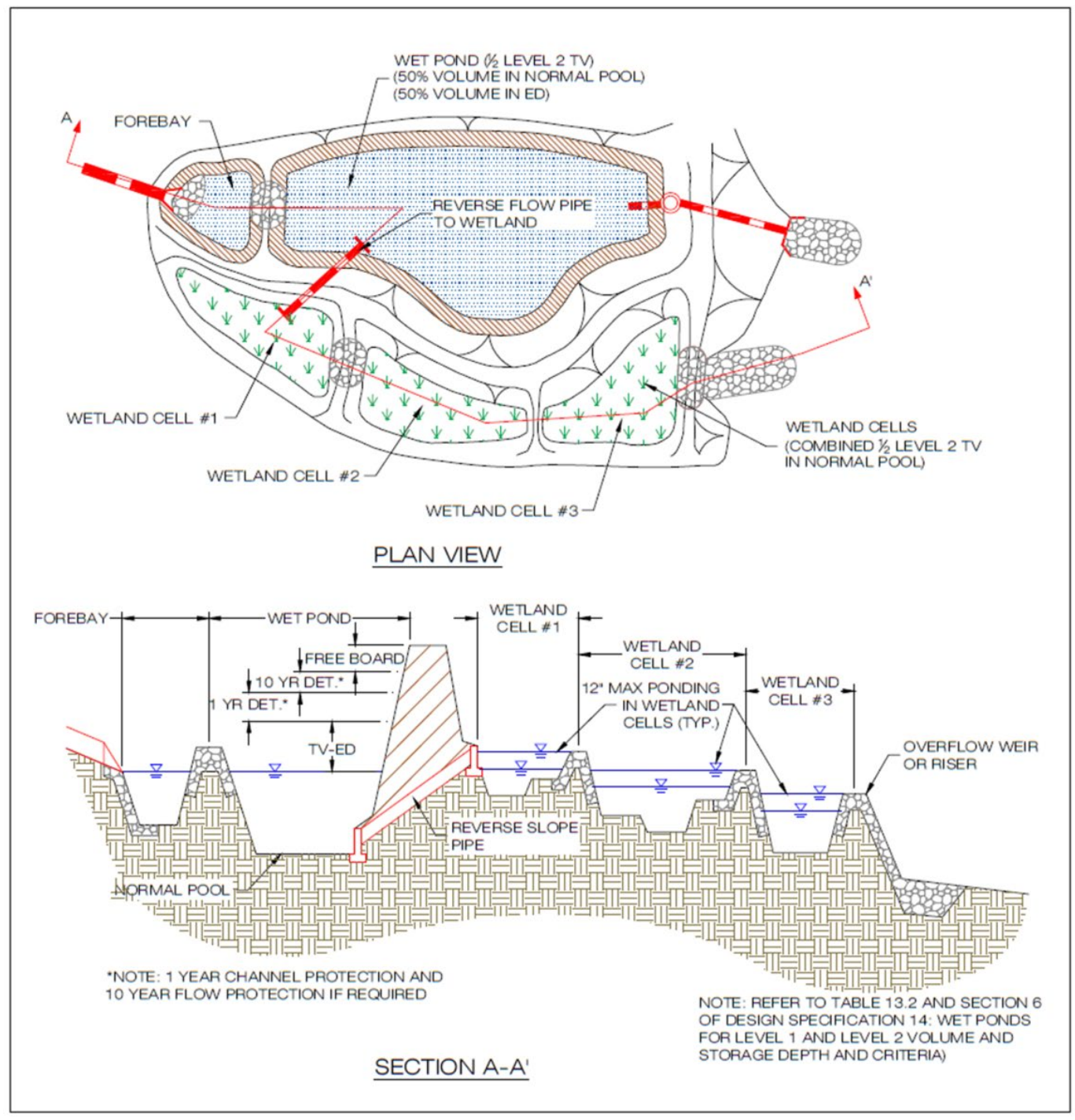


Figure P-BAS-01-5 Constructed Wetland Level 2 Combination Wet Pond and Wetland Plan and Section



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 T_v for the Level 1 design (i.e., $1.50[R_v][A]$). 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 T_v 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 T_v and channel protection above the pool is limited to 12 inches (the T_v 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 T_v storage above the wetland cell pools – the entire T_v 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 T_v or larger design storms: maximum of 8 inches during the T_v (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 T_v in the form of the permanent pool and 50 percent of the wet pond cell T_v 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" (RF_m) – 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 Zones¹

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. ▪ Pipe velocities support minimum velocities for sediment flushing per Virginia Department of Transportation (VDOT) Drainage Manual requirements. 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 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 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 (T_v) 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

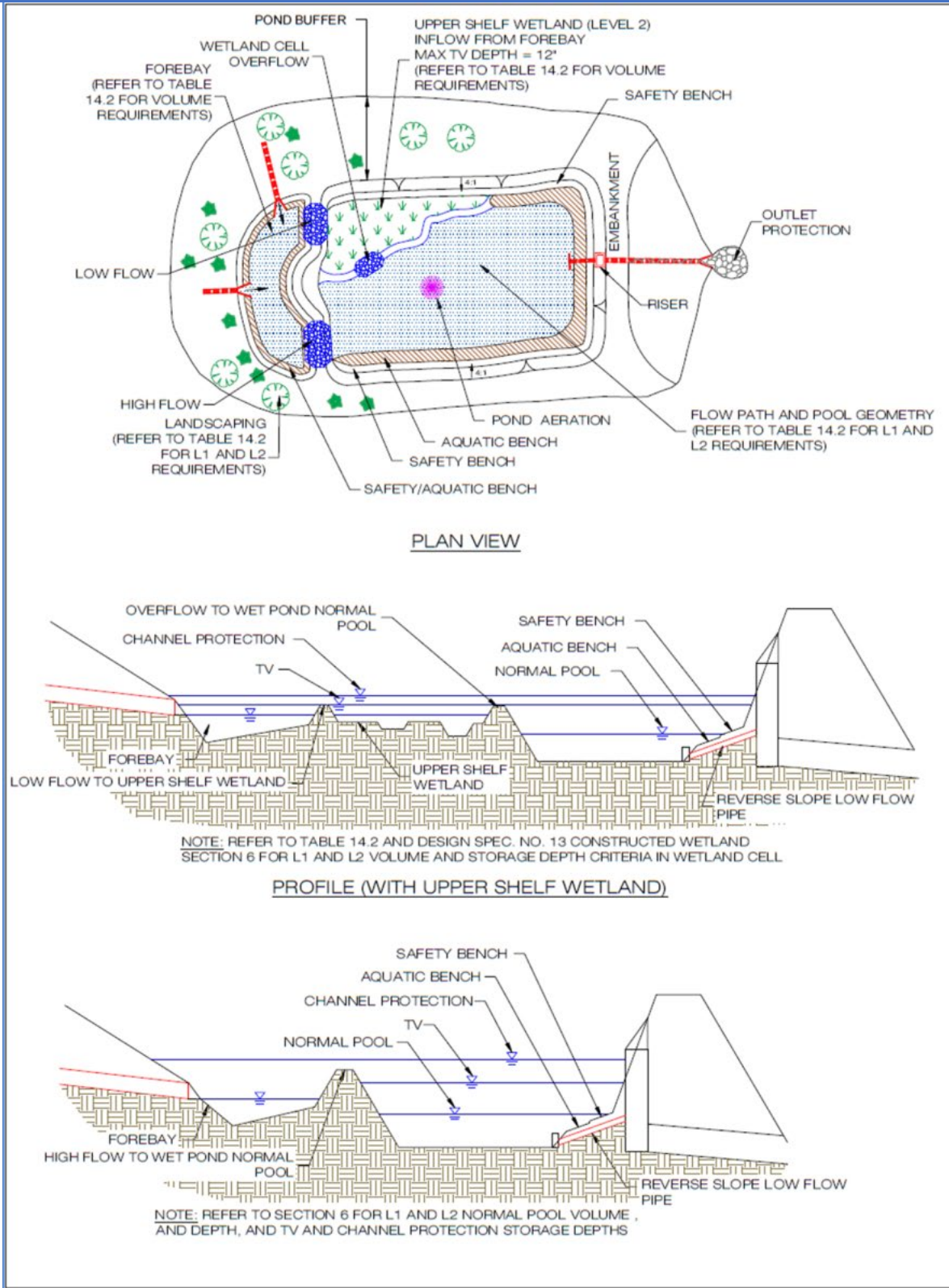
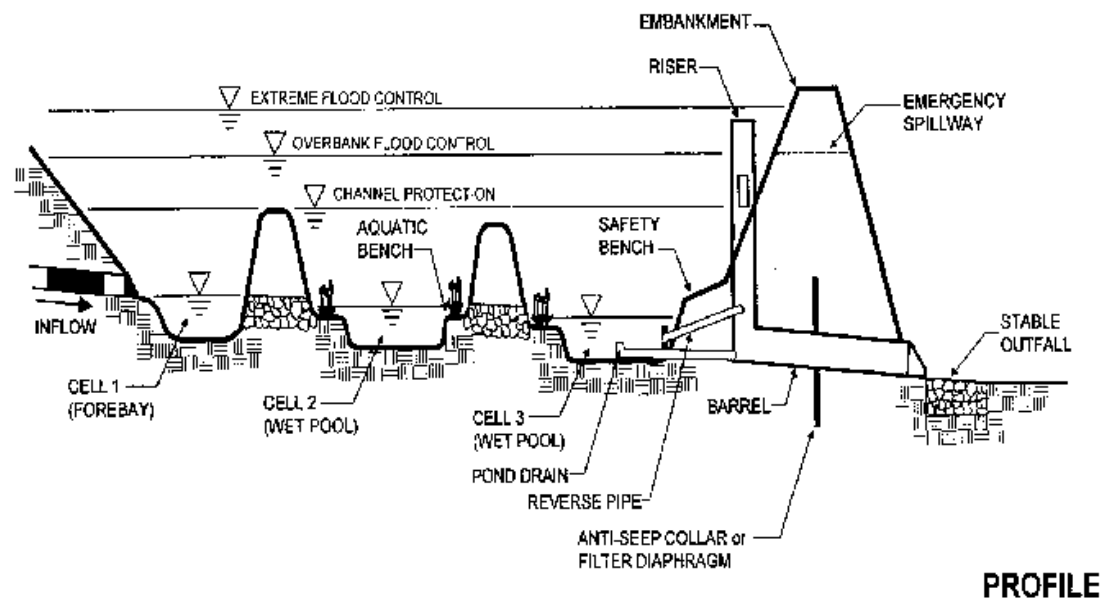
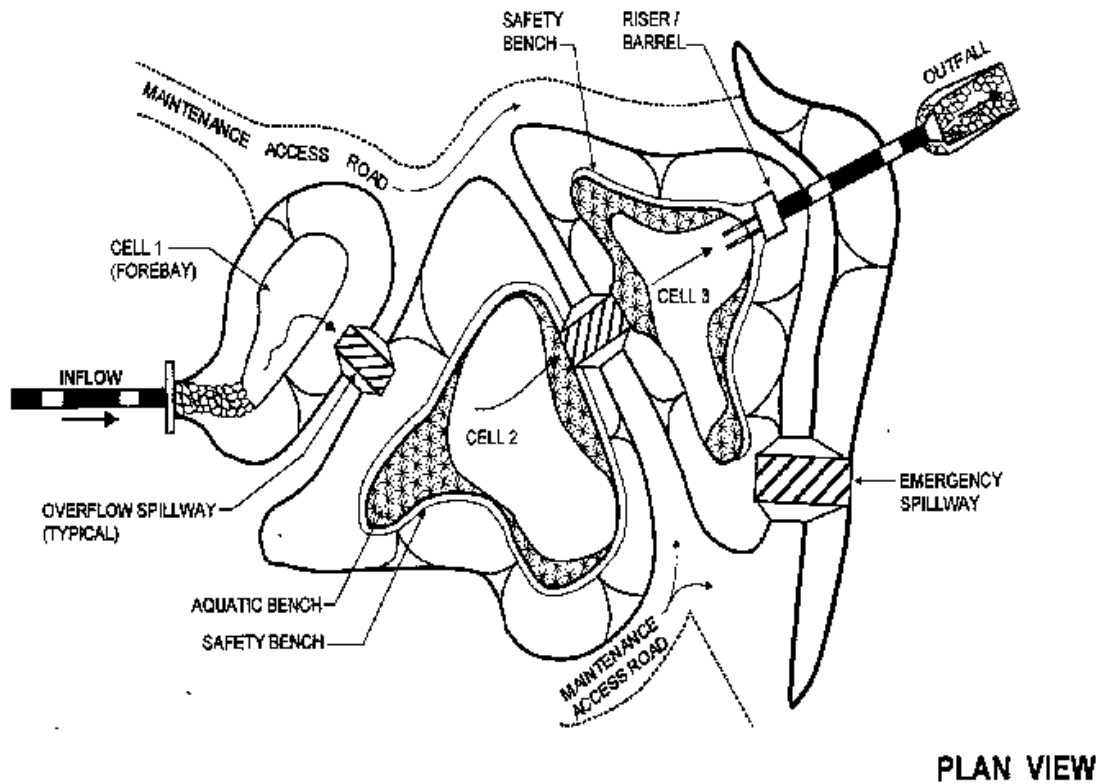


Figure P-BAS-02-2 Multi-Pond System



(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. 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: • Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC 2005). • Plant salt-tolerant vegetation in pond benches. • Do not submerge inlet pipes and provide a minimum 1 percent pipe slope to discourage ice formation. • Locate low-flow orifices so they withdraw at least 6 inches below the typical ice layer. • Place trash racks at a shallow angle to prevent ice formation. • Oversize riser and weir structures to avoid ice formation and pipe freezing. • 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 Virginia 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 <i>not</i> excavated to bedrock	24 inches of soil with a maximum hydraulic conductivity of 1×10^{-5} cm/sec.
Pond excavated to bedrock	24 inches of clay ¹ with a maximum hydraulic conductivity of 1×10^{-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 denitrification 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. 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/vaconvisvnl).
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/vaconvisvnl).
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.

Table P-BAS-02-5 Wet Pond Community & Environmental Concerns

Concern	Discussion
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-02-6 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-02-7](#). 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-02-7 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)
$T_v = [(1.0)(R_v)(A)/12]$ – volume reduced by upstream BMP	$T_v = [1.5 (R_v) (A) /12]$ – volume reduced by upstream BMP
Single pond cell (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
Safety and aquatic benches	Safety and aquatic benches

Table P-BAS-02-7 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)
Pond buffers: 25-foot vegetated turf buffer from maximum water surface elevation 25-foot buffer from principal spillway with no woody vegetation 15-foot buffer from toe of embankment with no woody vegetation	Pond buffers: (See Figure P-BAS-02-3 below) 25-foot vegetated buffer with from maximum water surface elevation with trees, shrubs, and herbaceous plants including shoreline landscaping to discourage geese 25-foot buffer from principal spillway with no woody vegetation 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-02-3 Vegetated buffer surrounding wet pond



(<https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf>)

Table P-BAS-02-8 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)
$T_v = [(1.0)(R_v)(A)/12]$ – volume reduced by upstream BMP	$T_v = [1.5 (R_v) (A) /12]$ – 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-02-8 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:

$$\text{Pond inches} = \text{ft}^3/\text{s} * (2.592\text{E}6) * (12"/\text{ft}) / \text{SA of Pond (ft}^2\text{)}$$

Where:

2.592E6 = Conversion factor: ft³/s to ft³/month.

SA = surface area of pond in ft²

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-02-9 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. • 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. • 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. Outlet protection should be provided consistent with state or local guidance. Outlet protection or energy dissipation should be provided consistent with BMP C-ECM-15 Outlet Protection.

Table P-BAS-02-9 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. Where the inlet pipe needs to be submerged, the following criterion needs to be met. • Pipe velocities support minimum velocities for sediment flushing per VDOT Drainage Manual requirements. 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-02-10](#):

Table P-BAS-02-10 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-02-11](#); (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-02-11](#). Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table P-BAS-02-11 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-02-12](#)). 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-02-12 Typical Wet Pond Maintenance Tasks and Frequency

Maintenance Items	Frequency
- Mowing – twice a year - Remove debris and blockages - 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 - A full maintenance inspection - Open up the riser to access and test the valves - 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. 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. 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: • Be designed with a maximum 24-hour detention time (to avoid excessive warming of runoff); • Have a minimum outlet micro-pool volume sufficient to prevent clogging; • Be planted with trees so it becomes fully shaded; and • 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 T_v equal to $1.25(R_v)(A)$ 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)
$T_v = [(1.0)(R_v)(A)] / 12$ – the volume reduced by an upstream BMP	$T_v = [(1.25)(R_v)(A)] / 12$ – the volume reduced by an upstream BMP
A minimum of 15 percent of the T_v in the permanent pool (forebay, micro-pool)	A minimum of 40 percent of T_v 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 T_v Drawdown Time = 24 hours	Average T_v 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	Includes 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., $1.25[R_v][A]$; 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., $1.25[R_v][A]$; additional CPv is not included). 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): 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. 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: • 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. • 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. • Safety benches and aquatic benches should be landscaped with vegetation that hinders or prevents access to the pool. • 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 safety 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 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.
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.

Table P-BAS-03-8 Conveyance and Overflow Design

Component	Details
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. Where the inlet pipe needs to be submerged, the following criterion needs to be met. • Pipe velocities support minimum velocities for sediment flushing per Virginia Department of Transportation (VDOT) Drainage Manual requirements. 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 T_v 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: • Do not submerge inlet pipes. • Provide a minimum 1 percent slope for inlet pipes to discourage standing water and potential ice formation in upstream pipes. • Place all pipes below the frost line to prevent frost heave and pipe freezing. • Locate low-flow orifices in the micro-pool so they withdraw at least 6 inches below the typical ice layer. • Place trash racks at a shallow angle to prevent ice formation. • 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 pondscape 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 pondscape 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 checklist in Appendix H 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

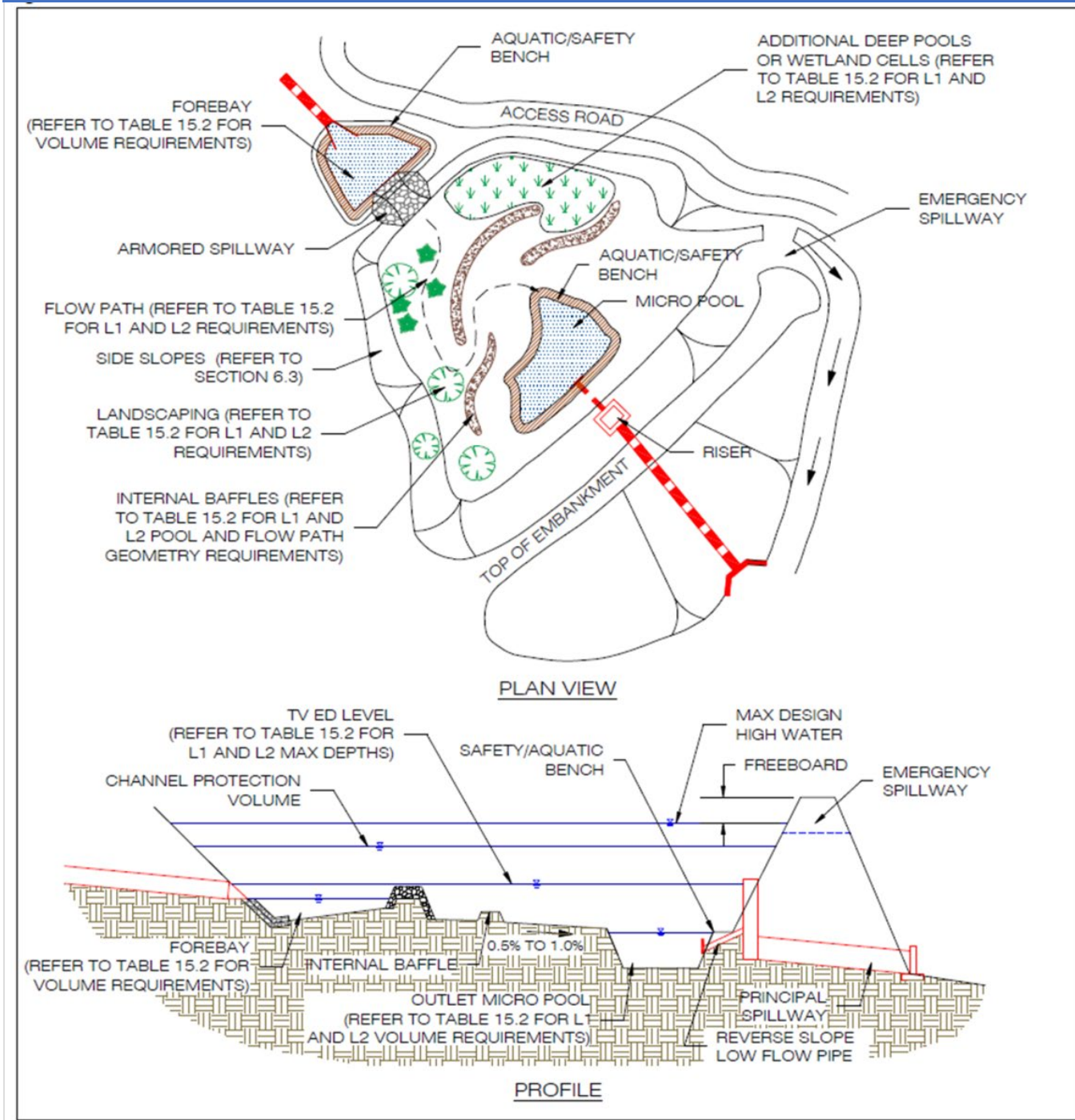
- Exposed soils on pond bottom, side slopes, and buffer areas are stabilized with specified seed mixtures, stabilization matting, mulch, or other BMPs in accordance with approved plans.
- Appropriate number and spacing of plants is installed and protected on the aquatic bench and pond buffer in accordance 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, Center 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.
	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.
	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.

Table P-BAS-04-1 Rainwater Harvesting Considerations

Consideration	Details
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.
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.

Table P-BAS-04-1 Rainwater Harvesting Considerations

Consideration	Details
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. Limestone or other materials may be added in the tank to buffer acidity if desired.
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).

Table P-BAS-04-1 Rainwater Harvesting Considerations

Consideration	Details
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.
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).
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. 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). For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events. Use heat tracing to avoid freezing of lines and tanks. 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:

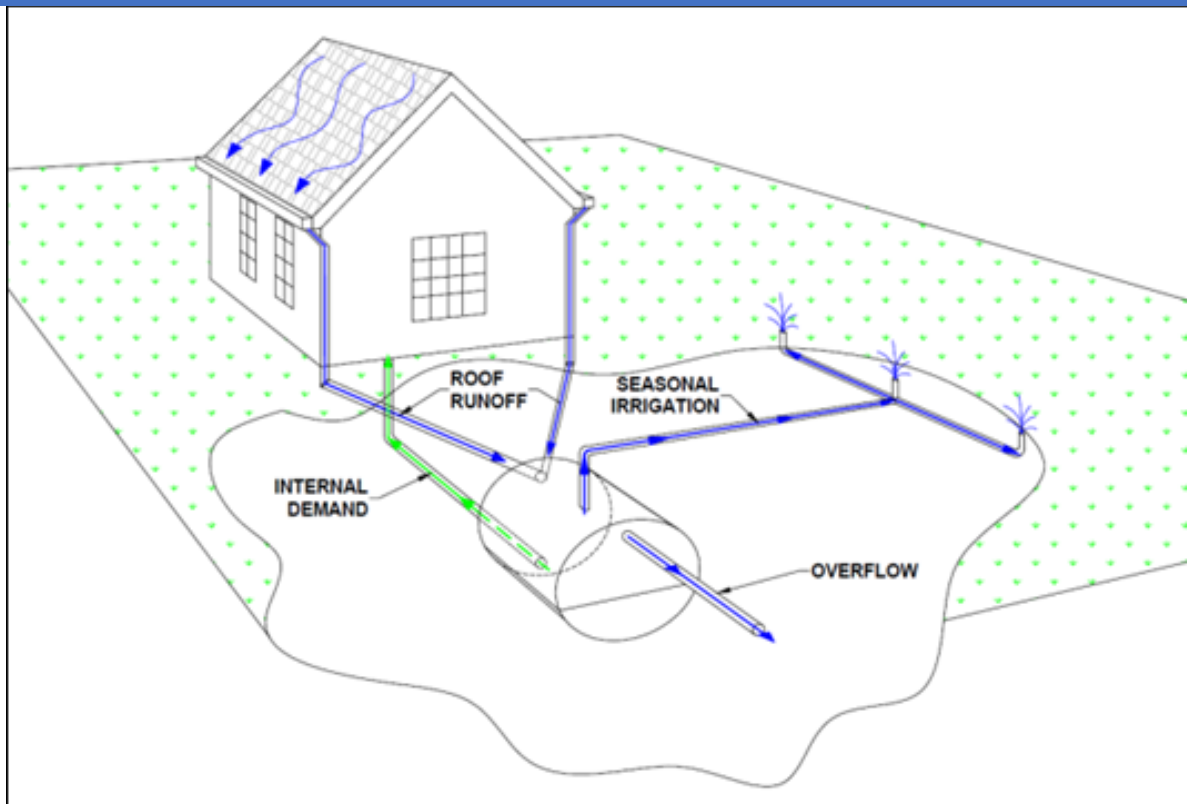
1. Year-round indoor use with seasonal indoor and/or outdoor uses;
2. Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice; and
3. Seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction 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.

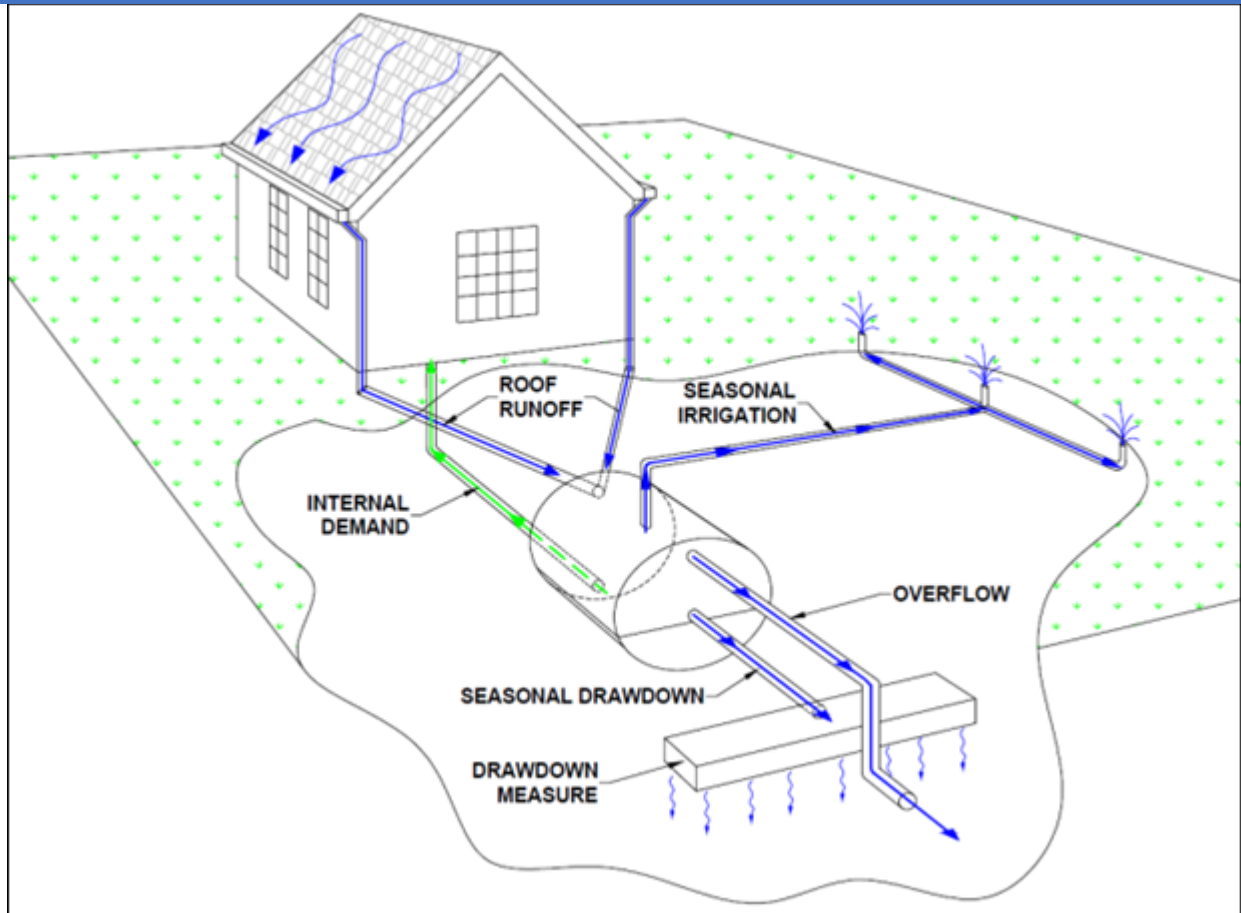


The only runoff reduction volume credit derived from this configuration is the year-round indoor use. While the seasonal uses do not provide an annual credit, they generally use a large volume of water (i.e., irrigation) such that the owner may elect to increase the system size to provide for the seasonal 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

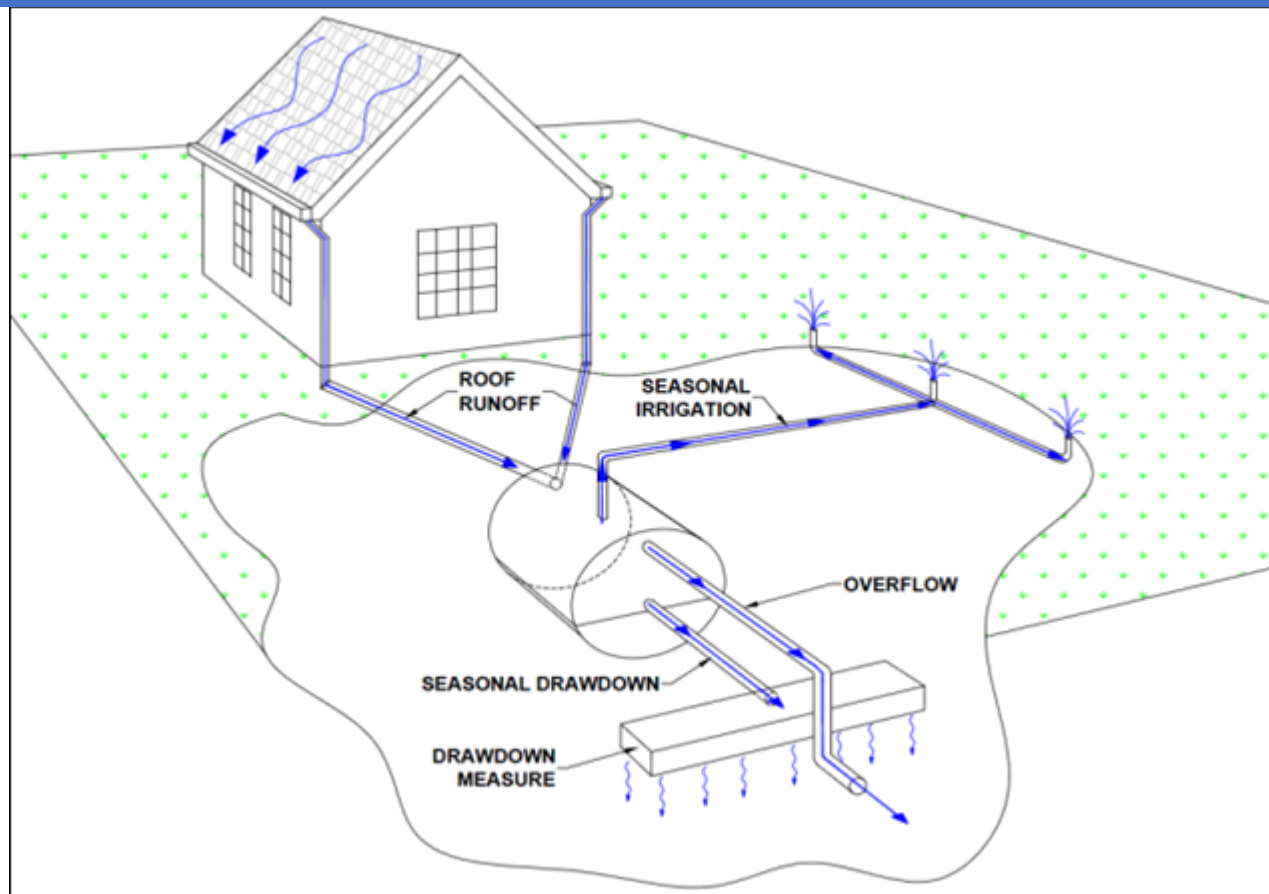


Several system design elements are discussed herein including considerations related to secondary drawdown in conjunction with large storm controls (for channel or flood protection).

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 Reduction ¹ 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 T_v , 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 above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for aboveground 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 immovable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast-in-Place Concrete	Durable, immovable, 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 immovable; 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

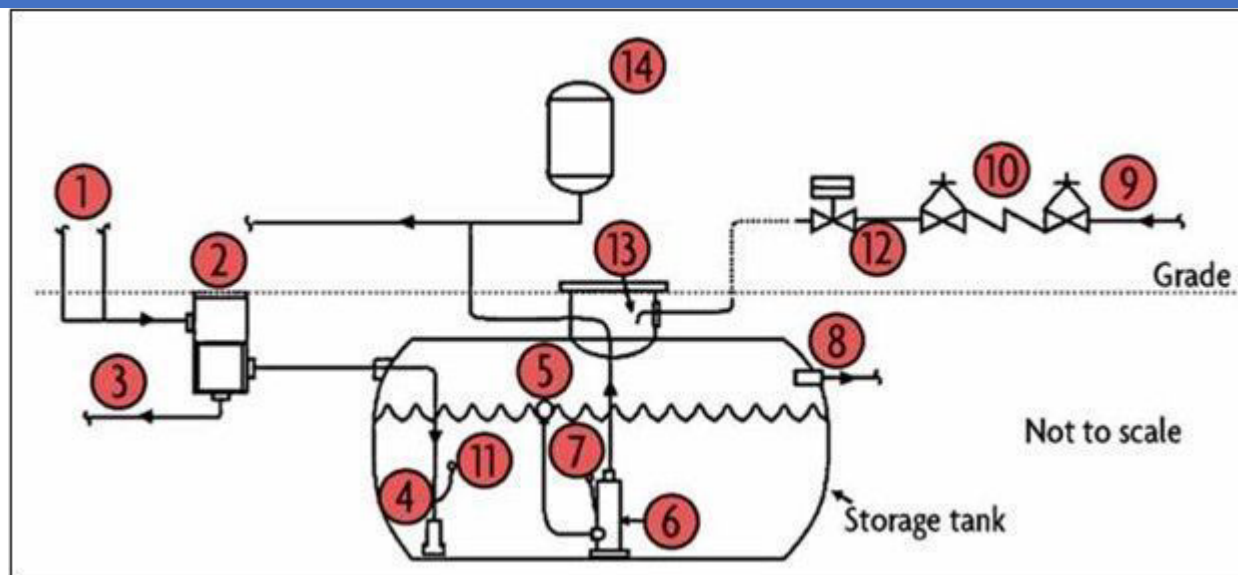


Source: Village Craftsmen (www.villagecraftsmen.com)

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

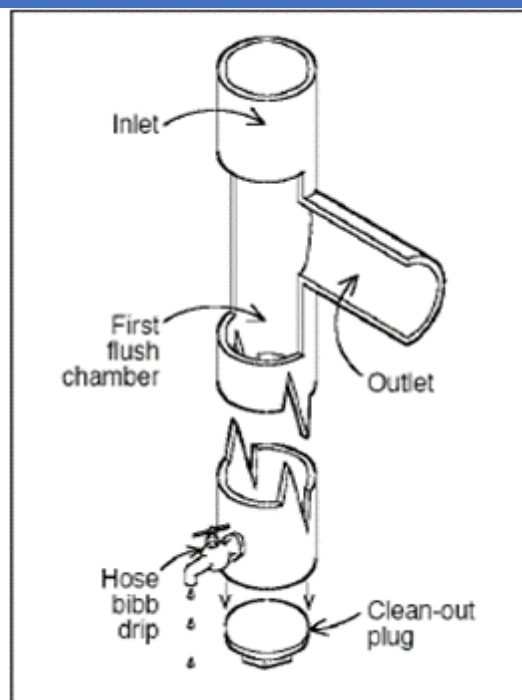
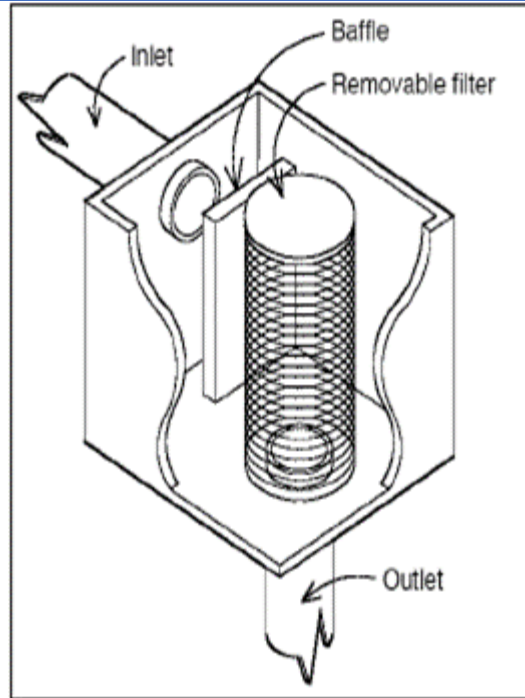


Figure P-BAS-04-11 Roof Washer



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.
	The size of the rainwater harvesting system(s) is determined by the design calculations.
	Materials used to construct storage tanks should be structurally sound. Reused tanks should have been used previously for potable water or food-grade products.
	All storage tanks should be watertight and sealed using a water-safe, non-toxic substance.
	Aboveground storage tanks should be both UV- and impact-resistant and should be opaque to prevent the growth of algae.
	Underground rainwater harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line.
	Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic).
	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.
	Storage tanks should be screened to discourage mosquito breeding and reproduction.
	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.
Gutters and Downspouts	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.
	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.
	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): • Leaf screen (1 mm mesh size); • First flush diverter; • Roof washer; and • Approved MTD
Distribution Lines	Distribution lines to and from the storage tank should be buried beneath the frost line. Distribution lines from the rainwater harvesting system to the building should have shutoff valves that are accessible when snow cover is present. 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.

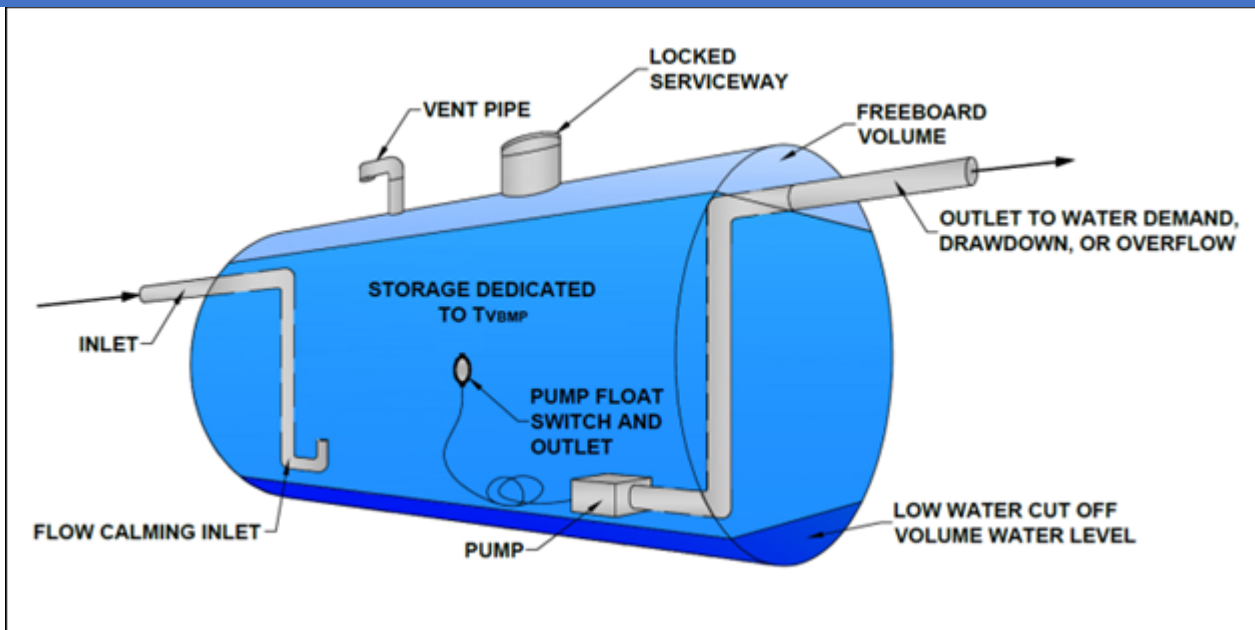
5.3 Design Objectives and Tank Design Setups

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 T_v 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.

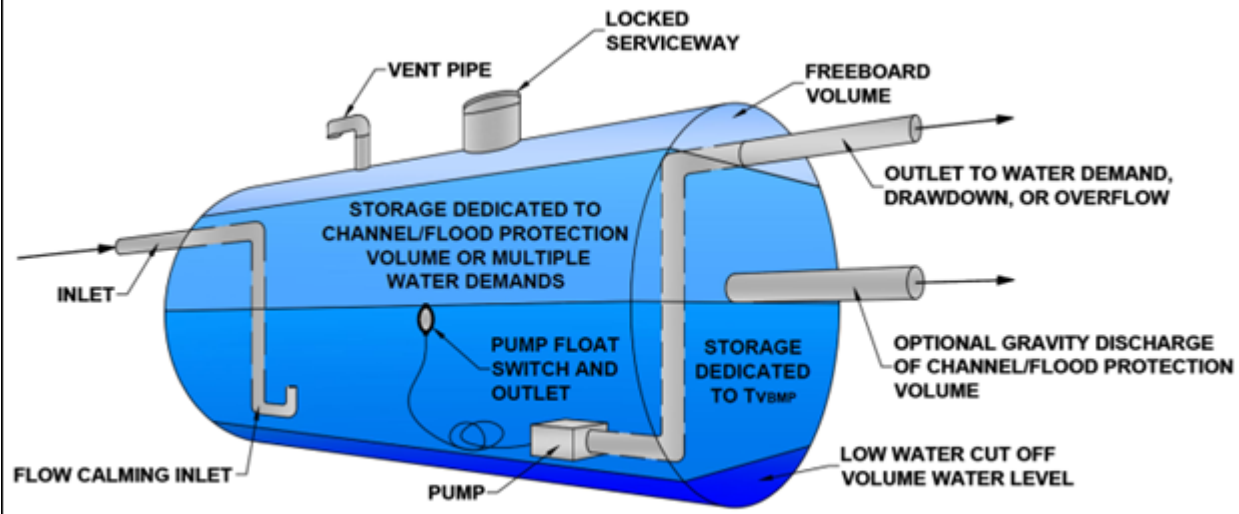
Note: [Figure P-BAS-04-12](#) and [Figure P-BAS-04-13](#) are schematic representations of the relative configuration of the storage volume and outlets. If these tanks are configured below grade, there would be a mechanical system to pump the required flow to meet the water demand or drawdown, requiring 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 (T_v) only



Tank Design 2. The second tank setup (Figure P-BAS-04-13) uses tank storage to manage the T_v and runoff reduction volume credit objectives as well as using an additional detention volume above the T_v 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 T_v 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.

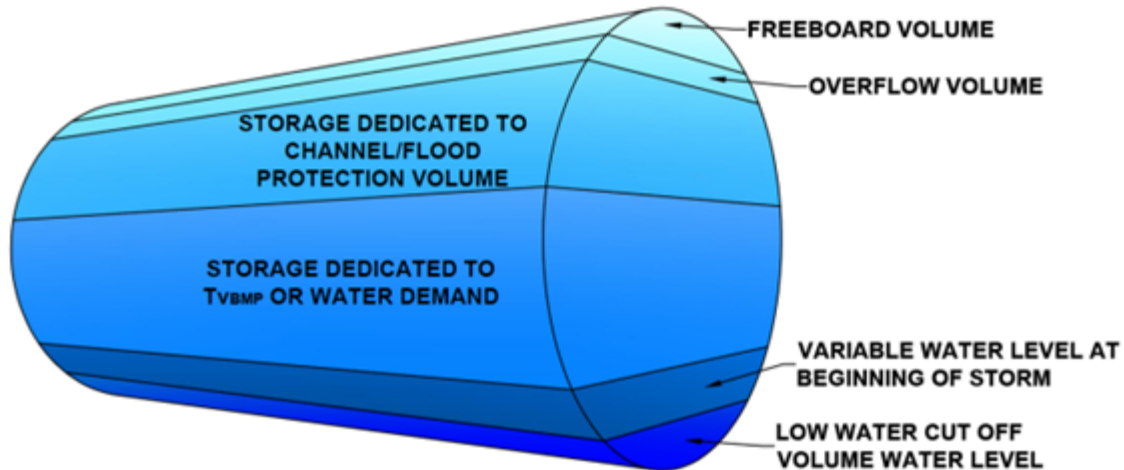
5.4.2 Sizing for Management of Larger Storms

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
I: Third-party inspector

8.0 References

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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 .
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.

Table P-CNV-01-1 Design Feasibility

Parameter	Details
Sequencing Considerations	While all construction sequences will vary by site, the following items should be considered by the designer when planning the construction sequence: 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. 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)	
	Partial			
Channel & Flood Protection	▪ Use Virginia Runoff Reduction Method (VRRM) Compliance spreadsheet to calculate a curve number (CN) adjustment			

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
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.

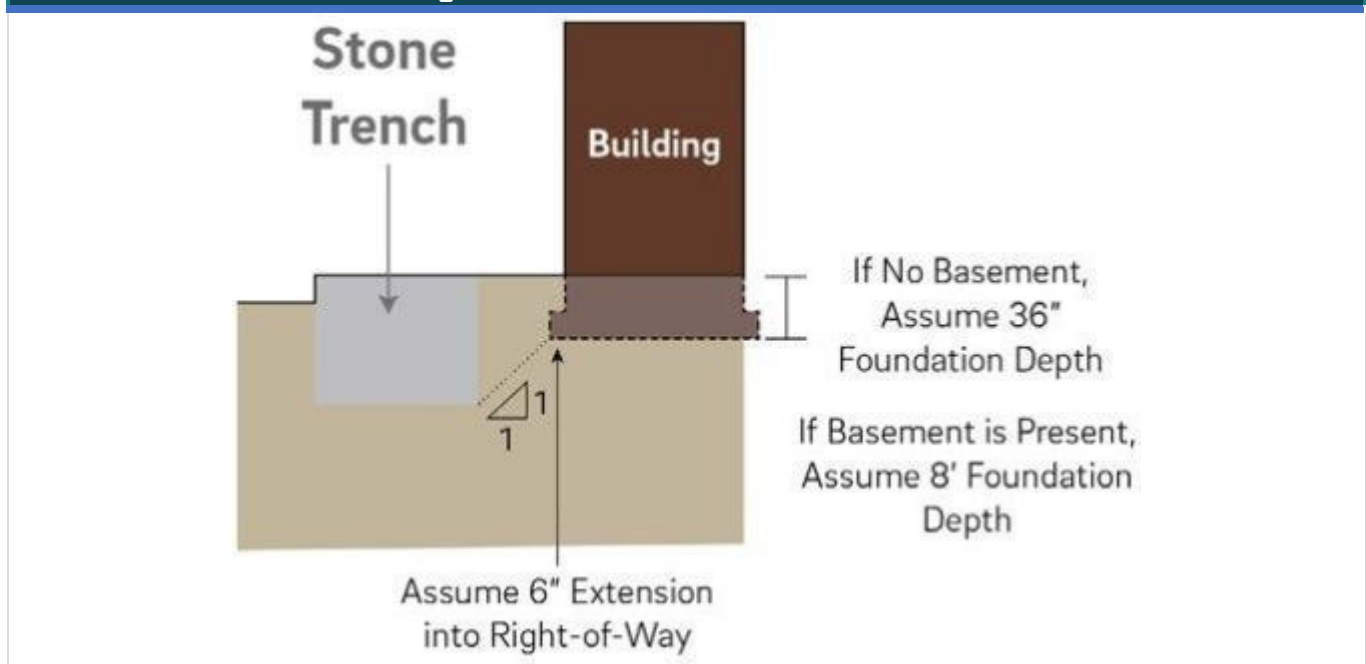
Table P-CNV-01-4 Grass Channel Offset Guidance

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	
Sewer laterals	5 feet horizontal, 12 to 18 inches vertical	
Water mains	5 feet horizontal	

Table P-CNV-01-4 Grass Channel Offset Guidance

Feature	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	
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).
 - 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; Kebbin 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

$$W = (n)(q_{ptv}) / (1.49D^{5/3}S^{1/2})$$

Equation P-CNV-01-2. Channel Velocity

The corresponding velocity is solved using

$$V = \frac{q_{ptv}}{W \times D}$$

This equation provides a solution for the minimum width:

Equation P-CNV-01-3. Minimum Channel Width

$$W = (n)(q_{pTv}) / (1.49D^{5/3}S^{1/2})$$

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	6	4.5
	5 - 10	5	3.8
Kentucky bluegrass / Tall fescue	0 - 5	5	3.8
	5 - 10	4	3
	> 10	3	2.3
Grass-legume mixture	0 - 5	4	3
	5 - 10	3	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: ▪ 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. ▪ 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). ▪ The minimum depth to the bedrock layer is 18 inches. ▪ A minimum slope of 0.5% must be maintained to ensure positive drainage. ▪ 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: ▪ The minimum depth from the swale invert to the seasonally high water table should be 12 inches. ▪ A minimum slope of 0.5% must be maintained to ensure positive drainage. ▪ 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

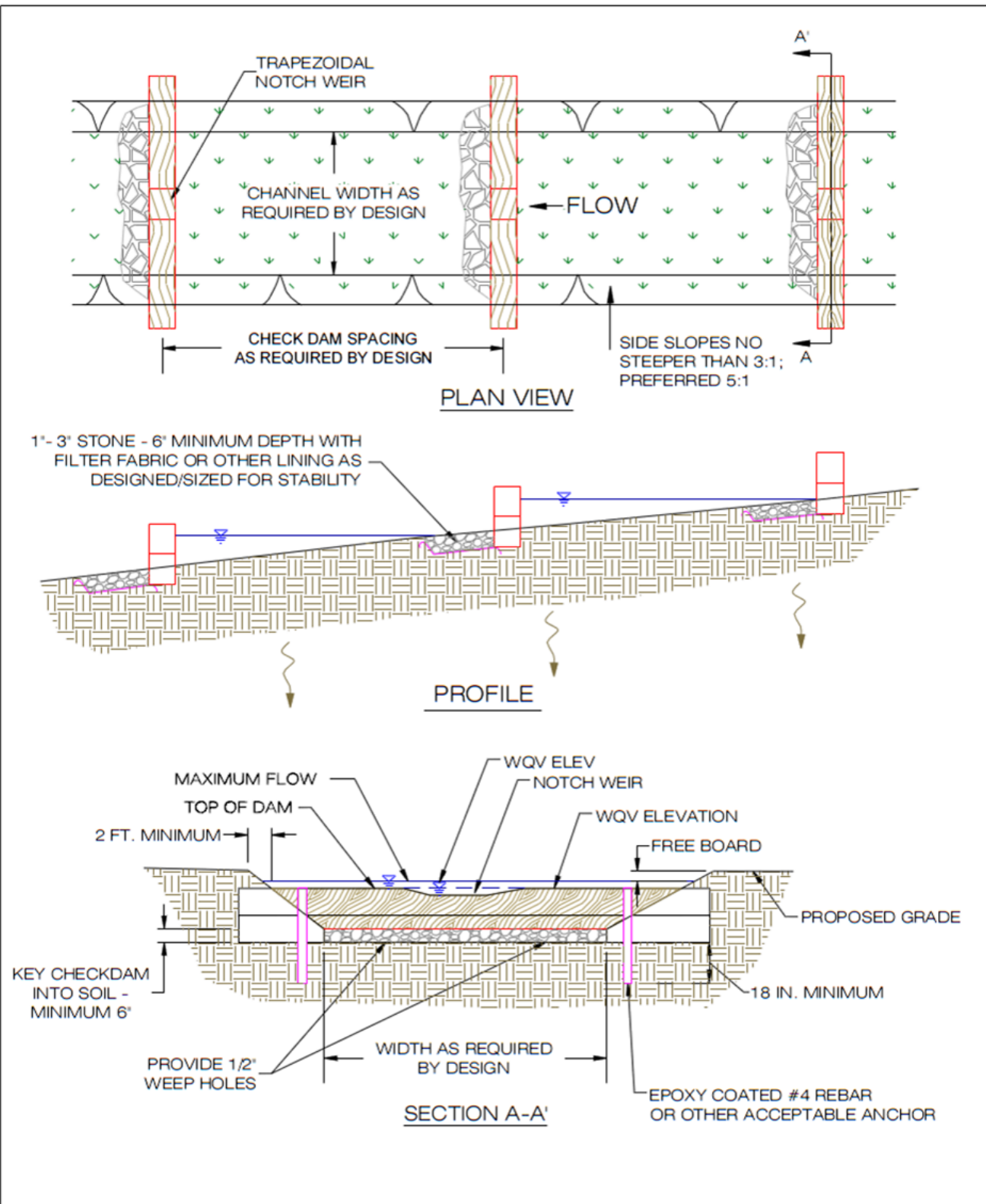
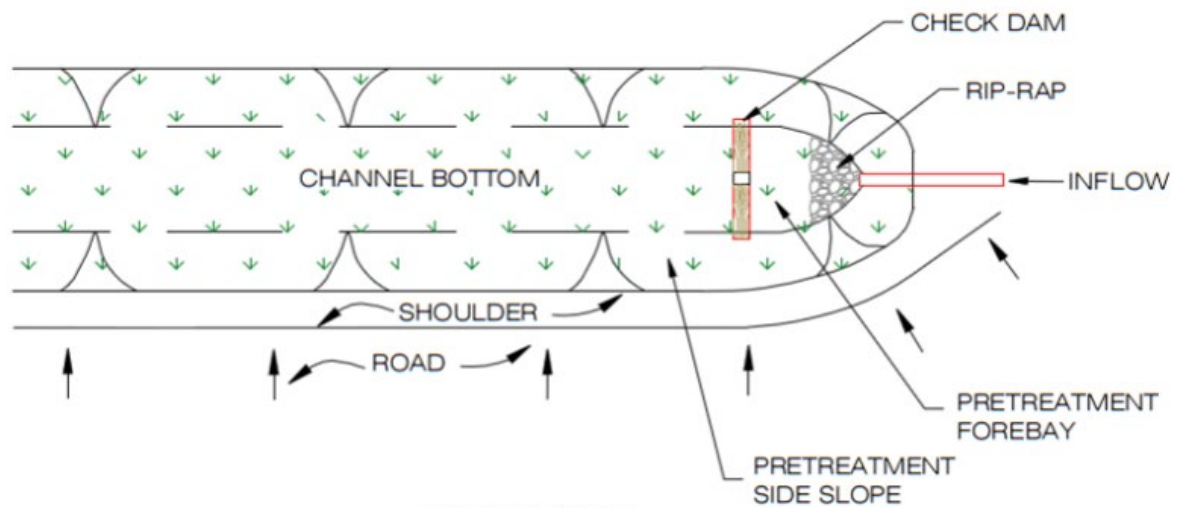
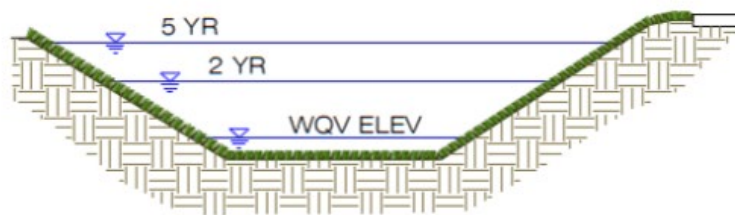


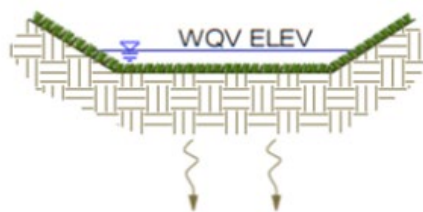
Figure P-CNV-01-3 Grass Channel with Check Dams – Typical Plan, Profile, and Section



PLAN VIEW



PROFILE



LIMITED INFILTRATION

TYPICAL SECTION

Figure P-CNV-01-4 Grass Channel with Compost Amendments - Section

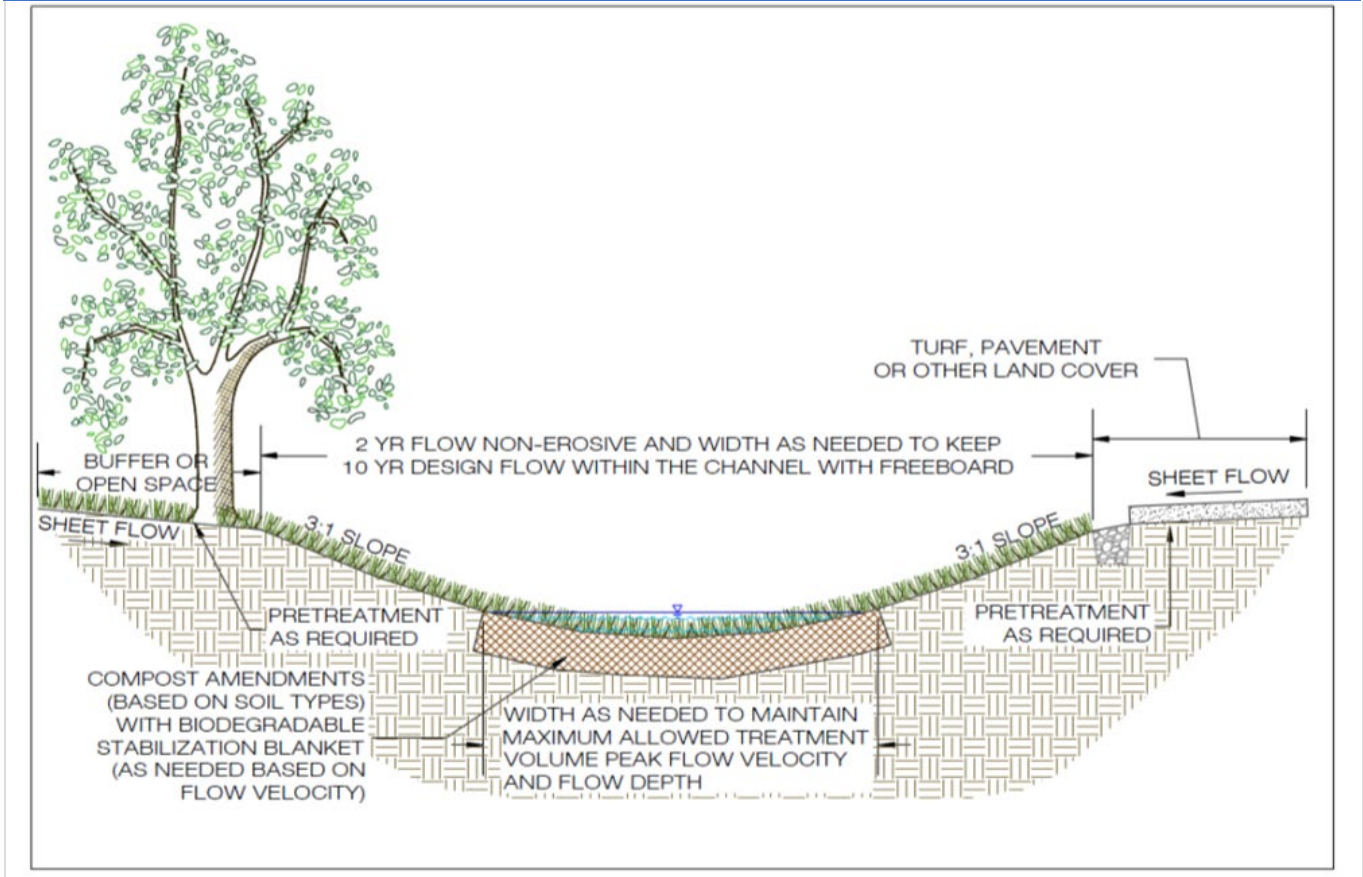


Figure P-CNV-01-5 Pre-treatment I and II - Grass Filter for Sheet Flow

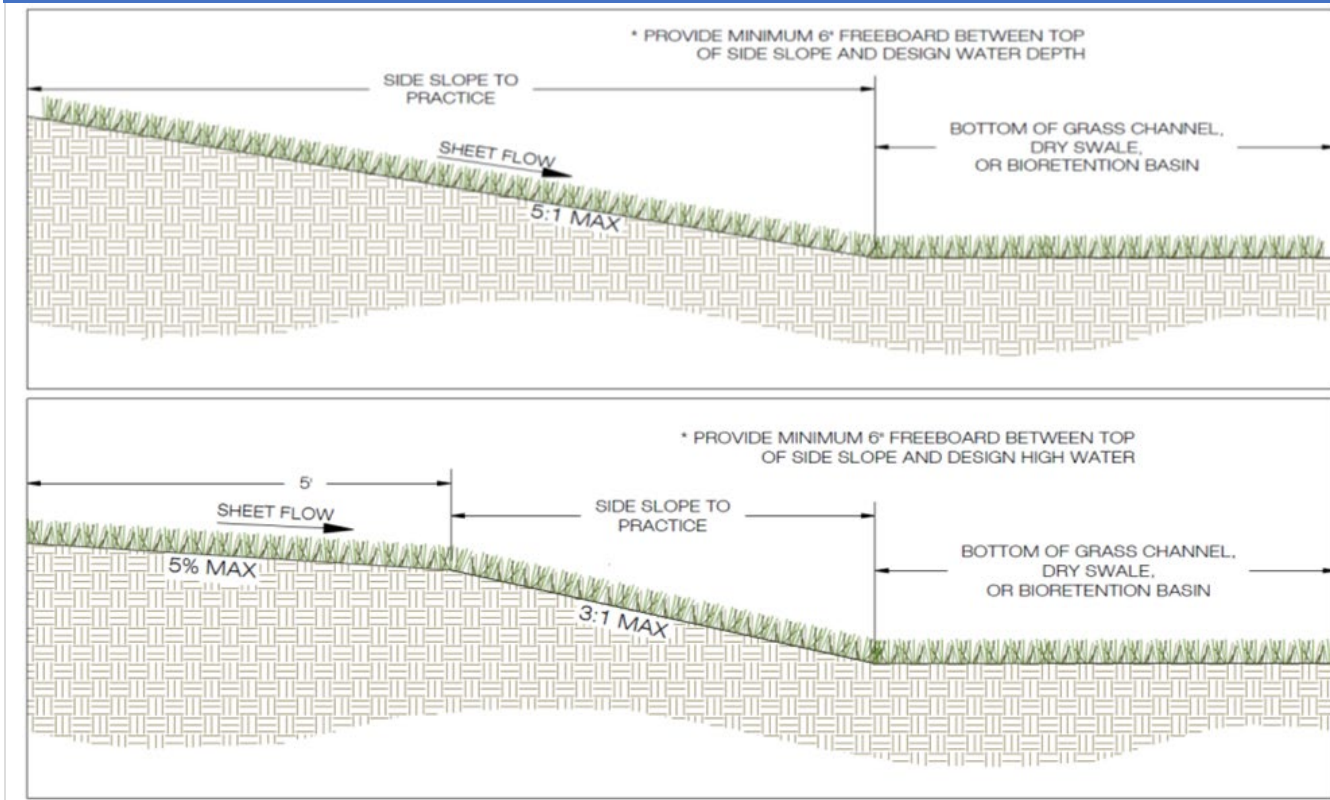


Figure P-CNV-01-6 Pre-treatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

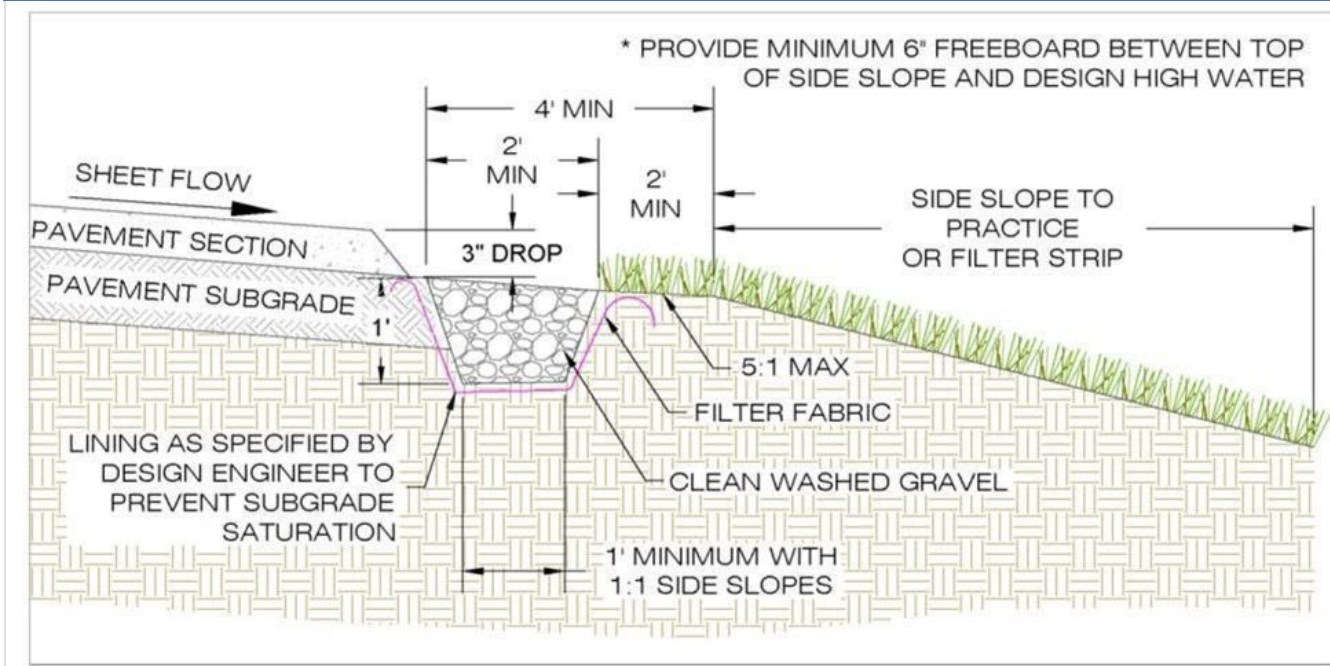


Figure P-CNV-01-7 Pre-Treatment – Gravel Flow Spreader for Concentrated Flow

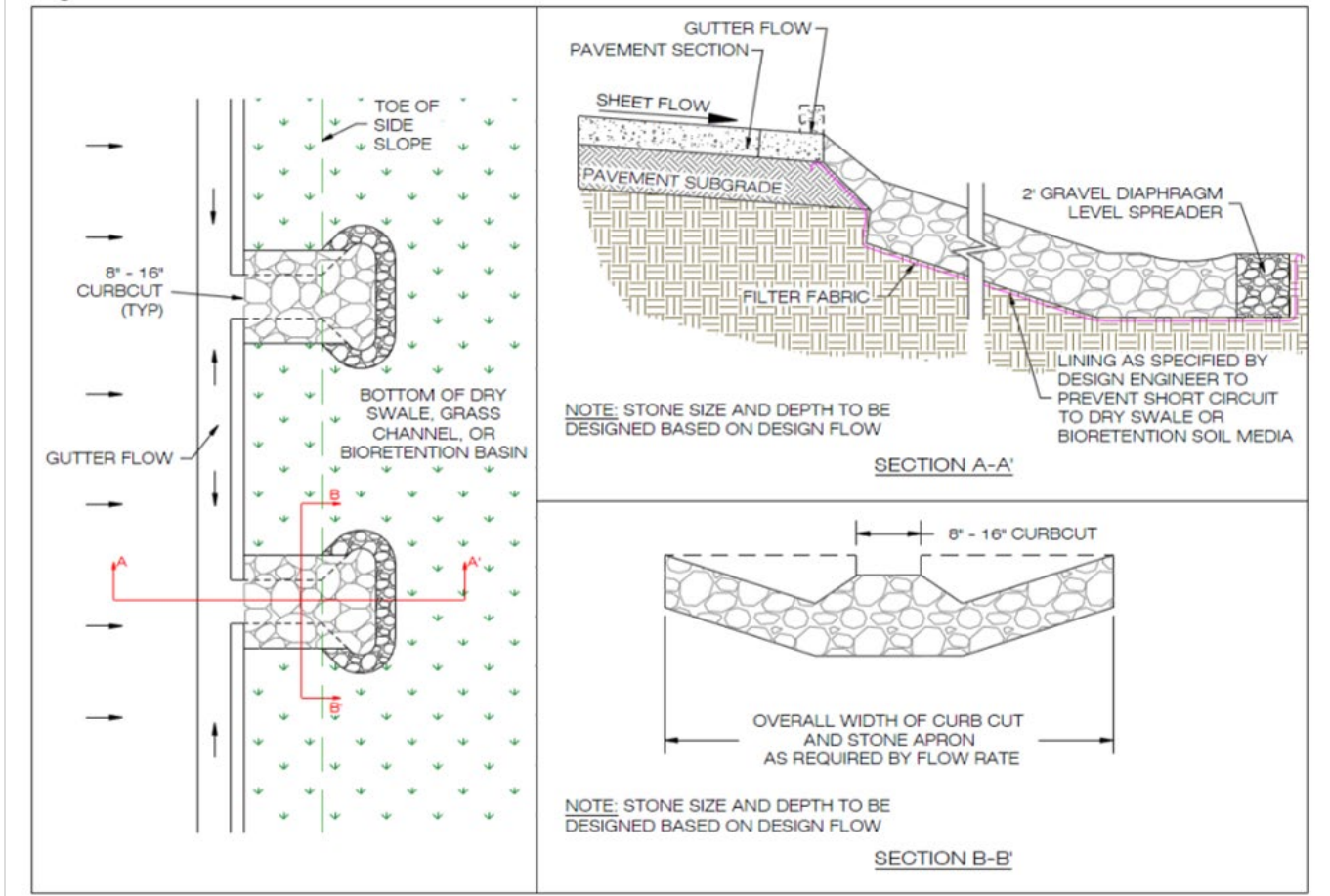
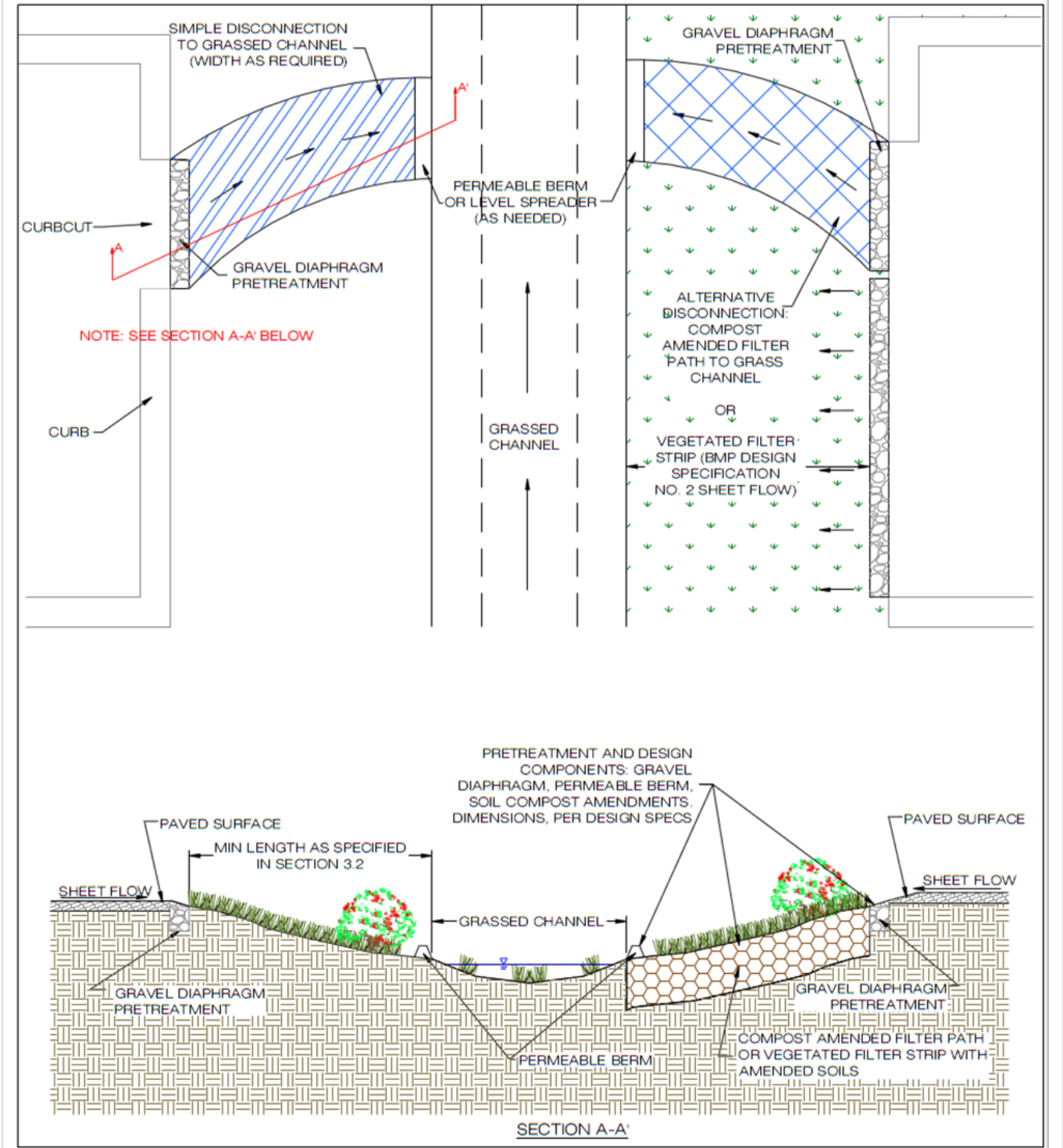


Figure P-CNV-01-8 Filter Path to Grass Channel



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 from 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. 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). 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 may 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 OR 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: Surface Area (sq. ft.) = (Tv – the volume reduced by an upstream BMP)/Storage depth ¹	Sizing: 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; Recommended maximum = 36 inches	Media Depth minimum = 24 inches 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; <i>OR</i> 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	
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-inch height 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 (η) for each of the materials is (see Figure P-CNV-02-1):

Dry Swale Soil Media $\eta = 0.25$

Gravel $\eta = 0.40$

Surface Storage behind check dams $\eta = 1.0$

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

$$SA \text{ (sq. ft.)} = (TvBMP - \text{volume of surface storage})/0.5 \text{ ft.}$$

The Level 2 Dry Swale SA is computed as:

Equation P-CNV-02-4. Dry Swale Level 2 Design SA

$$SA \text{ (sq. ft.)} = [(1.1 * TvBMP) - \text{volume of surface storage}]/0.9 \text{ ft.}$$

Where:

SA = Minimum surface area of dry swale (sq. ft.)

$TvBMP$ = BMP design Treatment Volume (cu. ft.) = $[(1.0 \text{ in.})(R_v)(A)] / 12$

(NOTE: R_v = 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 T _v 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: • 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). • Earthen check dams should be used where space allows. • The height of the check dam relative to the normal channel elevation should not exceed 12 inches. • 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). • 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	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 downstream toe.
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. • 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. • 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. • 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 T_v .

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). 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: • 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). • A minimum underdrain slope of 0.5% should be maintained to ensure positive drainage. • The underdrain should be tied into the drainage ditch system. • 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. 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 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 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 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 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 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 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 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

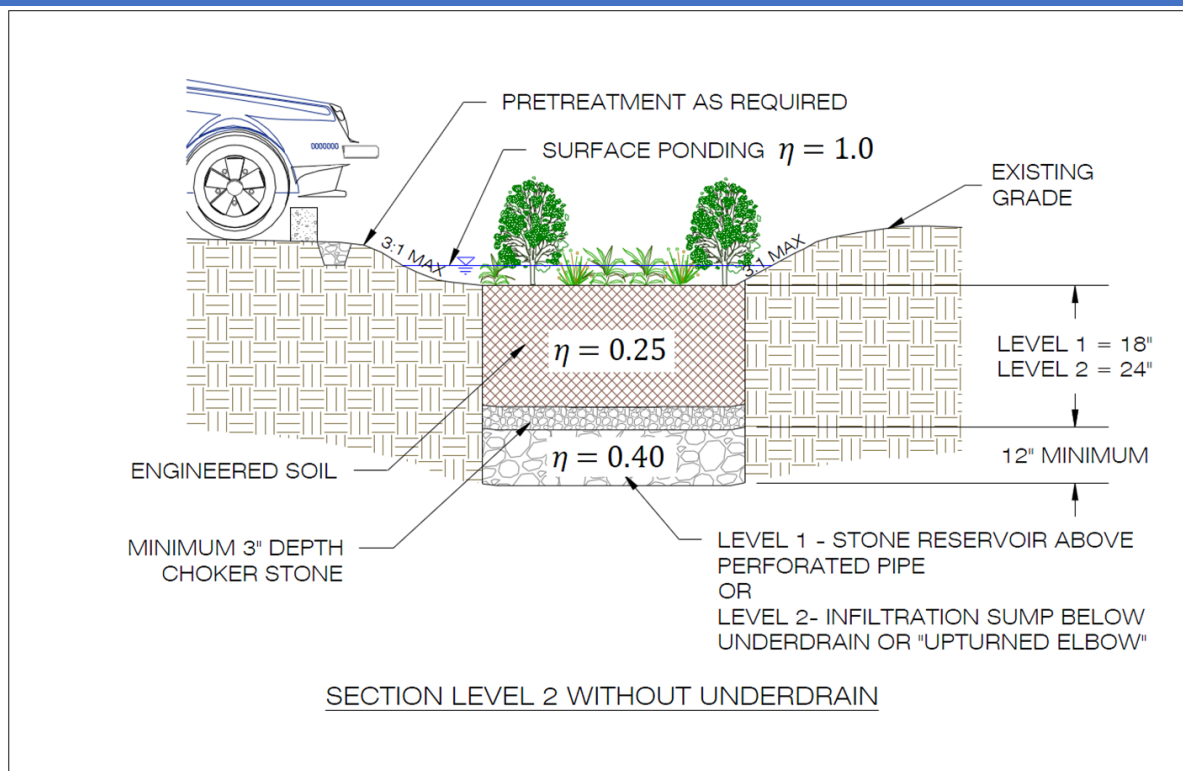


Figure P-CNV-02-2 Spacing of Check Dams for Surface Storage and Effective Slope

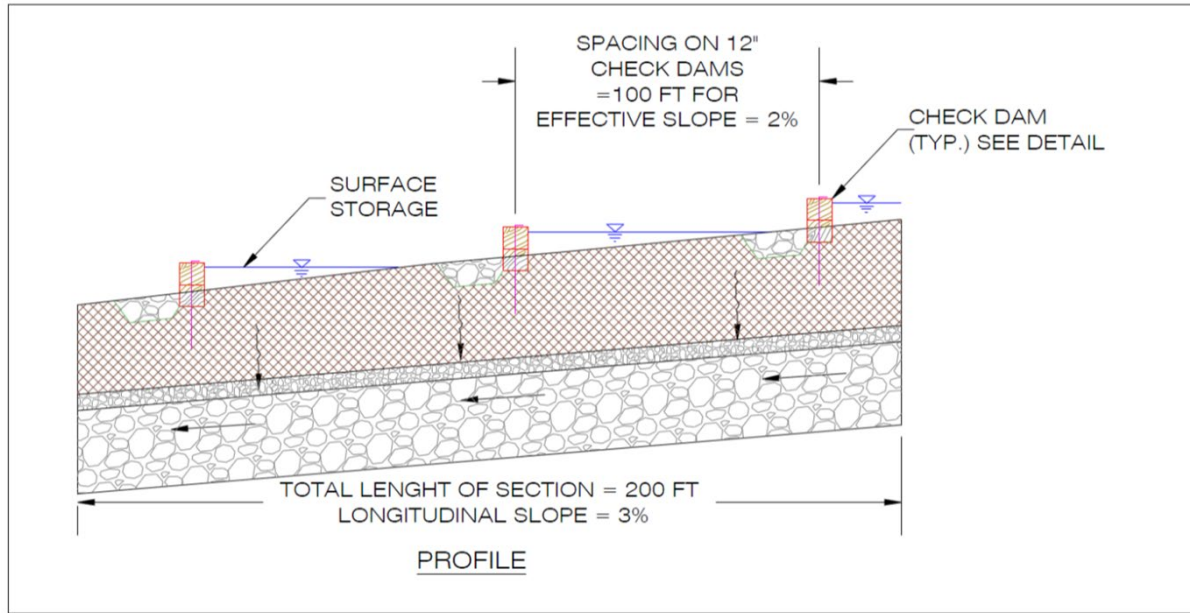


Figure P-CNV-02-3 Dry Swale Observation Well

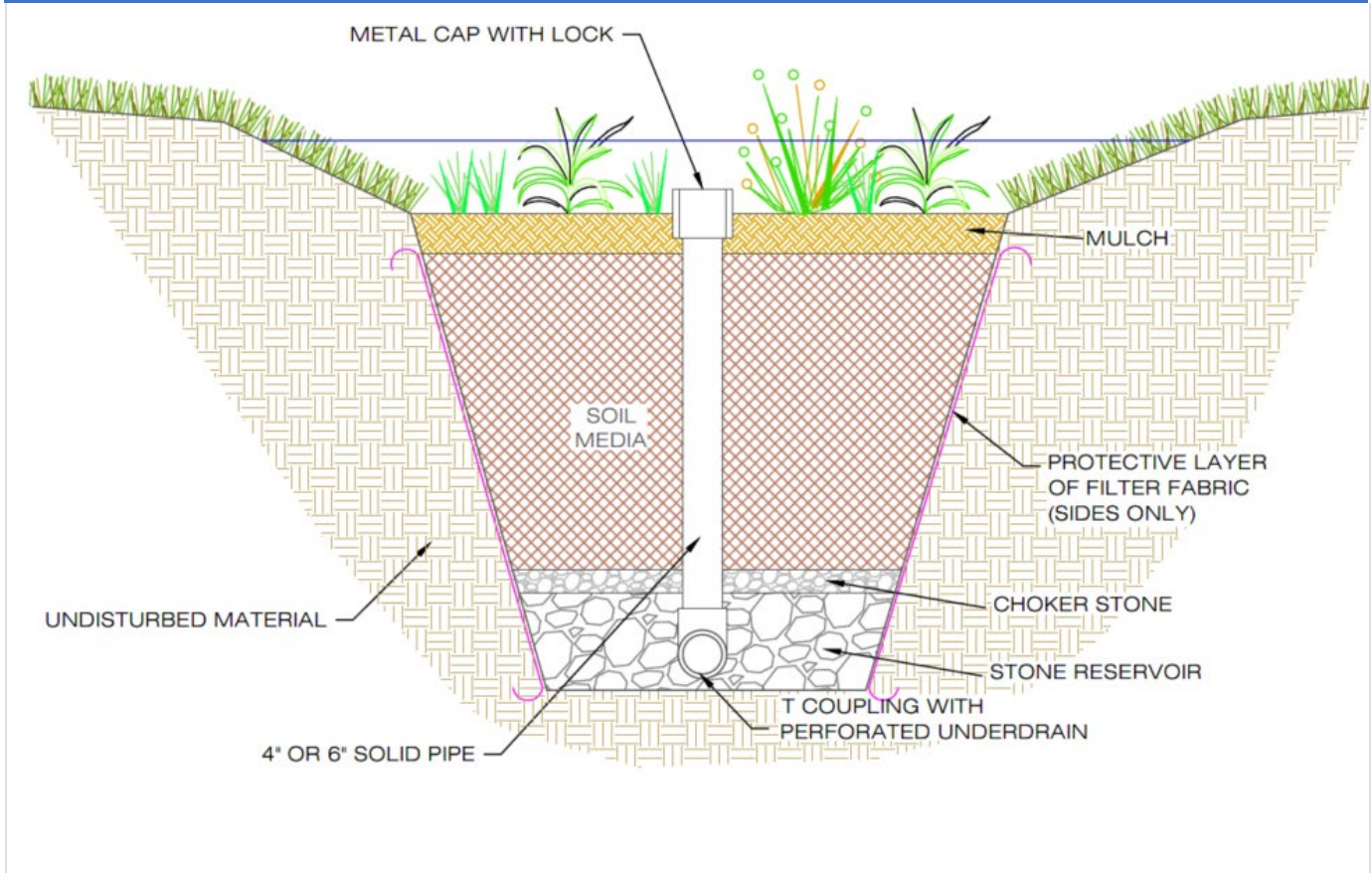


Figure P-CNV-02-4 Dry Swale Underdrain Cleanout

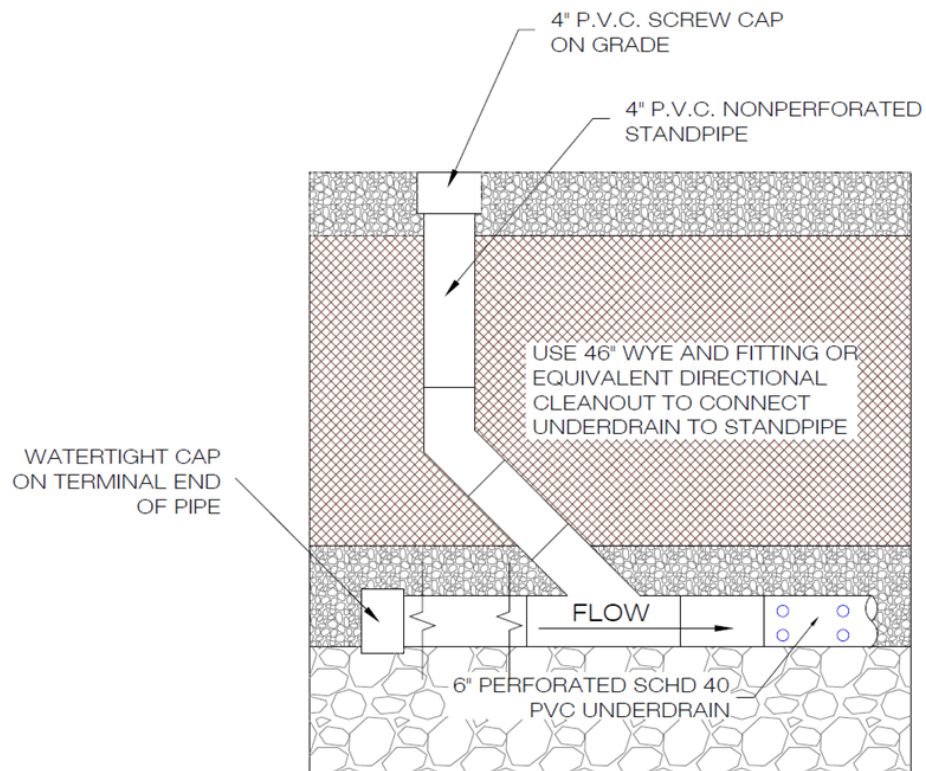


Figure P-CNV-02-5 Typical Details for Level 1 and 2 Dry Swales

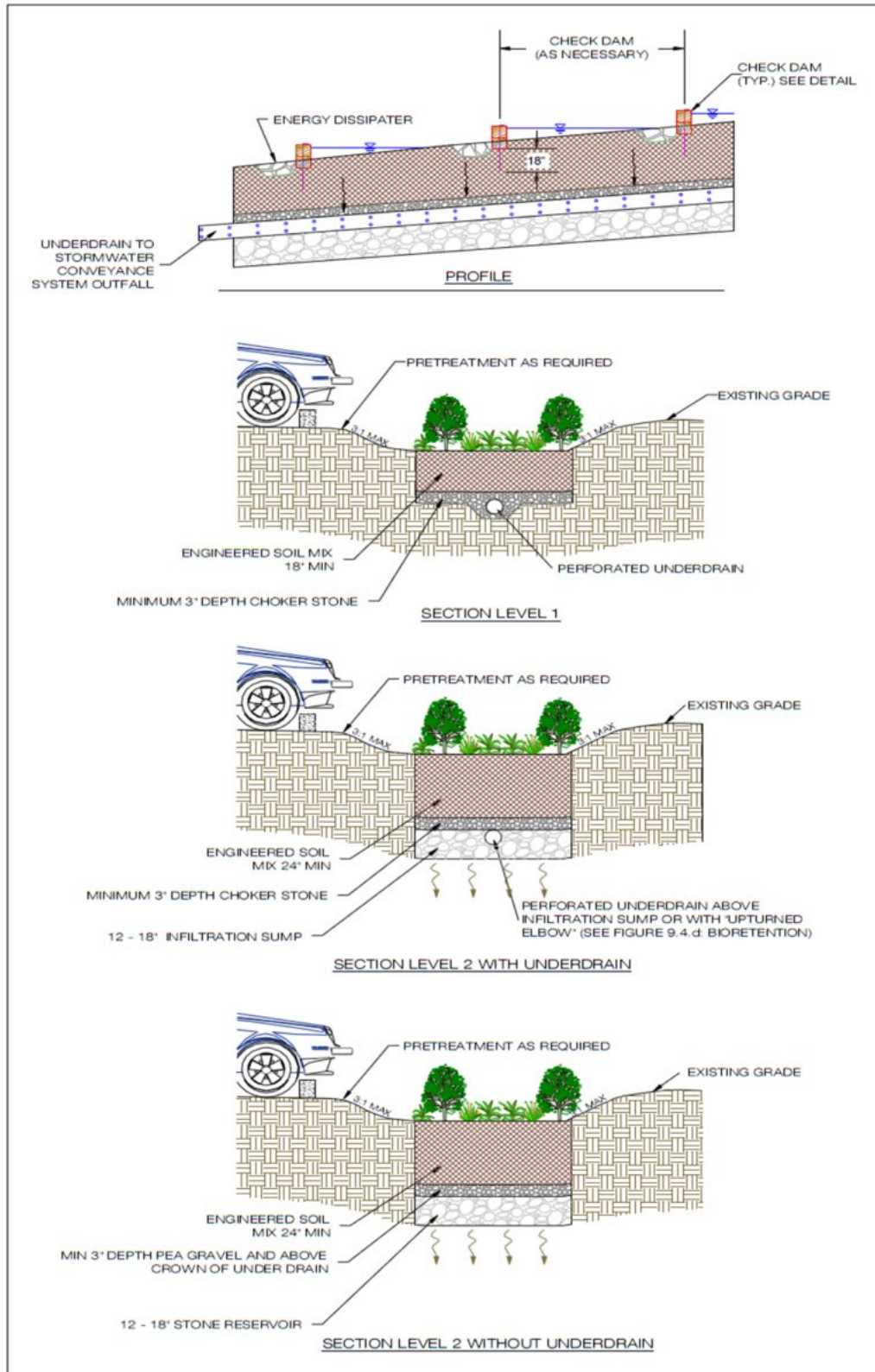


Figure P-CNV-02-6 Typical Detail for Dry Swale Check Dam

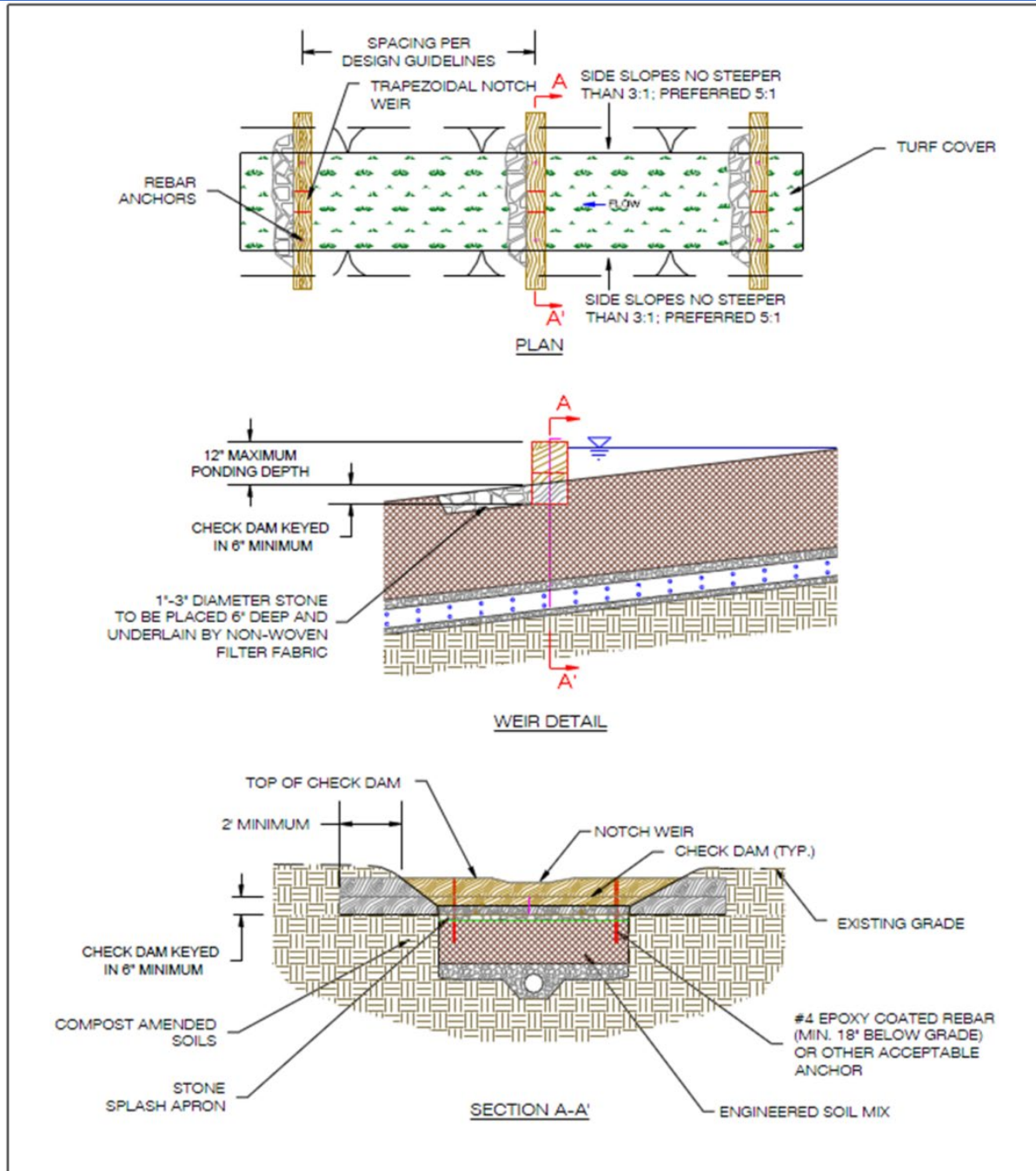


Figure P-CNV-02-7a Pretreatment I – Grass Filter for Sheet Flow

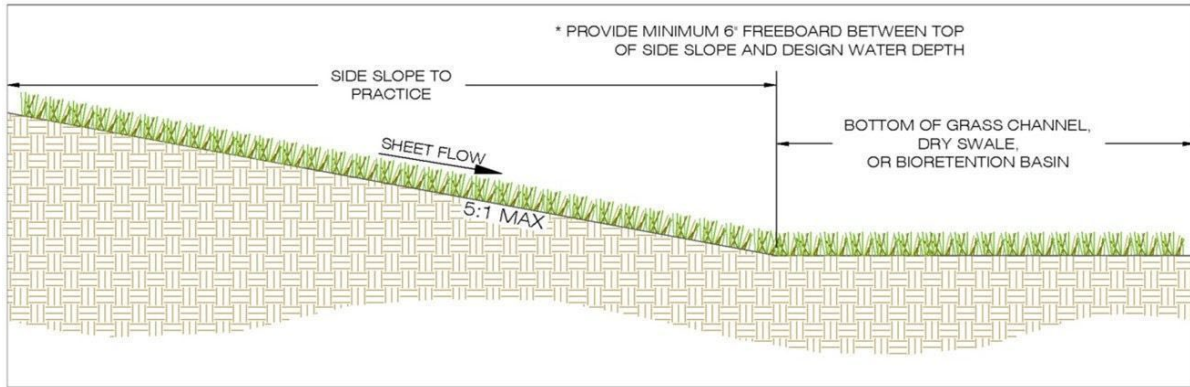


Figure P-CNV-02-7b Pretreatment II – Grass Filter for Sheet Flow

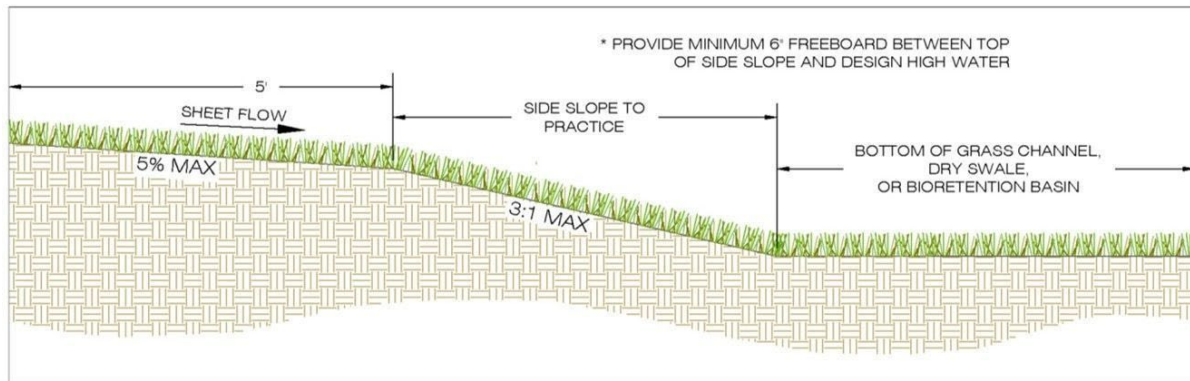


Figure P-CNV-02-8 Pre-treatment – Gravel Diaphragm for Sheet Flow from Impervious or Pervious

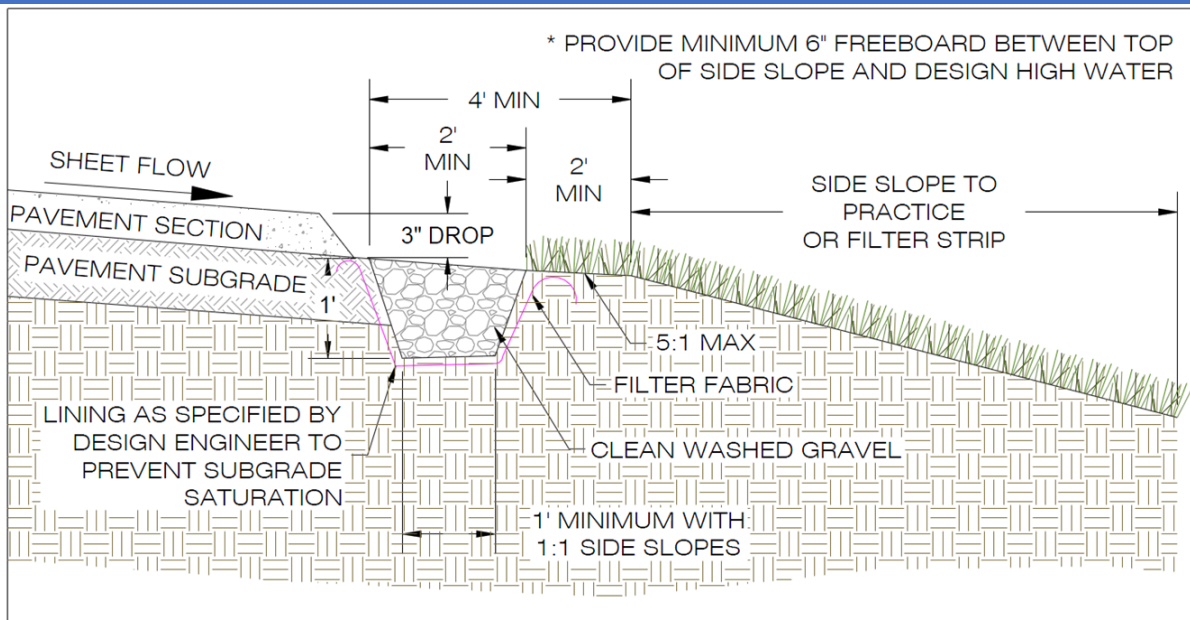
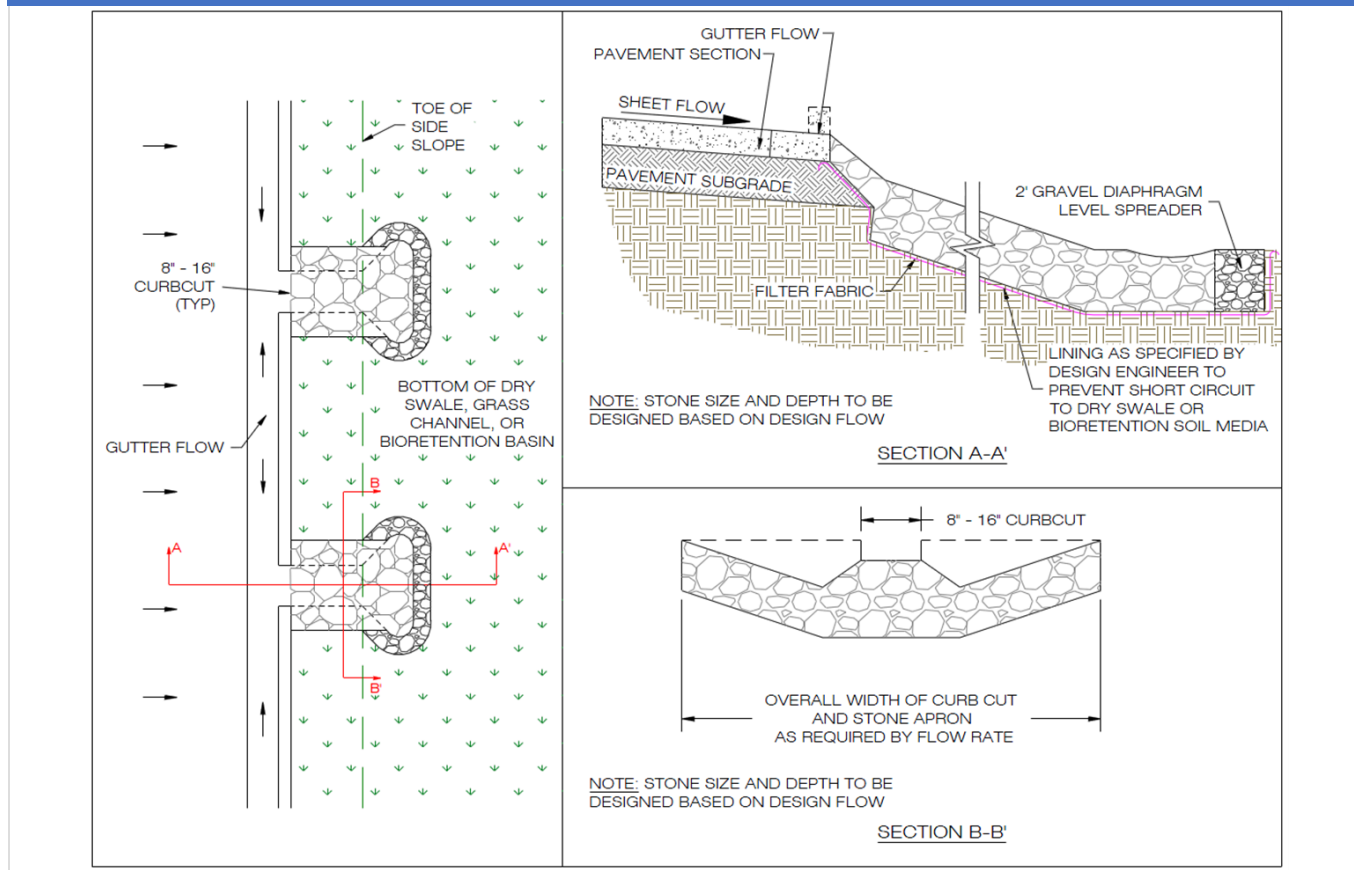


Figure P-CNV-02-9 Pre-Treatment – Gravel Flow Spreader for Concentrated Flow



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). 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.
	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.
	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-03-2 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-03-2 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 (T_v) 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- 03-3 Wet Swale Design Criteria

Level 1 Design (RR:0; TP:20; TN:25)	Level 2 Design (RR:0; TP:40; TN:35)
$T_v = [(1 \text{ inch})(R_v)(A)] / 12$ – the volume reduced by an upstream RR BMP	$T_v = [(1.25 \text{ inch})(R_v)(A)] / 12$ – 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 T_v 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 T_v 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

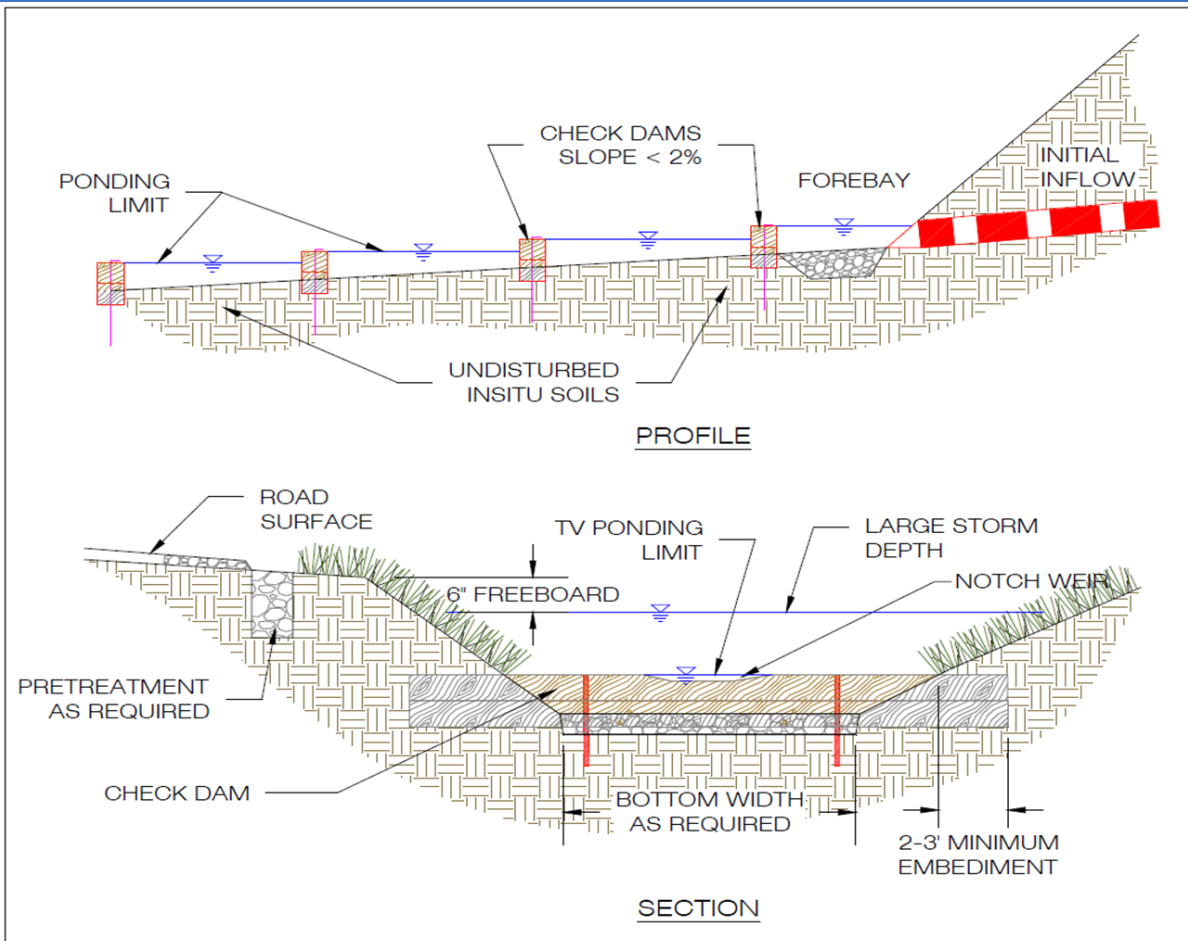
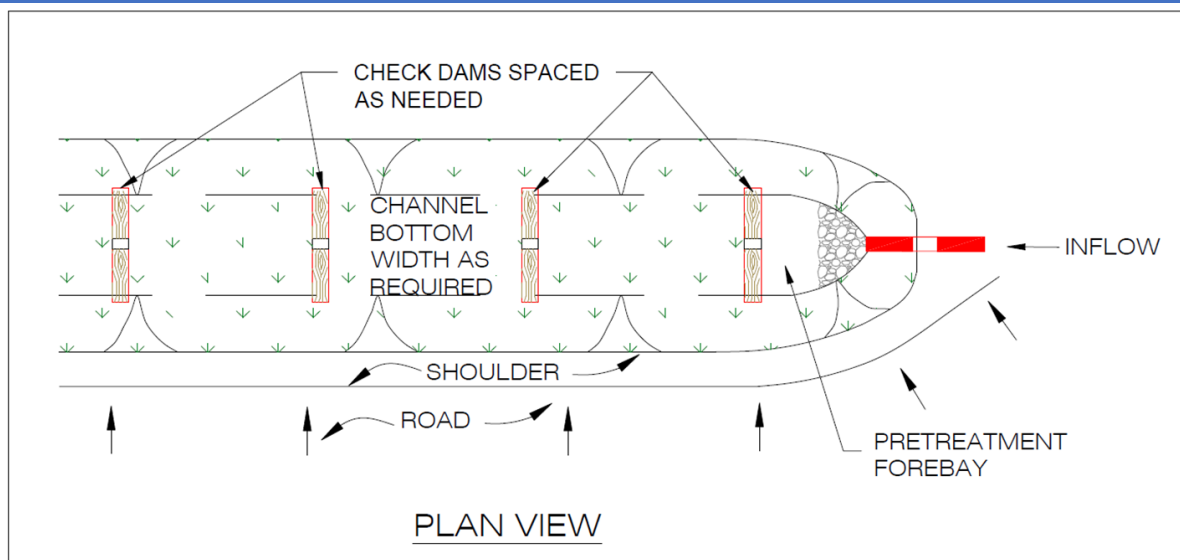


Figure P-CNV-03-2 Typical Wet Profile and Section



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

- Anne Arundel County Watershed Ecosystems and Restoration Services, Step Pool Conveyance Systems, Annapolis, MD. Available online at:
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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.
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.

Table P-CNV-04-1 Feasibility Criteria

Parameter	Details
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.
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. 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.

Table P-CNV-04-3 Community and Environmental Concerns

Concern	Details
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	$1.5 \times T_v$ (See Section 5.1 for T_v calculation)

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.pdf> <https://www.aacounty.org/public-works/bwpr/watershed-restoration/step-pool-stormwater-conveyance-systems-spscs>

For additional information about the design and 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:

$$T_v = \frac{1.2 \text{ in} \times (R_v) \times A \times 43560 \frac{\text{ft}^2}{\text{acre}}}{12 \frac{\text{in}}{\text{ft}}}$$

Where:

T_v = water quality volume (ft^3)

R_v = 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:

$$VP_{\text{Total}} = VP_{\text{Sand}} + \sum VP_{\text{Pools}}$$

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:

$$VP_{\text{SAND}} = (\text{VSB}) * (N)$$

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:

$$VP_{POOLS} = (V_{POOL_1}) + (V_{POOL_2}) + (V_{POOL_3}) + \dots$$

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 $T_v(\text{target})$

When the $VP \geq T_v(\text{target})$ then the water quality treatment requirements are met for this practice. When the $VP < T_v(\text{target})$, 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:

$$L_{GCS} = L_{pool} = \frac{L_{RSC \text{ Path}}}{\frac{\Delta E}{2}}$$

Where:

L_{GCS} = Length of grade control structure

L_{pool} = Length of pool

$L_{RSC \text{ Path}}$ = 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 (ft²)

R = A/wetted perimeter (ft)

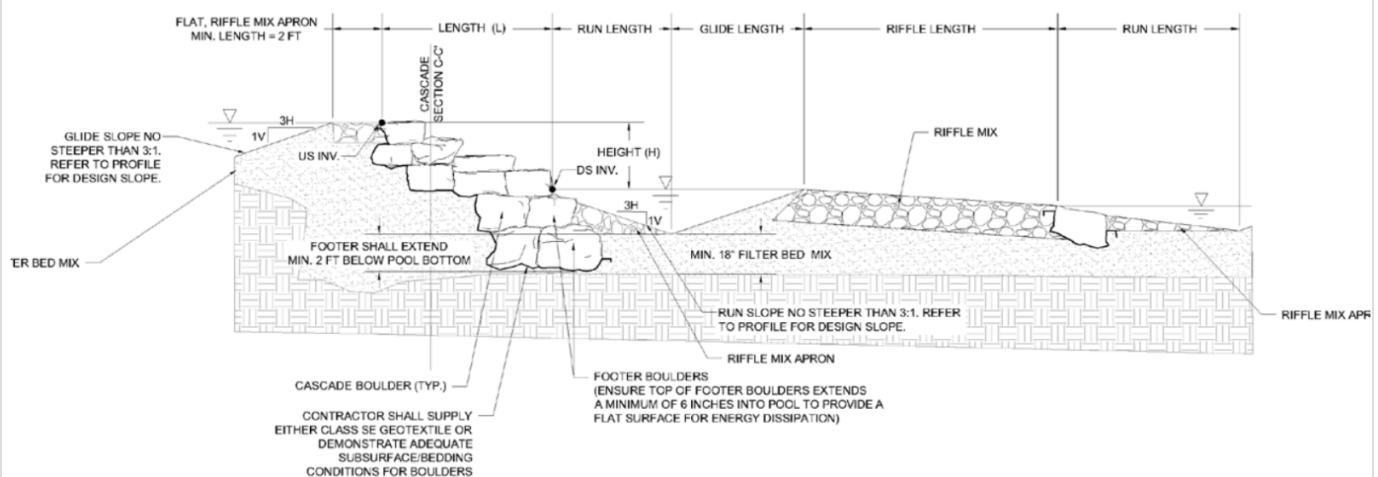
S = Channel slope (ft/ft)

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
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

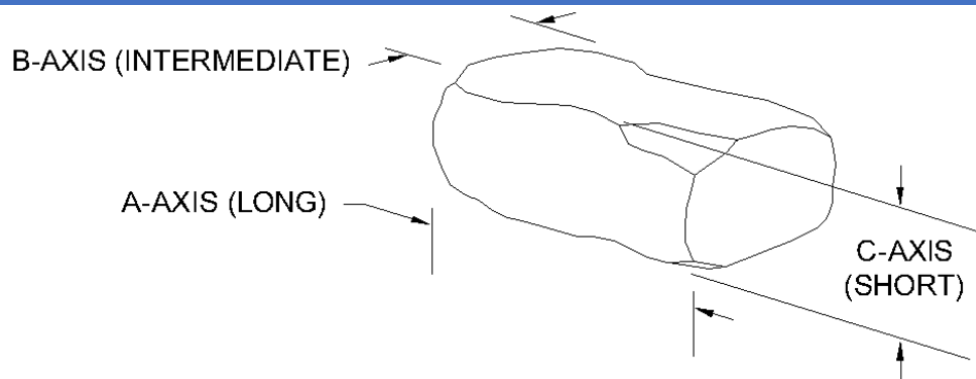


Source: Anne Arundel County Bureau of Watershed Protection and Restoration 2022

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 . 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 Agriculture, 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 (p_d) 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 p_d 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-spssc-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 Appendix G Plant Selection
Rip Rap and Outlet Protection	BMP C-ECM-15 Outlet Protection BMP C-ECM-13 Riprap
Sediment Forebay	P-SUP-06 Pre-Treatment
Erosion Control Blankets	C-SSM-05 Soil Stabilization Blankets and Matting 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.
- 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.

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.

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.	
Repair any erosion, rills, or gullies that may form in the practice. Conduct any needed repairs or stabilization.	
Repair areas with bare or dead grass in the contributing drainage area or around the RSC.	Upon establishment
Watering and spot fertilization may be necessary during first 2 months to establish vegetation.	
Remove and replace dead, damaged, or diseased plants.	
Prune and weed vegetation.	Four times per year
Remove trash, sediment, and debris.	
Add additional plants to maintain needed vegetation density.	
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.	Annually
Prune trees and shrubs (when they are dormant). Remove any invasive species.	
Remove any sediment accumulation in pretreatment area and inflow points.	
Remove accumulated sediment in pools.	Once every
Repair damage to weirs, riffles, pools, or other structural components.	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

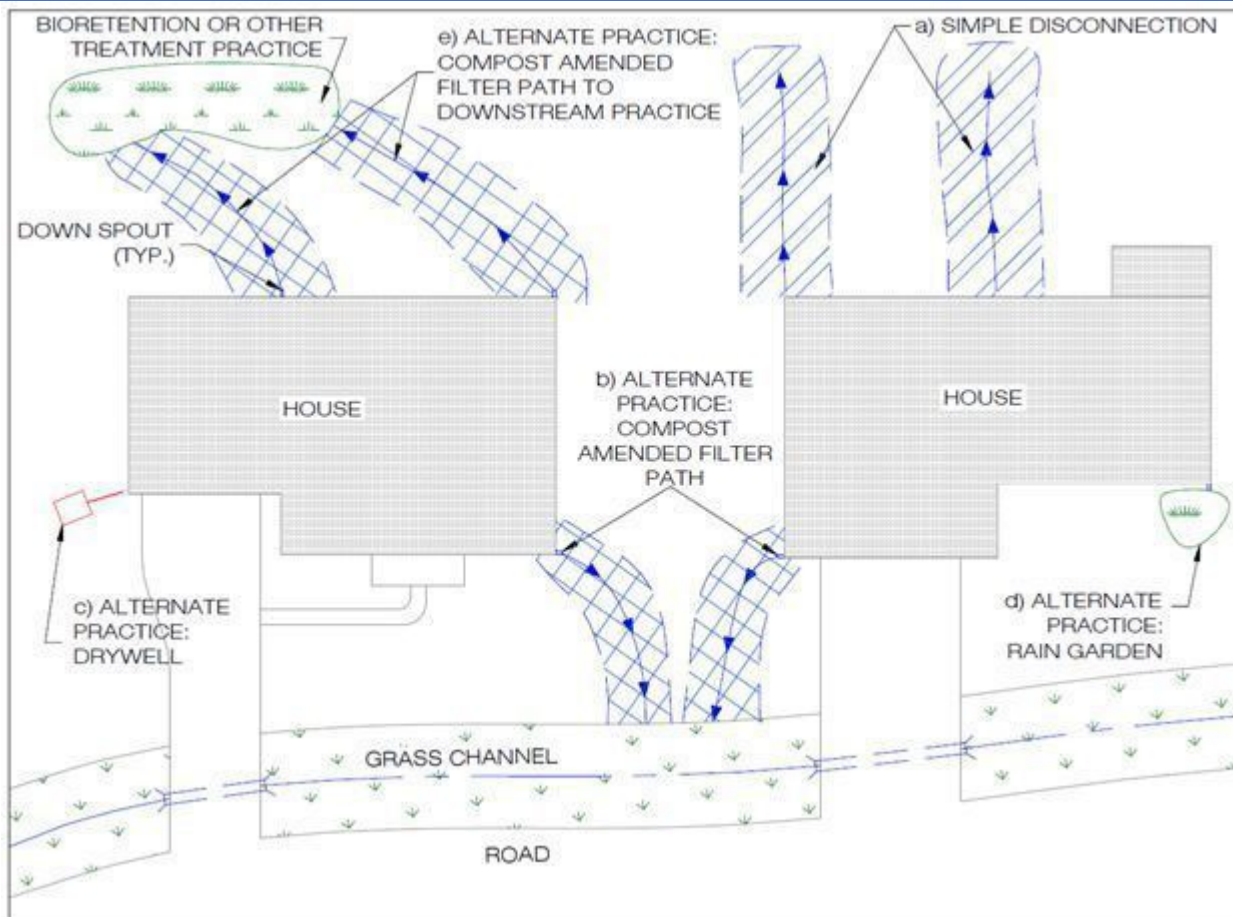
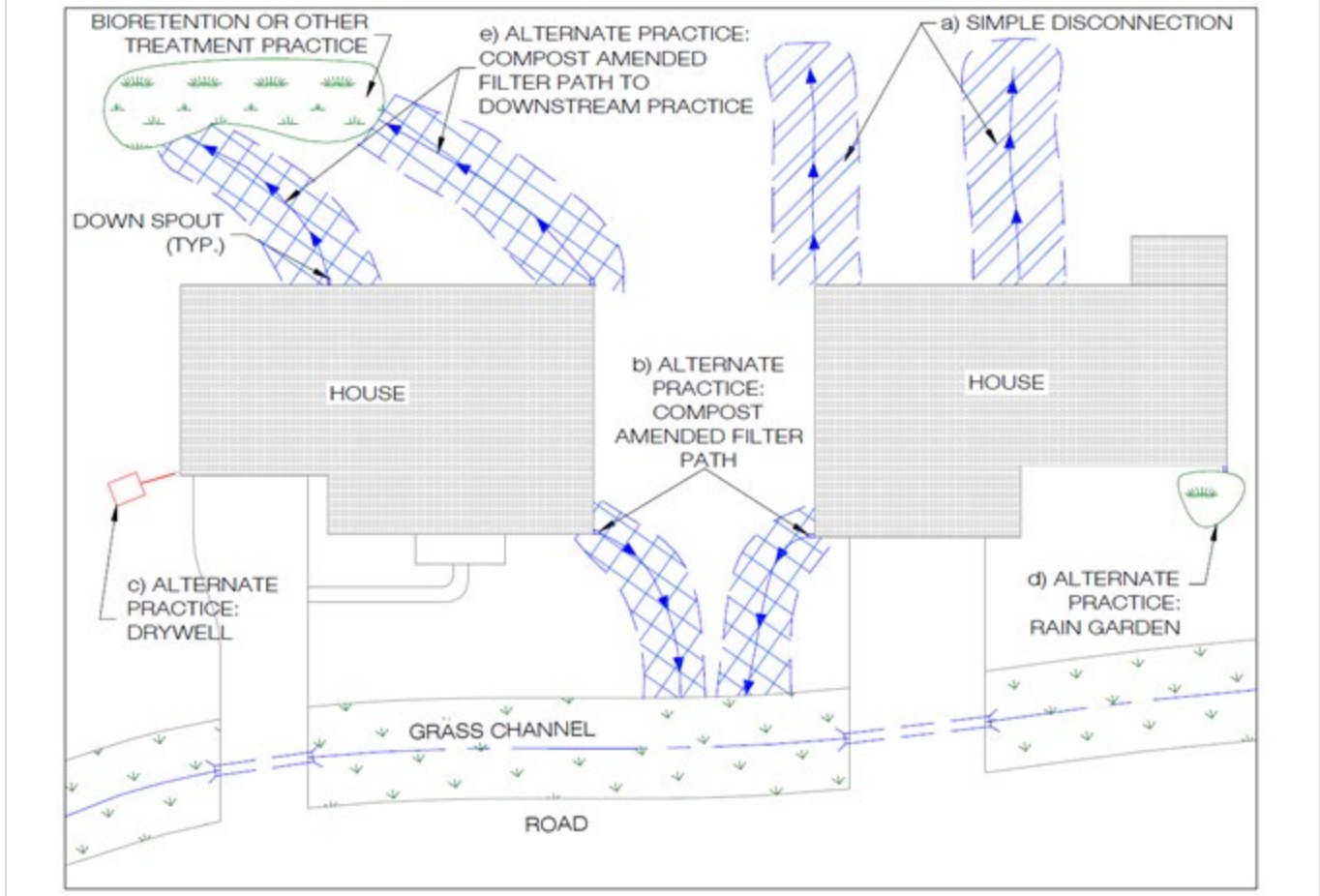


Figure P-FIL-01-2 Residential Rooftop Treatment – Plan View



- 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. and 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 $\geq$ 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

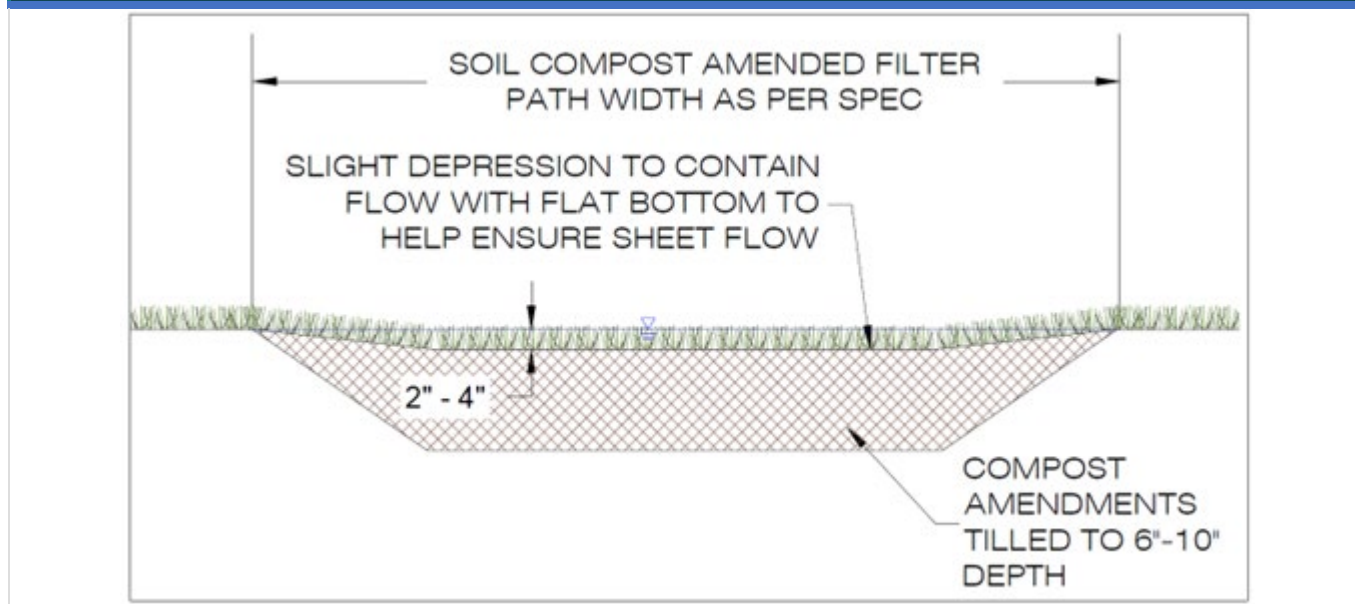


Figure P-FIL-01-4 Disconnection: Alternate Practice: Compost Amended Filter Path to Downstream Bioretention Section View

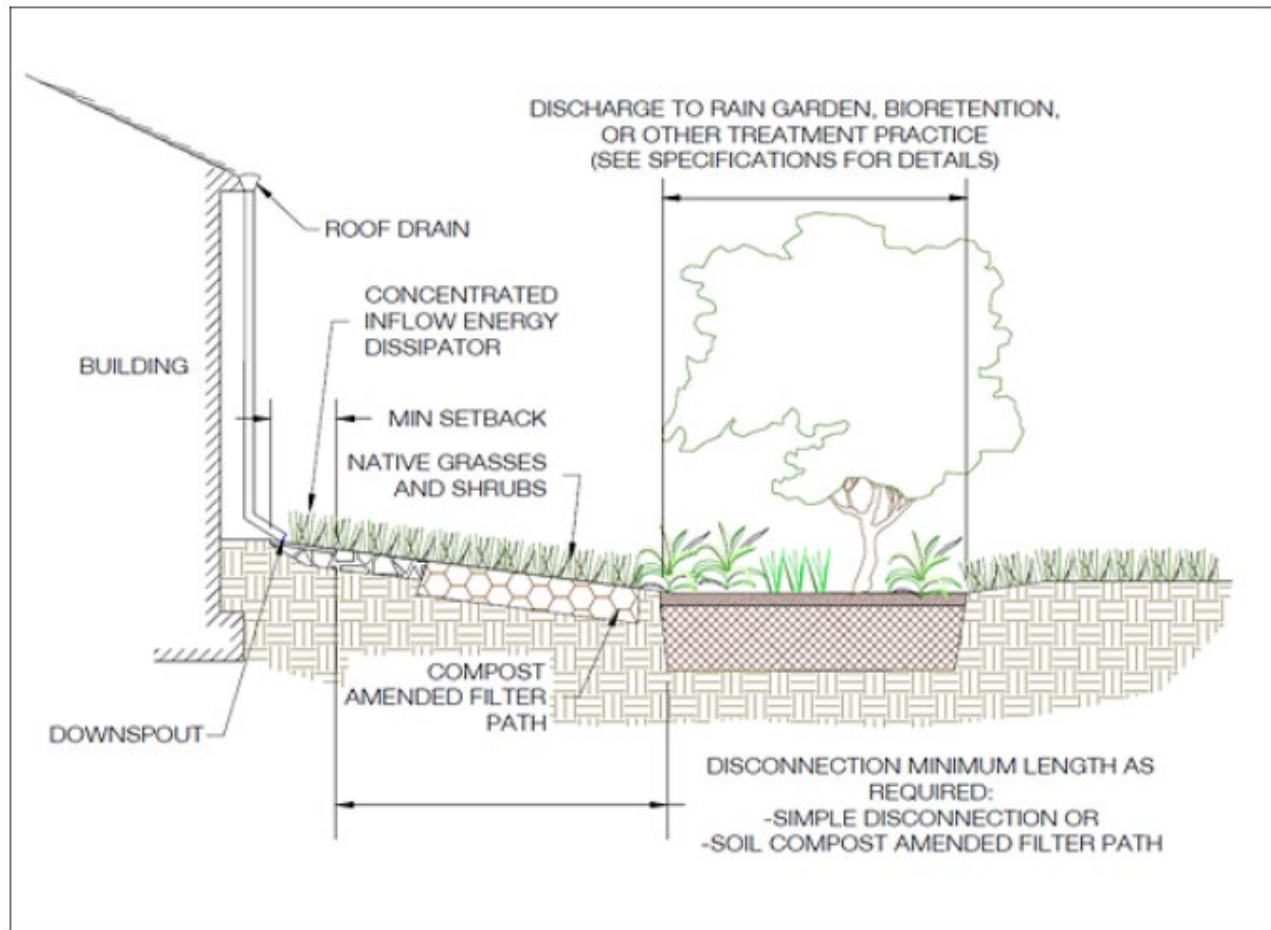
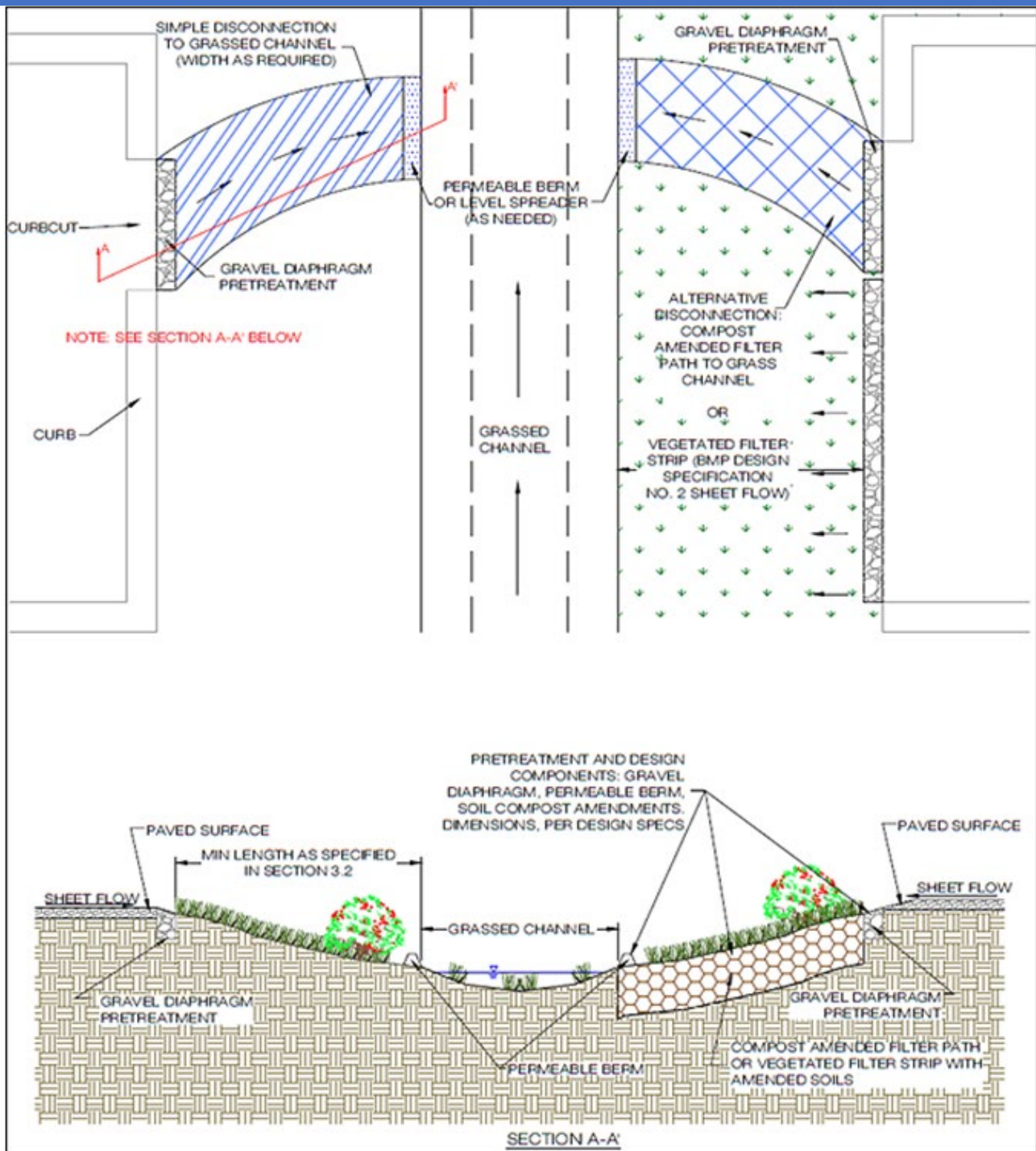


Figure P-FIL-01-5 Disconnection: Alternate Practice Amended Filter Path to Downstream Grass Channel (or other treatment)



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

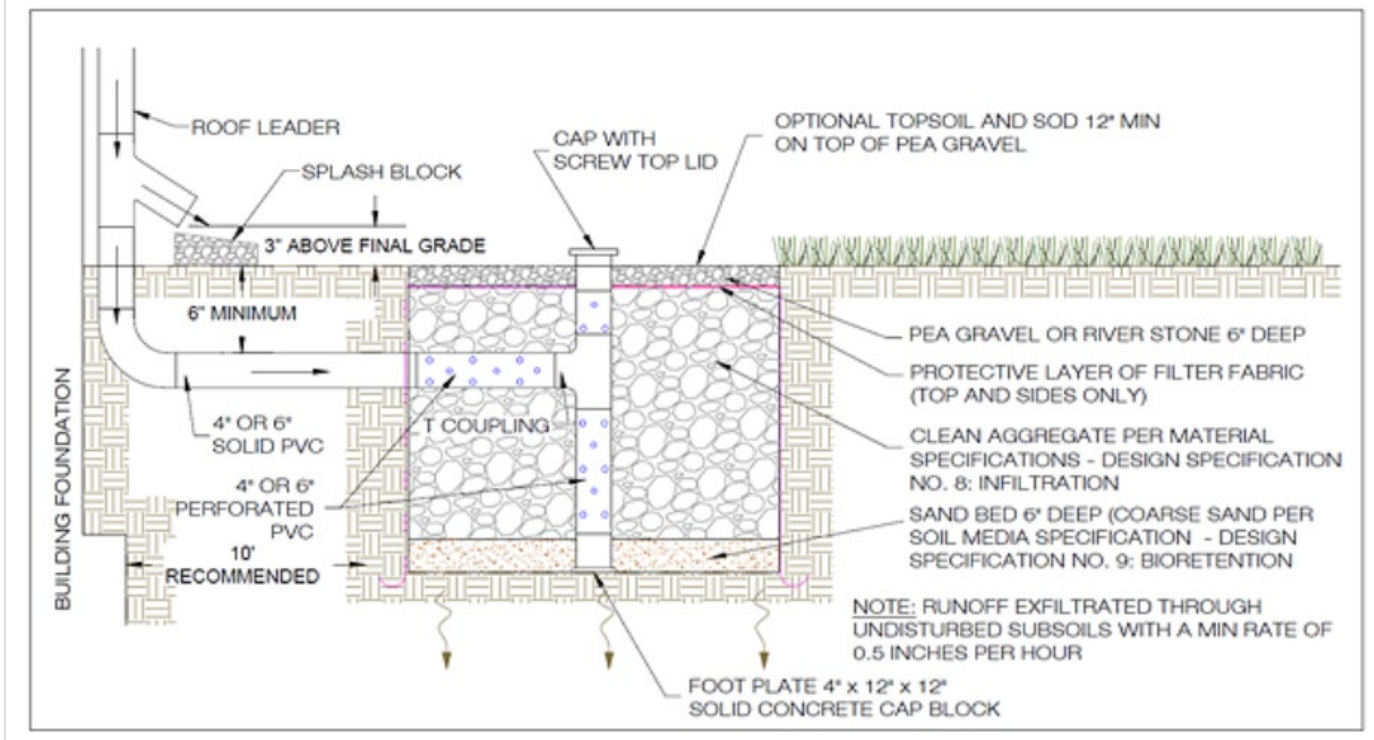
Design Factor	Micro-Infiltration Design
Roof Area Treated	250 to 2,500 square feet
Typical Practices	Dry Well and Rock Trench
Recommended Maximum Depth	3 feet
Runoff Reduction Sizing	See BMP P-FIL-04 , Infiltration Practices
Minimum Soil Infiltration Rate	0.5 inch/hour
Observation Well	No
Type of Pretreatment	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-Bioretenention

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-bioretenention (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-bioretenention 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-bioretenention 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-Bioretenction 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
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-bioretenction 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-Bioretenction 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**

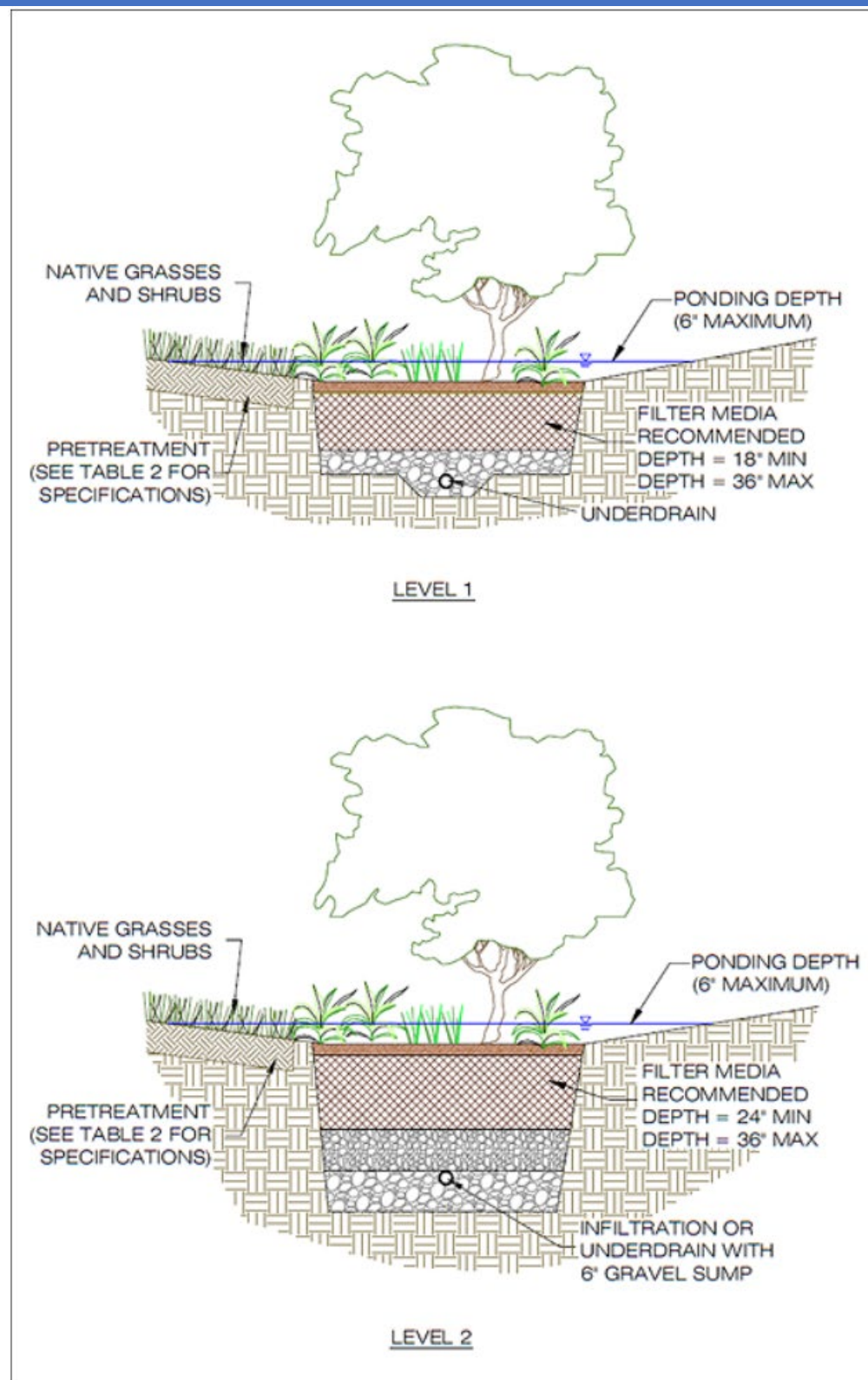


Table P-FIL-01-5 Regional and Special Case Design Adaptations

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-bioretenment, 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.
- CWP and CSN 2008. Technical Memorandum: The Runoff Reduction Method.
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- NYDEC. 2015. New York State Stormwater Management Design Manual. Originally Prepared by the Center for Watershed Protection, updated by the New York State Department of Environmental Protection.
- Virginia Cooperative Extension. 2019. Best Management Practice Fact Sheet 3: Grass Channels. Publication 426-122. Available online at: <https://digitalpubs.ext.vt.edu/vcedigitalpubs/3588686348927379/MobilePagedReplica.action?pm=1&folio=1#pg1>.
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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-02-1 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-02-1 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: • 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; • The age and accessibility of the existing roof. • The capability of the building owner(s) to maintain the roof. 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-02-1 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-02-2](#).

Table P-FIL-02-2 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-02-3](#) lists the design criteria for Level 1 and 2 designs.

Table P-FIL-02-3 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

$$\text{Vegetated Roof Volume} = (RA \cdot D \cdot n) / 12$$

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-02-3](#). 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): 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. 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. 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. 4. Cover the waterproof membrane completely with either flashing or growing medium. Any exposed membrane is susceptible to ultraviolet light damage. 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. 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. 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.

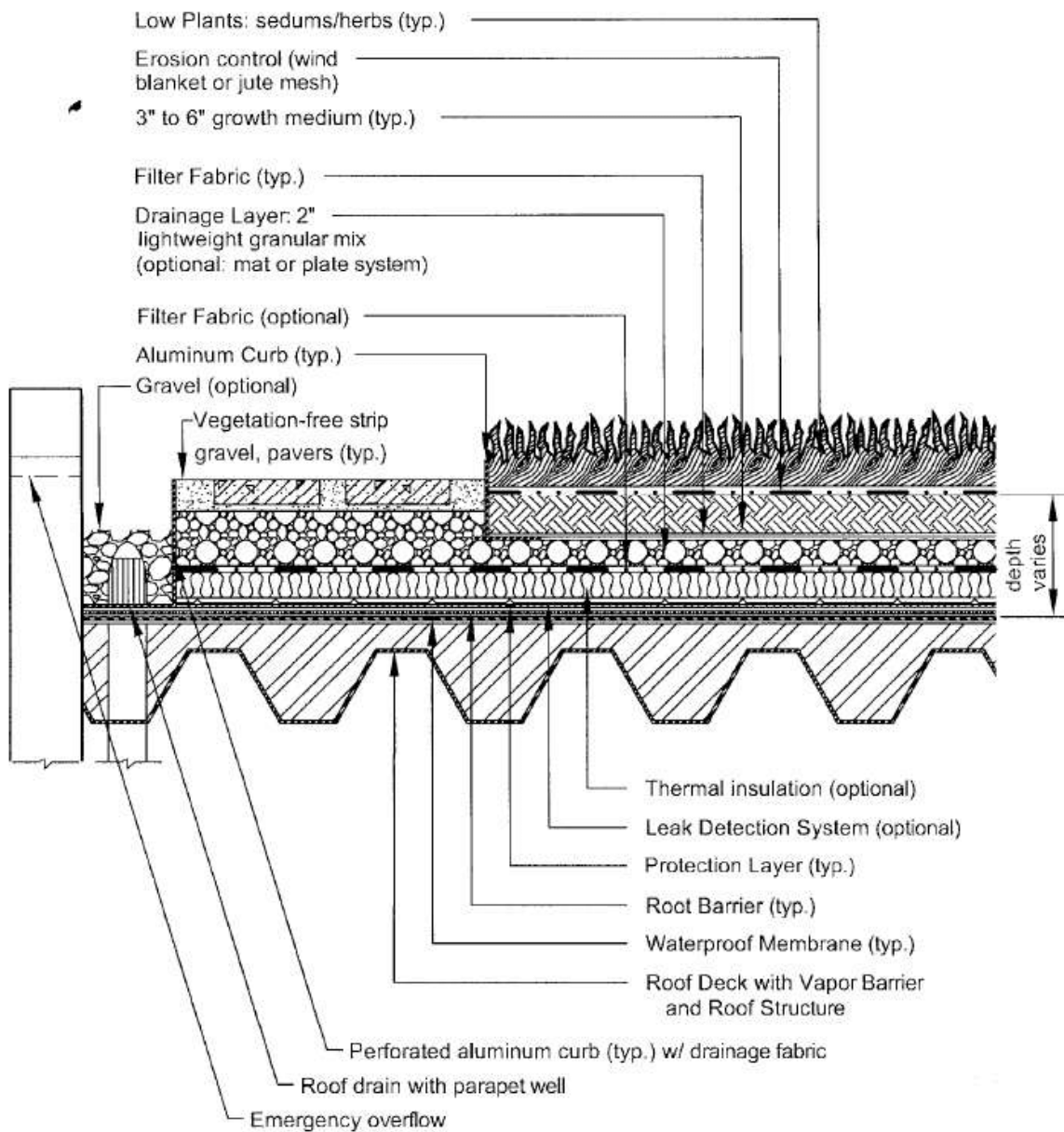
Table P-FIL-02-4 Vegetated Roof Layer Composition

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. <u>Conveyance and Overflow:</u> 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

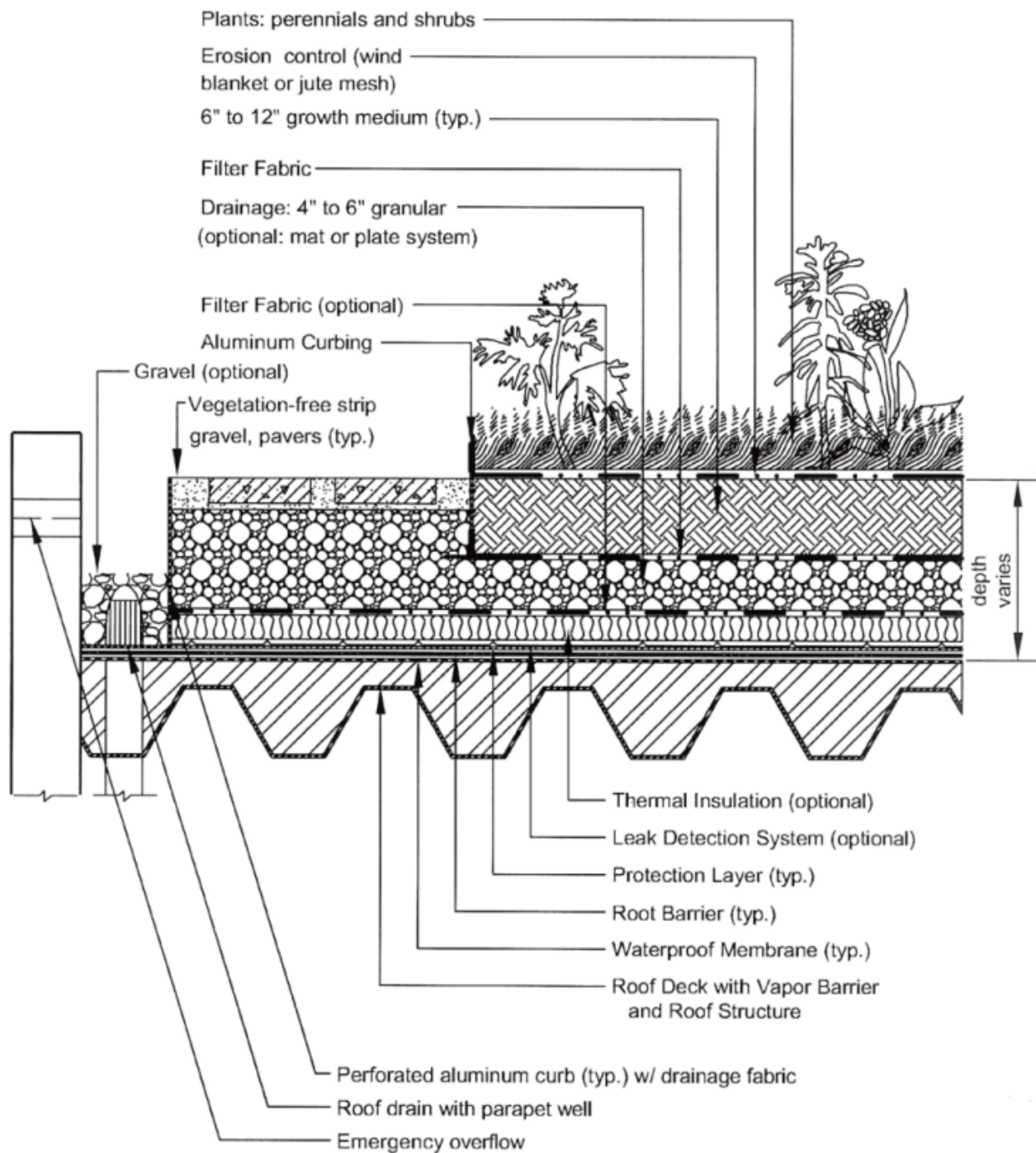
Layer	Composition
Growing Media	Growing medium for a vegetated roof is typically 2.5 to 8 inches deep. The recommended growing medium for extensive vegetated roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria, or other 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%. 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. 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. 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.
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.

Table P-FIL-02-6 Extensive Vegetated Roof Material Specifications

Material	Specification
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). 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.
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.	As Needed (following construction)
Inspect the vegetated roof and replace any dead or dying vegetation.	
Inspect the waterproof membrane for leaking or cracks. Apply annual fertilization (first 5 years).	Semi-Annually
Weed to remove invasive plants.	
Inspect roof drains, scuppers, and gutters to ensure they are not overgrown or contain organic matter deposits. Remove any accumulated organic matter or debris.	
Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.	

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

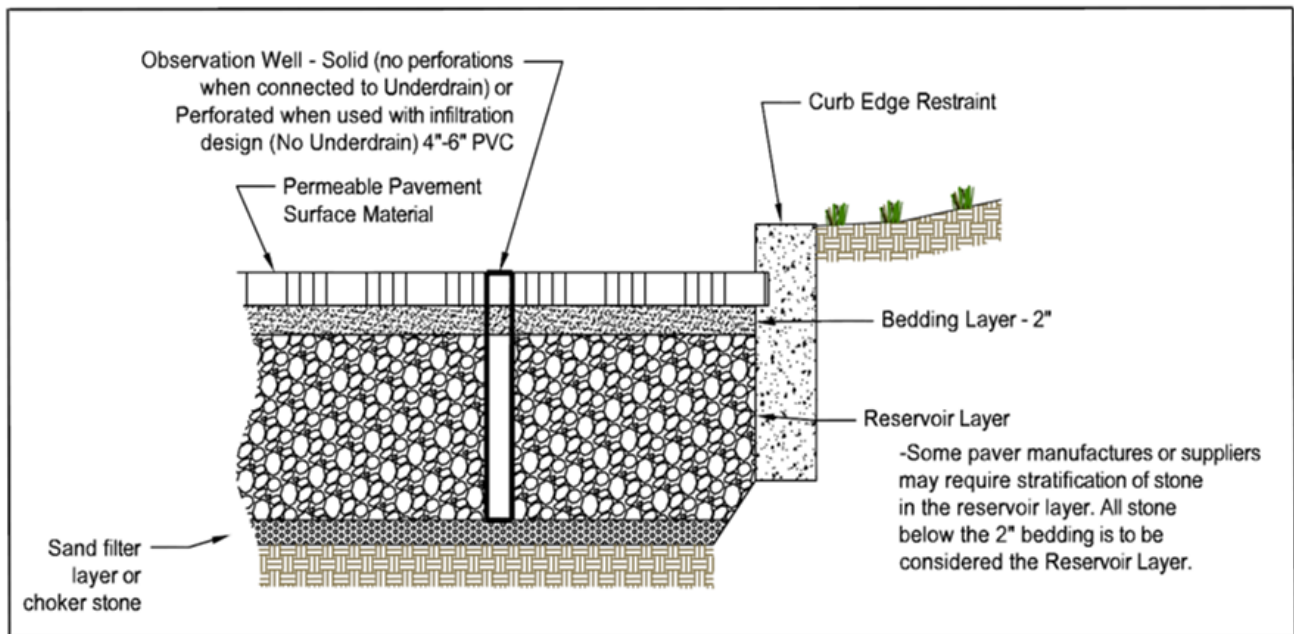
1.0 Definition

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 be 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. 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. 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. 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 Court Yards Plazas Individual Sidewalks	Sidewalk Network Fire Lanes Road Shoulders Spill-Over Parking Plazas	Parking Lots with more than 40 spaces Low Speed Residential Streets
Most Suitable Pavement	IP	PA, PC, and IP	PA, PC, and IP
Load Bearing Capacity	Foot traffic 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 25 feet if upgradient	10 feet if downgradient 50 feet if upgradient	25 feet if downgradient 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. PA: 2 inches of No. 57 stone. 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. 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%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 MPa. 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%. Thickness: 3.5 inches. Compressive strength: 35 MPa. 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. Compressive strength: Varies, depending on fill material. 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 %. Thickness: 4 to 8 inches. Compressive strength: 2.8 to 28 MPa. 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%. Thickness: 3 to 7 inches (depending on traffic load). 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. 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. Additional winter maintenance considerations include: • 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. • 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. • 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. • 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.
	<i>Vehicle Safety.</i> 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 Reduction ¹ 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 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 , , , and .

Table P-FIL-03-9 Permeable Pavement Design Criteria

Level 1 Design	Level 2 Design
$T_v = (1)(R_v)(A) / 12$ The volume reduced by an upstream BMP1	$T_v = (1.1)(R_v)(A) / 12$
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 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 3. The T_v 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 • 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

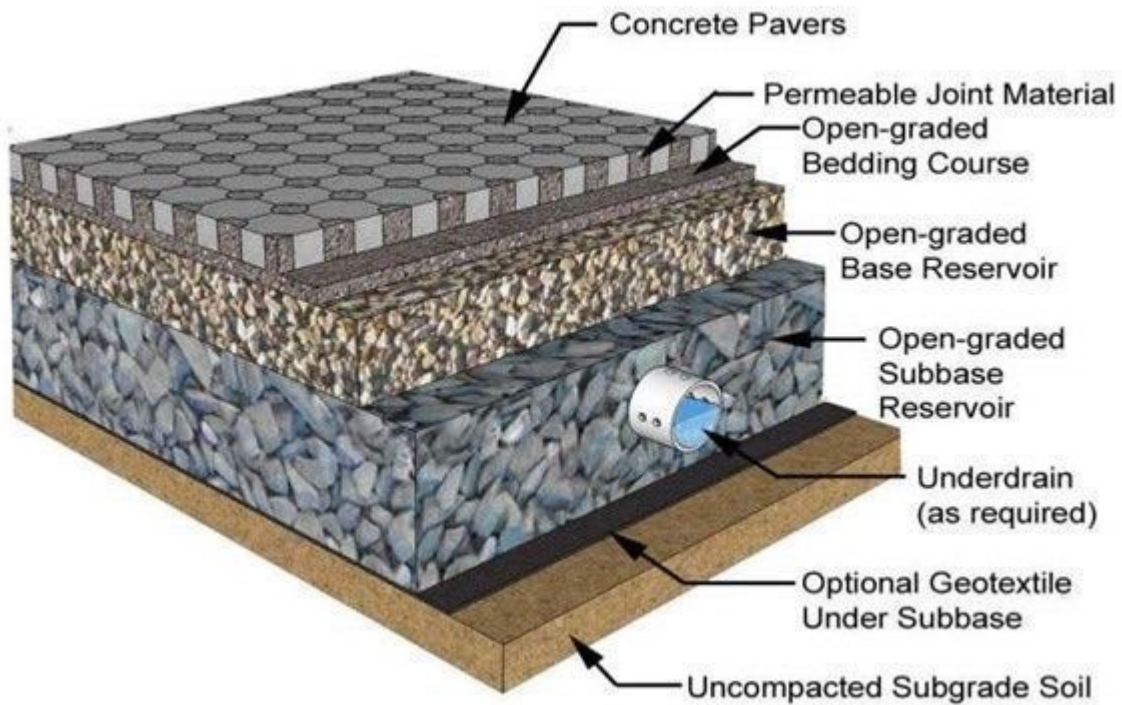
Level 2 Design

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 2009

Figure P-FIL-03-4 Typical Section Permeable Pavement Level 1

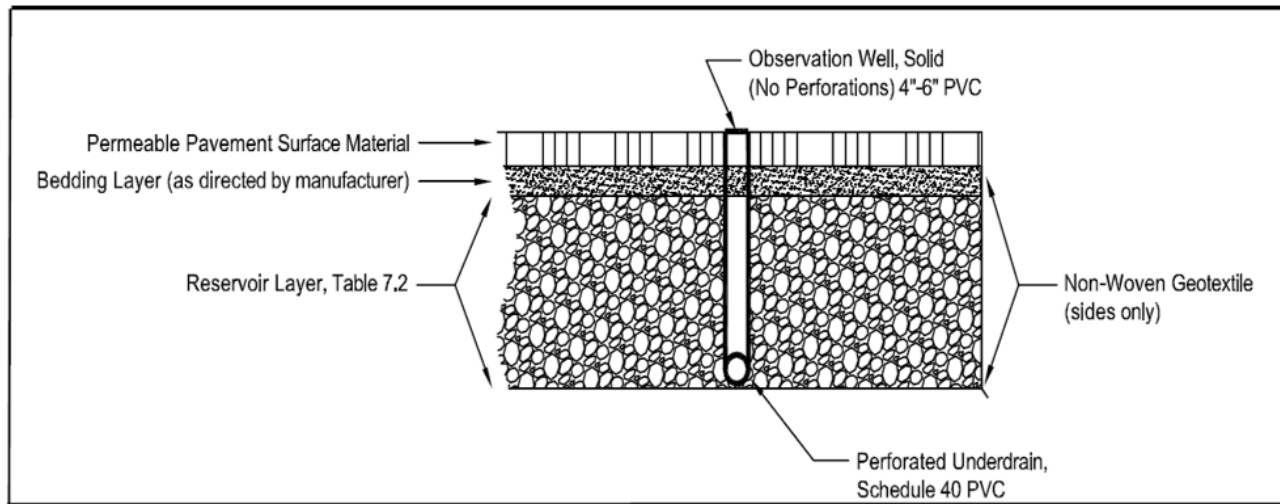


Figure P-FIL-03-5 Typical Section Permeable Pavement Level 2 with Infiltration Sump

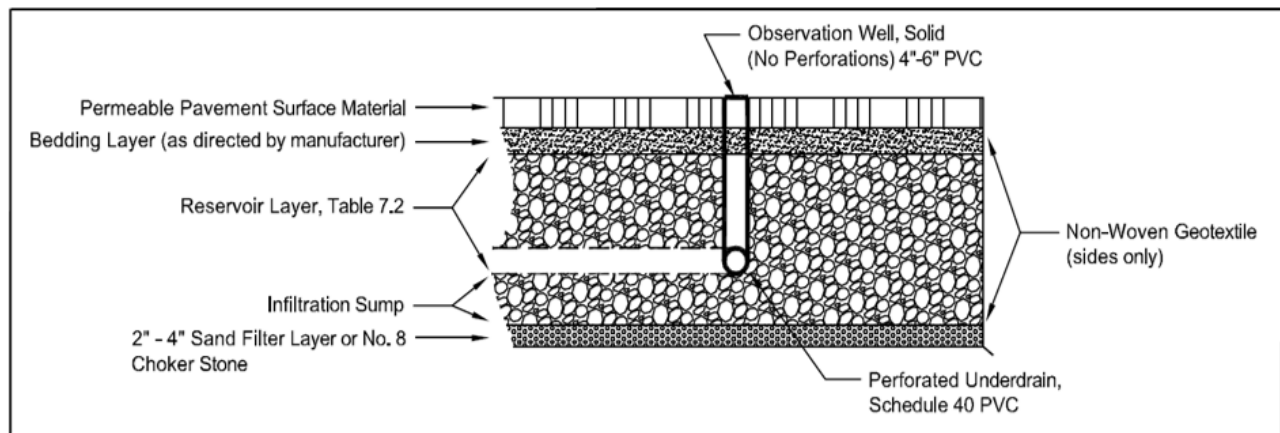


Figure P-FIL-03-6 Infiltration Sump with an “Upturned Elbow” or Weir Control

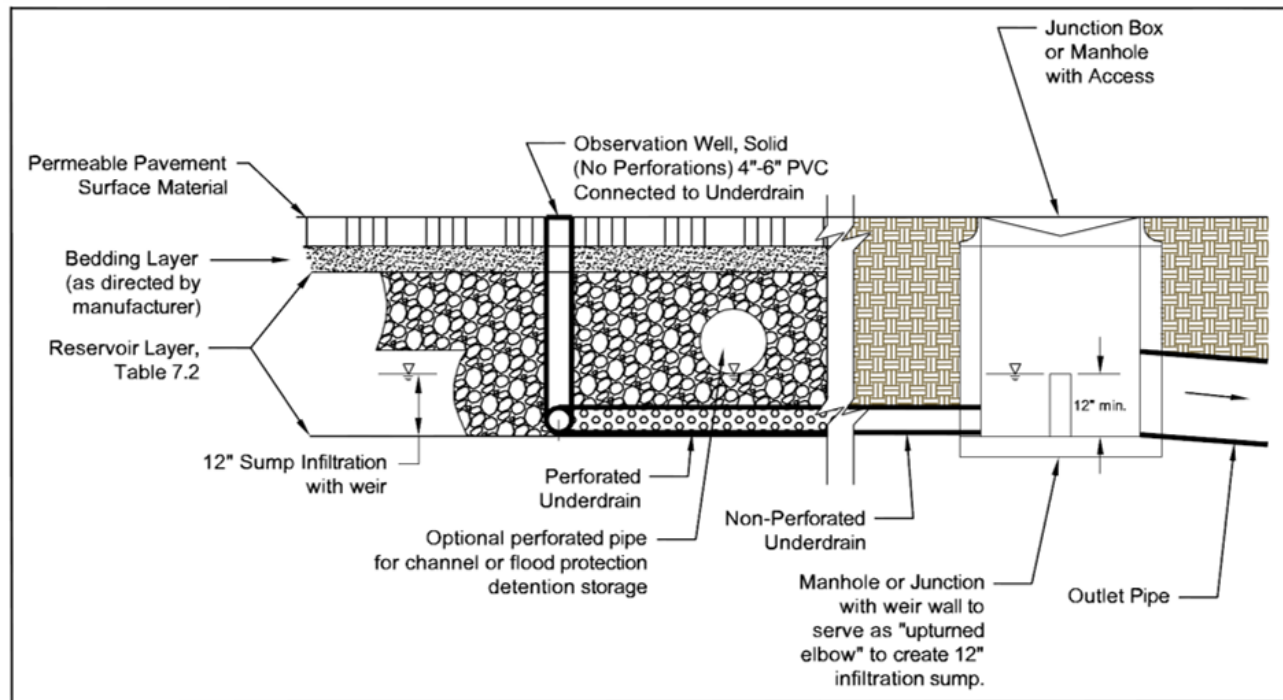
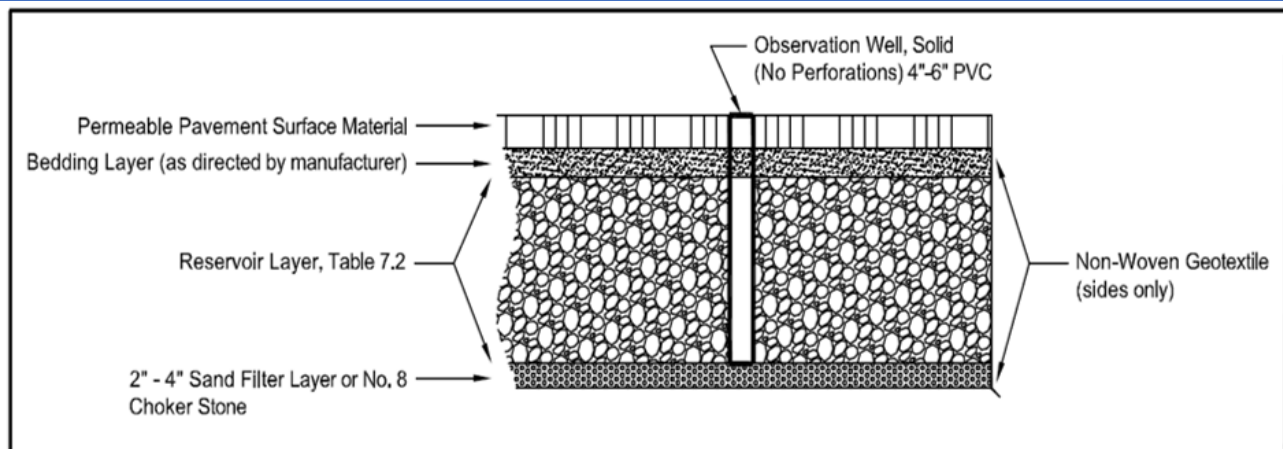


Figure P-FIL-03-7 Typical Section Permeable Pavement Level 2 with Infiltration



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 (M_r);
- 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 (T_v) 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 T_v 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:

d_{stone} = 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.

A_I = Contributing impervious drainage area (square feet).

Rv_I = Volumetric runoff coefficient for impervious cover = 0.95.

A_P = Area of permeable pavement (square feet).

η_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 A_I will refer to the contributing drainage area and the term Rv_I 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, 48 hours.

η_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 T_v 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 T_v must be added above the sump through additional stone. As an option, the entire T_v 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 , or it can be placed at the bottom of the reservoir sump with an upturned elbow configuration as shown on . 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 T_v storage.

Slow Drawdown. The permeable pavement stone reservoir should be designed to detain the design T_v 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 .
- 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 Positioning 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. 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. 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.

8.0 References

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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 French Drain Paving Blocks	Infiltration Trench Permeable Paving ¹	Infiltration Trench 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

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.
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. 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:

- 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.
- 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.
- 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 (T_v) 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.
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.

Table P-FIL-04-4 Community and Environmental Concerns

Concern	Requirement
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: • The bottom of the practice should extend below the frost line. • 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). • Pretreatment measures can be oversized to account for the additional sediment load caused by road sanding (up to 40% of the Tv). • 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		✓
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%
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 • Design for extra storage (optional; as needed) on the surface or in the subsurface storage volume to accommodate larger storm volumes, and use USDA-NRCS TR-55 Runoff Equations² to compute the CN Adjustment.	

Table P-FIL-04-7 Summary of Stormwater Functions Provided by Infiltration

Stormwater Function	Level 1 Design	Level 2 Design

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: $T_v = [(R_v)(A)/12]$ – the volume reduced by an upstream BMP	Sizing: $T_v = [1.1(R_v)(A)/12]$ – the volume reduced by an upstream BMP
At least two forms of pretreatment (see Table P-FIL-04-11)	At least three forms of pretreatment (see Table P-FIL-04-11)
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. T_v infiltrates within 36 to 48 hours.	
Building setbacks – see Table P-FIL-04-3 .	
All designs are subject to hotspot runoff restrictions/prohibitions.	
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

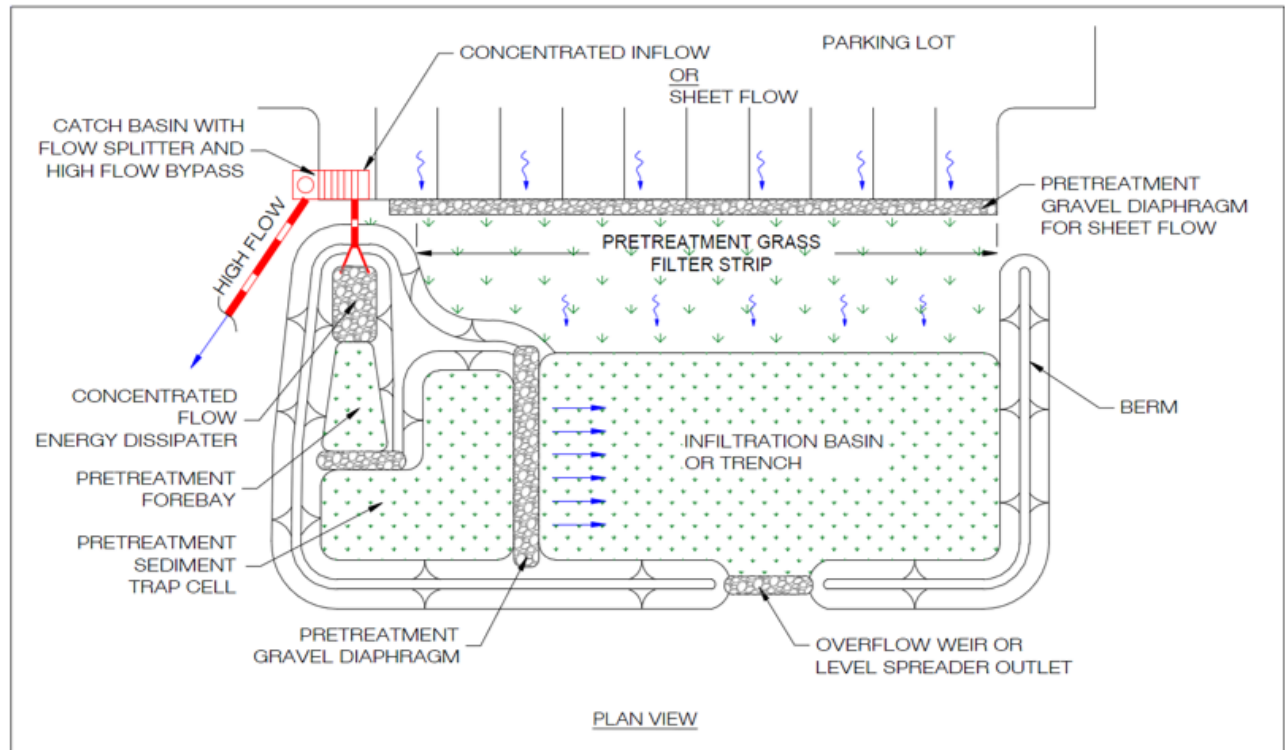


Figure P-FIL-04-2 Infiltration Trench or Basin Section View

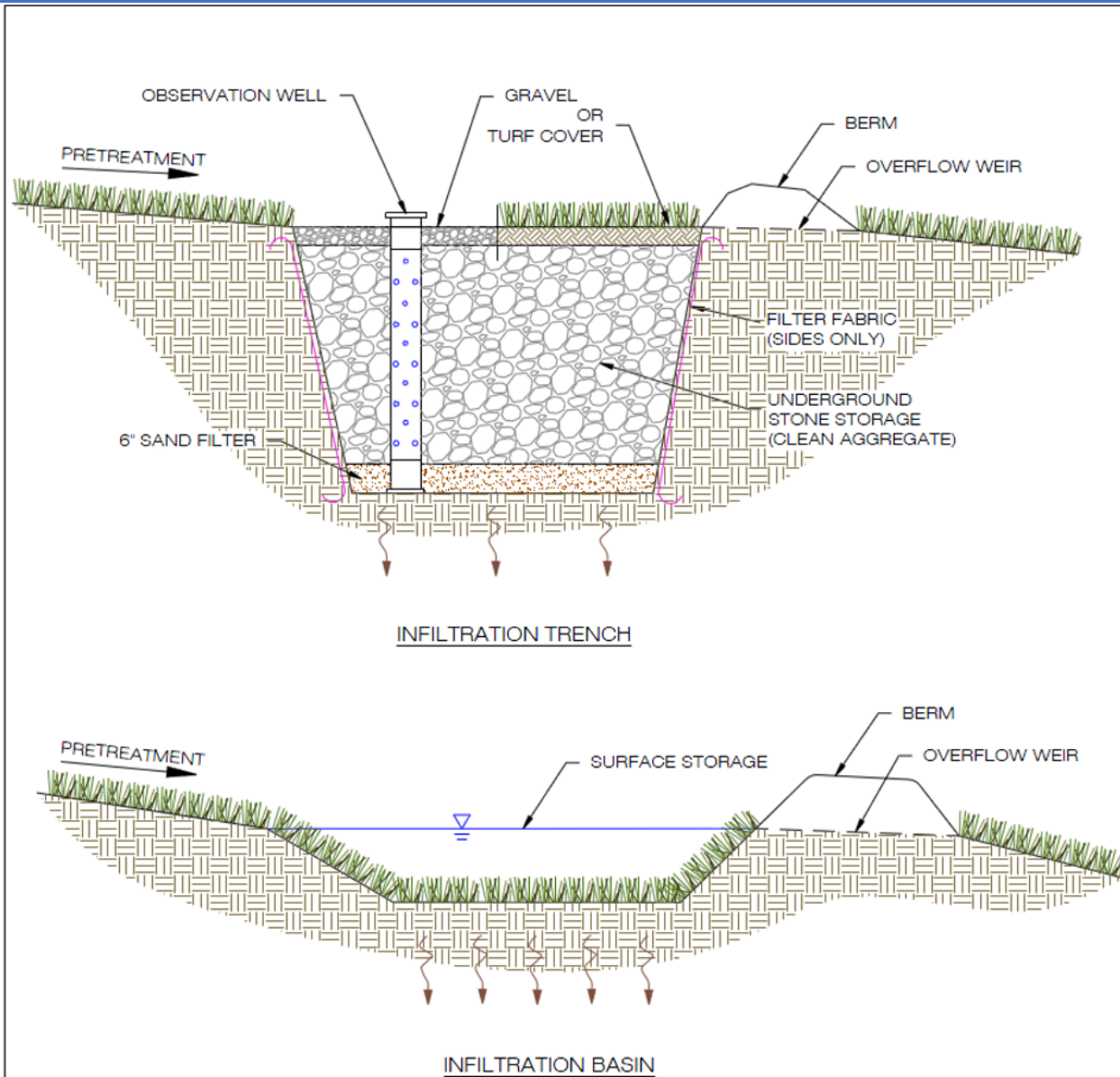


Figure P-FIL-04-3 Infiltration Section with Supplemental Pipe Storage

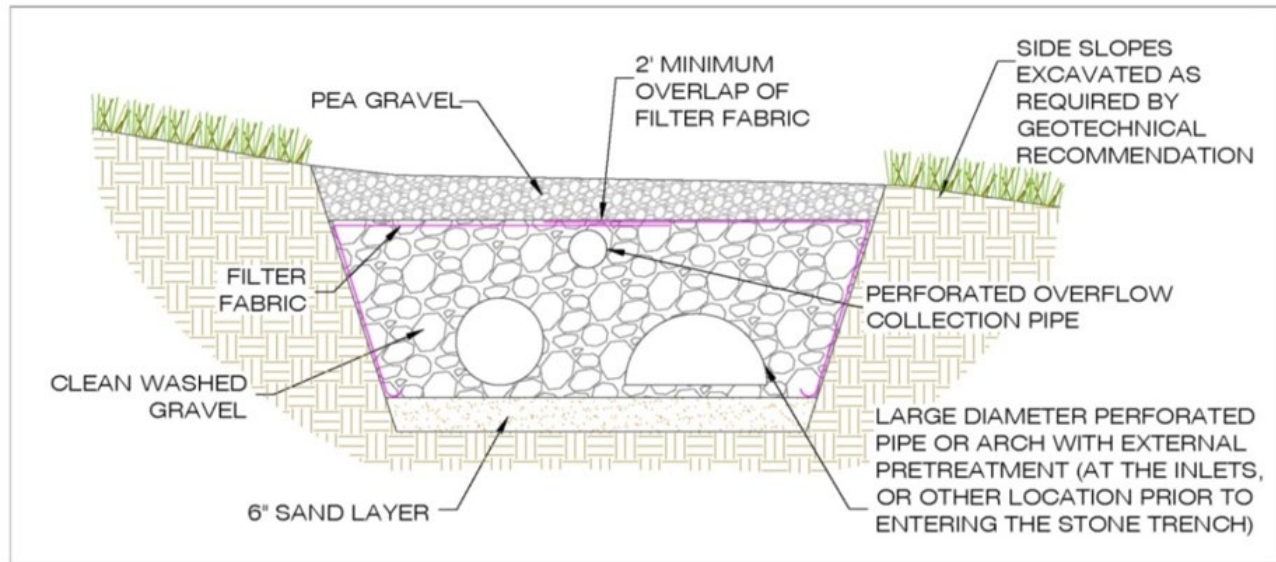


Figure P-FIL-04-4 Infiltration Combined with Detention (Channel and/or Flooding Protection)

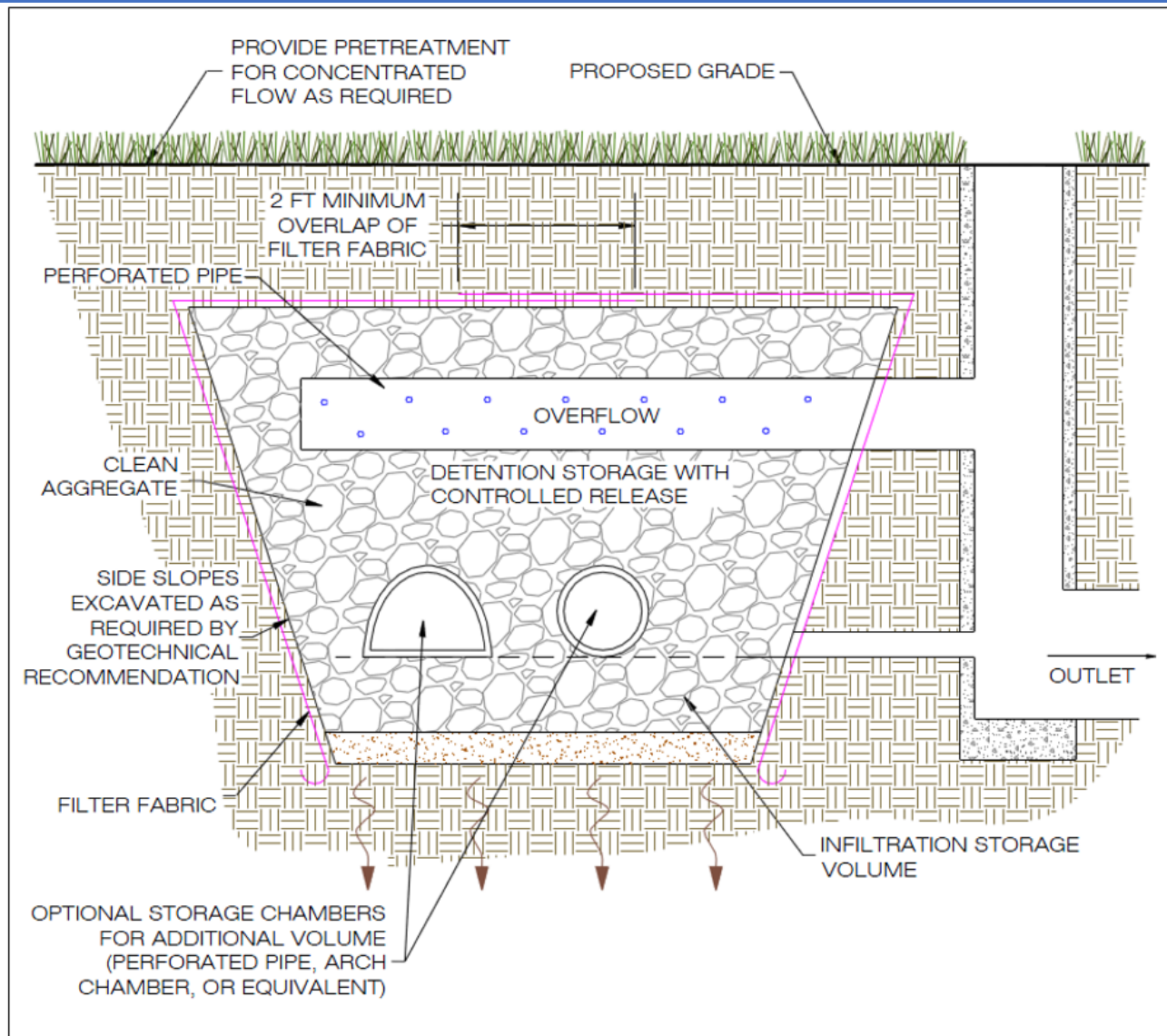


Figure P-FIL-04-5 Observation Well

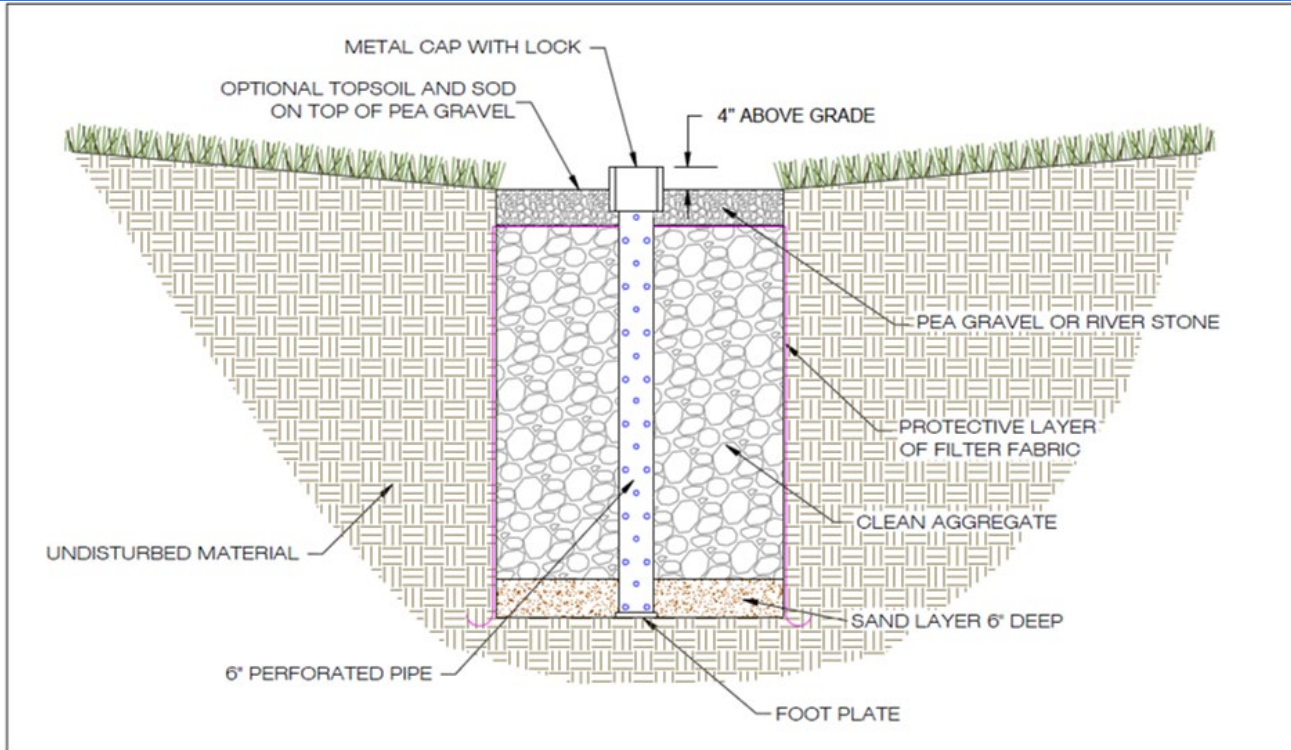
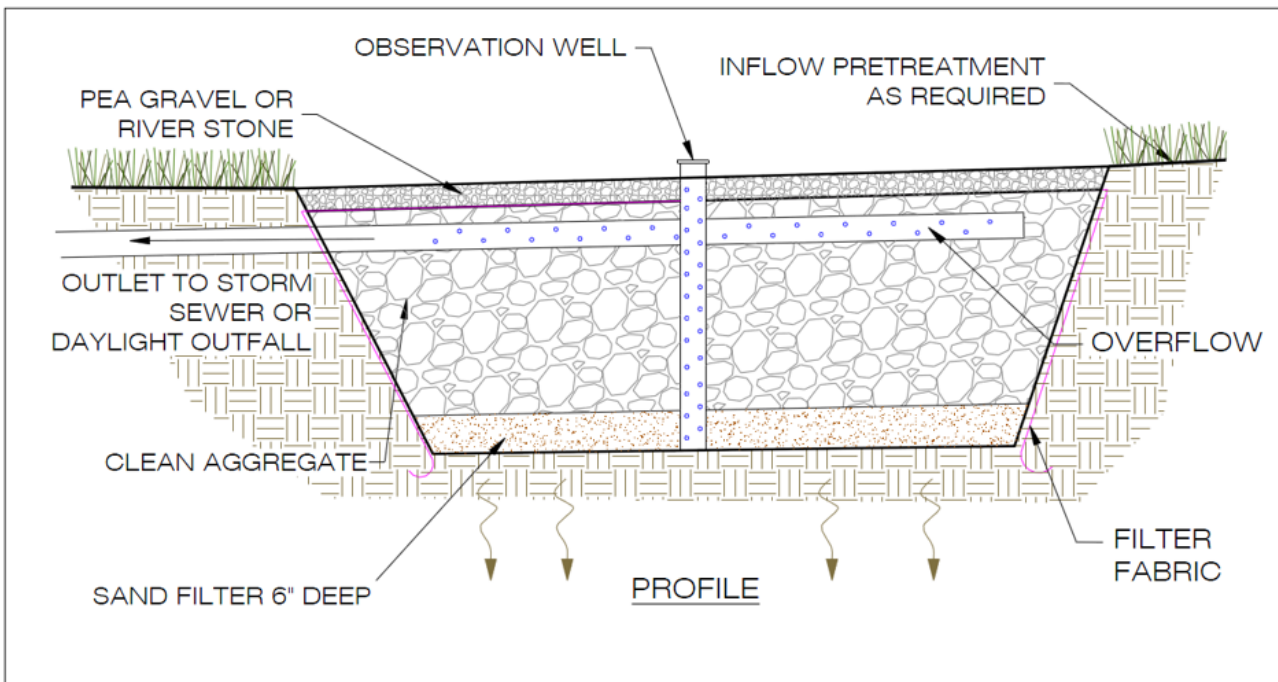


Figure P-FIL-04-6 Typical Infiltration Trench



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).

t_d = maximum drawn down time (normally 48 hours).

η = porosity of the stone reservoir (assume 0.4).

Designers should compare these results to the maximum allowable depths in [Table P-FIL-04-9](#), and use whichever value is *less* for subsequent design.

Table P-FIL-04-9 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

$$SA = Tv_{BMP}/d + \left[\frac{\left(\frac{1}{2}\right) f \times t_f}{12} \right]$$

Equation P-FIL-04-4 Underground Reservoir Surface Area

$$SA = Tv_{BMP}/(\eta \times d) + \left[\frac{\left(\frac{1}{2}\right) f \times t_f}{12} \right]$$

Where:

SA = Surface area (square feet).

Tv_{BMP} = Design volume for the BMP, e.g., Tv from the contributing drainage area plus any remaining volume from upstream runoff reduction practices (cubic feet).

η = 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).

t_f = 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 ($1.1 \times Tv$).

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-FIL-04-11](#). Refer to BMP [P-SUP-06](#), Pre-Treatment, for design details and guidance on pretreatment.

Table P-FIL-04-10 Required Pretreatment Elements for Infiltration Practices

Pretreatment:	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 Grass filter strip Upper sand layer Washed bank run gravel Roof stormwater isolation	Grass filter strip Grass channel Plunge pool Gravel diaphragm Treatment train Limit hydraulic loading	Sediment forebay Sand filter cell Inlet sumps Grass filter strip Grass channel Gravel diaphragm Manufactured treatment device Manufactured flow control devices Treatment train 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 T_v , 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-04-11). Where possible, conventional infiltration practices should be designed off-line to avoid damage from the erosive velocities of larger design storms.

Table P-FIL-04-11 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 T_v for the contributing drainage area, as long as other runoff reduction practices are applied at the site to meet the remainder of the T_v . Account for the total T_v 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-04-12](#).

Table P-FIL-04-12 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-04-12 Infiltration Material Specifications

Material	Specification	Notes
Stone	Use clean aggregate with a maximum diameter of 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 polypropylene 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-04-13](#). Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table P-FIL-04-13 Typical Maintenance Activities for Infiltration Practices

Maintenance Activity	Schedule
Replace pea gravel/topsoil and top surface filter fabric (when clogged). 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. Ensure that the contributing drainage area is stabilized. Remove sediment and oil/grease from pretreatment devices, as well as from overflow structures. 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. Inspect pretreatment devices and diversion structures for sediment build-up and structural damage. 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 settle 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-02-1](#), 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



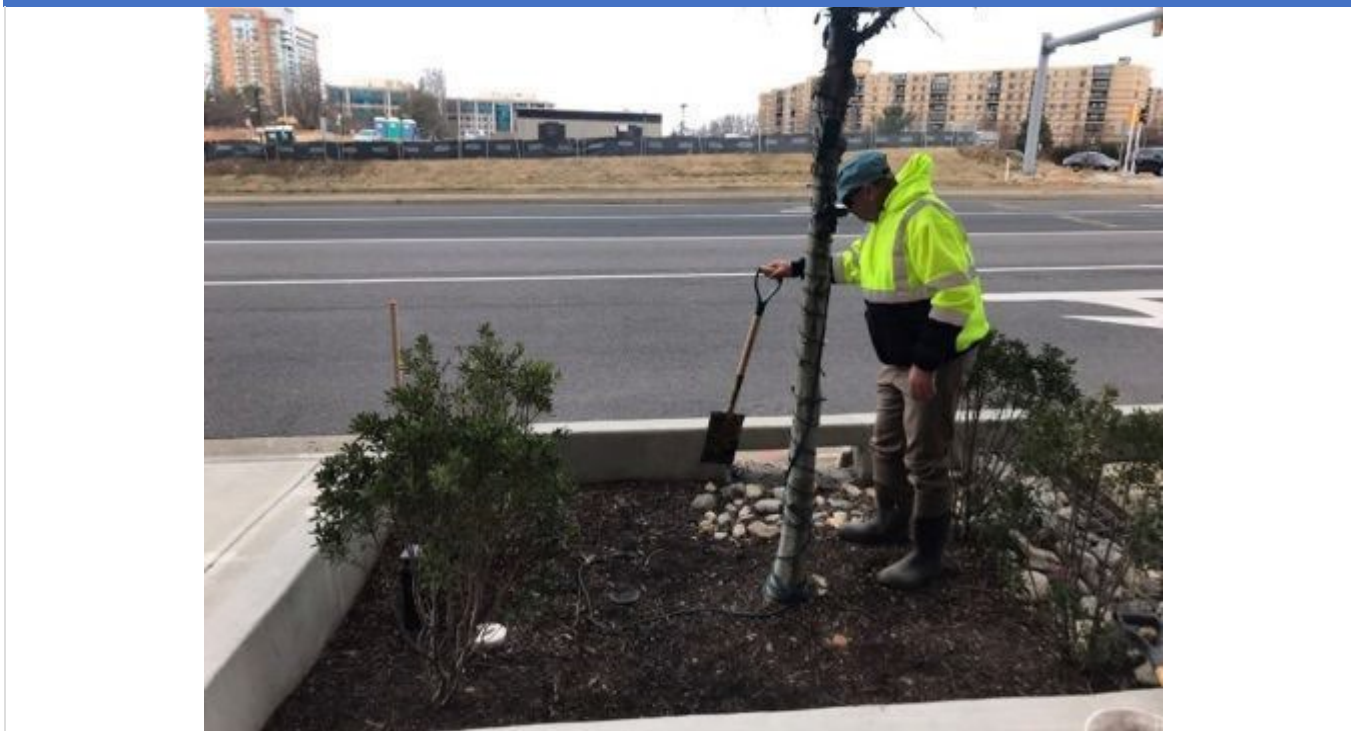
Figure P-FIL-05-3 Image of bioretention cell receiving stormwater runoff from multiple input points (3) in a mixed-use development in Blacksburg, VA



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-02-2](#)).

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-02-3](#). 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-02-3](#) below.

Table P-FIL-05-3 Bioretention Design Primary Criteria

Level 1 Design	Level 2 Design
<u>Surface Area:</u> $T_v \text{ (cu ft)}^\dagger = [(1.0)(R_v)(A)] / 12$ – the volume reduced by an upstream BMP	<u>Surface Area:</u> $T_v \text{ (cu ft)}^\dagger = [1.25(R_v)(A)] / 12$ – the volume reduced by an upstream BMP
Perform soil test if no underdrain	Soil Test must be performed
<u>Hydraulic conductivity (Ksat):</u> Min > 0.5 in./hr. to remove the underdrain requirement Max ≤ 10 in./hr. without underdrain*	<u>Hydraulic Conductivity (Ksat):</u> Min > 0.25 in./hr. Min > 0.5 in./hr. to remove the underdrain requirement Max ≤ 10 in./hr.*
<u>Drain Time:</u> Ponding Volume ≤ 48 hrs. Design Volume ≤ 48 hrs. (with underdrain) Design Volume ≤ 72 hrs. (if no underdrain)	<u>Drain Time:</u> 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:

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

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:

Min: 24 inches

Max: 48 inches§

Min: 36 inches rooting depth for trees**

Filter Media Depth:

Min: 36 inches

Max: 48 inches§

Min: 36 inches rooting depth for trees**

Filter Media: Supplied and certified by vendor per criteria provided in [Appendix F](#).

Gravel Layer:

Min choker stone layer: 3 in.

Min gravel layer with no underdrain: 0 in. Min

gravel layer with underdrain: 9 in.

Max gravel layer: 12 in.§

Gravel Layer:

Min choker stone layer: 3 in.

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:

Concentrated flow: Locate inlets and outlets as far apart as possible. Non-concentrated flow: Distribute inflow evenly across filter surface area.

Maintenance:

Deeded Maintenance Agreement

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 K_{sat} 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-02-3](#). 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-02-3](#)). 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 $T_{V_{BMP}}$, 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 area included within the contributing drainage area is not part of the $T_{V_{BMP}}$. The $T_{V_{BMP}}$ for Level 1 designs can be obtained from the VRRM spreadsheet. For Level 2 designs, use Equation P-FIL-05-1 to calculate the $T_{V_{BMP}}$:

Equation P-FIL-05-1: Treatment Volume Calculation.

$$T_{V_{BMP}} = (C_{Level} \times R_v \times A) / 12$$

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 $T_{V_{BMP}}$ (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.

$$SA = T_{V_{BMP}} / ESD$$

Where:

SA = surface area (sq. ft.)

$T_{V_{BMP}}$ = BMP treatment volume (cu. ft.)

= Level 1 BMP design treatment volume (cu. ft.) = $[(1.0 \text{ in.})(R_v)(A) / 12]$;

= Level 2 BMP design treatment volume (cu. ft.) = $1.25[(1.0 \text{ in.})(R_v)(A) / 12]$

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.)

η = 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 (η)
Ponding Area	1.0
Soil Media	0.25 *

Table P-FIL-05-4 Estimated Porosity for Each Bioretention Component

Bioretention Component	Available Porosity (η)
Gravel Layer	0.40

Note:

*Estimated value assuming full media dry-down.

Flow-rate Approach: In addition to utilizing the T_{vBMP} 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 K_{sat} 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.

$$SA = (12 \times T_{vBMP} \times d_{media}) / (t_d \times K_{sat} \times (d_{ponding} + d_{media}))$$

Where:

SA = surface area of bioretention practice (ft.²)

T_{vBMP} = 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 K_{sat} of the soil filter media;

if Level 2 or Level 1 without an underdrain, use the K_{sat} 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 (Tv_{BMP})	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) $DV = Tv_{BMP} + QV$
Hydraulic conductivity of soil filter media (media K_{sat})	in./hr.	Supplied by vendor or use 0.5
Hydraulic conductivity of native soil (soil K_{sat})	in./hr.	No underdrain: ≥ 0.5 and < 10 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, multiply Tv_{BMP} 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.

$$t_{d-PV} = 12 \times PV / (K_{sat} \times SA)$$

Where

t_{d-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 K_{sat} of soil filter media or native soil.
- Level 2, use limiting K_{sat} 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.

$$QV = (K_{sat} \times SA \times t_{d-TV} / 12) - TV_{BMP}$$

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.

$$SV_{practice} = [(SA_{avg-ponding} \times d_{ponding}) + (SA_{media} \times d_{media} \times \eta_{media}) + (SA_{gravel} \times d_{gravel} \times \eta_{gravel})]$$

Where:

$SV_{practice}$ = storage volume of the practice (ft.³)

$SA_{avg-ponding}$ = the average area of the ponding layer (ft.²)

= $0.5 \times [(\text{surface area at the top of the layer}) + (\text{surface area at the bottom of the layer})]$

d = depth of the respective layer (ponding, media, or gravel; ft.)

SA = surface area of the respective layer (media or gravel; ft.²)

η = 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 $SA_{avg-media}$ and/or replace SA_{gravel} with $SA_{avg-gravel}$ (as needed). The symbols for $SA_{avg-media}$ and $SA_{avg-gravel}$ refer to the following:

SA_{avg} = the average area of the respective layer (media or gravel; ft.²)

= $0.5 \times [(\text{surface area at the top of the layer}) + (\text{surface area at the bottom of the layer})]$

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 T_{VBMP} 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 T_{VBMP} 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.

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,



*A residential bioretention used to manage upgradient street runoff that was formerly causing nuisance flooding downstream
Photo Credit: Hirschman Water & Environment, LLC.*

- 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. 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. Drier 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	<i>Callicarpa americana</i>	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	<i>Clethra alnifolia</i>	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	<i>Cephalanthus occidentalis</i>	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	<i>Cornus amomum</i>	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	<i>Cornus racemosa</i>	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	<i>Cornus sericea</i>	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, moist soils. Stressed in heat/humidity. Can spread via rhizomes.
Winterberry	<i>Ilex verticillata</i> "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	<i>Ilex vomitoria</i>	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	<i>Itea virginica</i>	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	<i>Ilex glabra</i> "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	<i>Morella cerifera</i>	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	<i>Physocarpus opulifolius</i>	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	<i>Sambucus canadensis</i>	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	<i>Viburnum dentatum</i>	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	<i>Viburnum prunifolium</i>	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	<i>Andropogon gerardii</i>	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	<i>Asclepias incarnata</i>	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	<i>Carex pensylvanica</i>	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	<i>Chasmanthium latifolium</i> ,	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	<i>Commelina virginica</i>	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)	<i>Eutrochium fistulosum</i>	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	<i>Hibiscus moscheutos</i>	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	<i>Iris versicolor</i>	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	<i>Iris virginica</i>	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	<i>Juncus effusus</i>	1-4 ft	1-4 ft	Clay soil, deer	Mesic to wet	Seeds, potted plants	Full to part sun. Zone 4-9
Cardinal flower	<i>Lobelia cardinalis</i>	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	<i>Monarda didyma</i>	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	<i>Monarda fistulosa</i>	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	<i>Panicum virgatum</i> (many varieties)	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	<i>Rudbeckia hirta</i>	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	<i>Schizachyrium scoparium</i>	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	<i>Solidago odora</i>	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	<i>Amelanchier arborea</i> (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. Shrubber 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	<i>Acer rubrum</i>	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	<i>Asimina triloba</i>	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	<i>Betula nigra</i>	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	<i>Celtis occidentalis</i>	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	<i>Diospyros virginiana</i>	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	<i>Liquidambar styraciflua</i>	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	<i>Magnolia virginiana</i>	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	<i>Nyssa aquatica</i>	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	<i>Nyssa sylvatica</i>	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	<i>Platanus occidentalis/ Platanus x acerifolia</i>	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	<i>Prunus serotina</i>	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	<i>Quercus bicolor</i>	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	<i>Quercus michauxii</i>	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	<i>Quercus palustris</i>	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	<i>Quercus phellos</i>	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	<i>Quercus shumardii</i>	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	<i>Salix nigra</i>	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	<i>Taxodium distichum</i>	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/chesapeake natives.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](http://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/invspdflist>

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 daylight 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-02-3](#)). 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

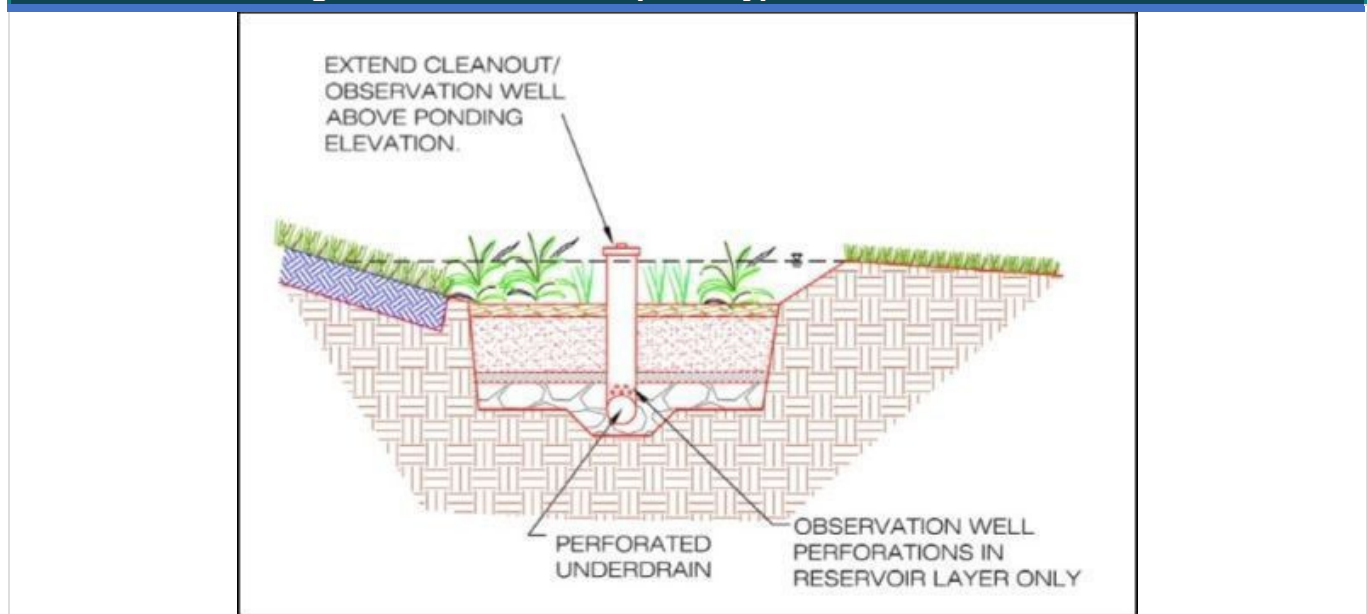
same elevation as the top of the sump. The IWS is used where limited head is a site constraint (e.g., relatively flat sites).

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](#).

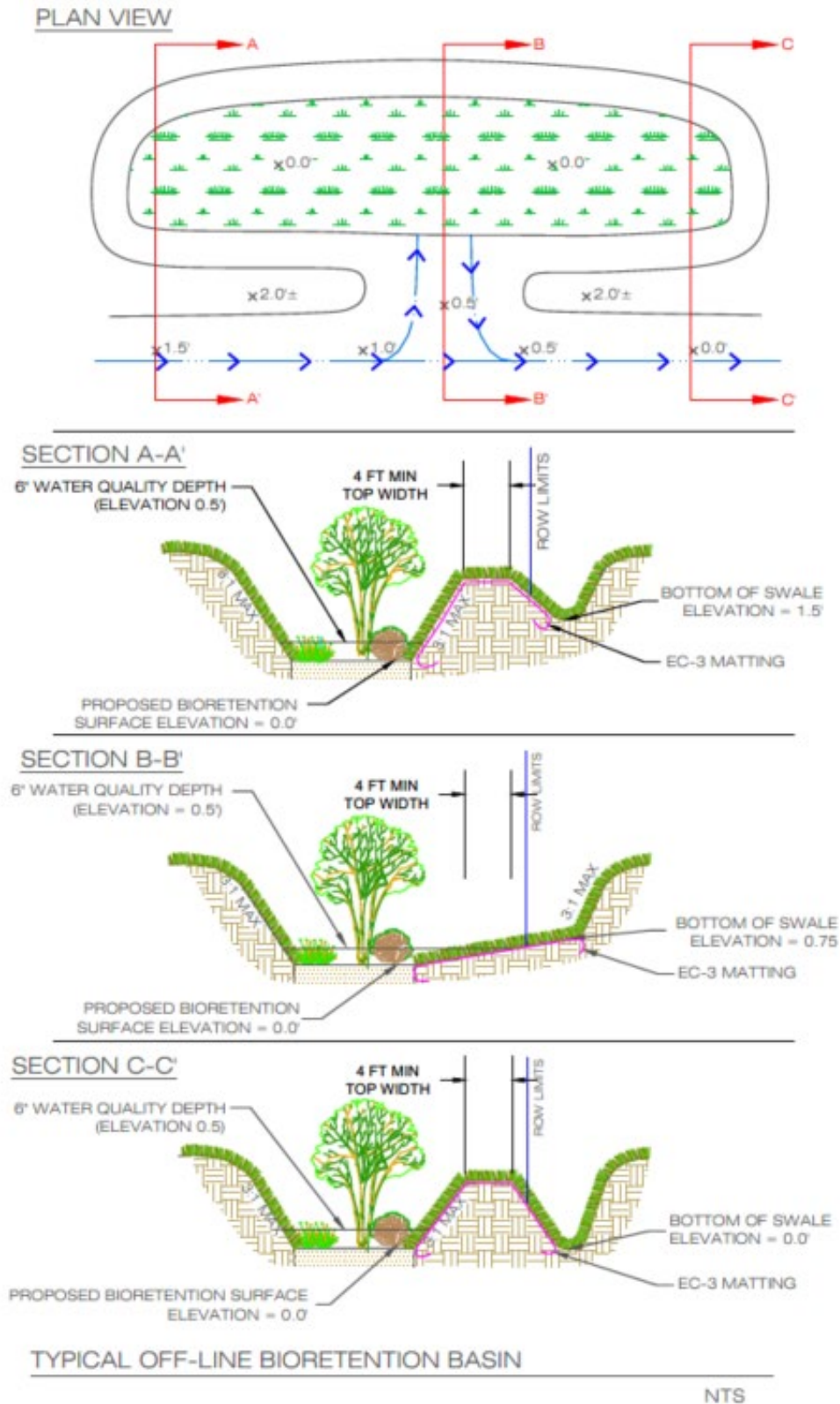
Table P-FIL-05-8 Advantages and Disadvantages of Offline Bioretention

Advantages	Disadvantages
The practice receives, at most, the T_vBMP 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 T_vBMP 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

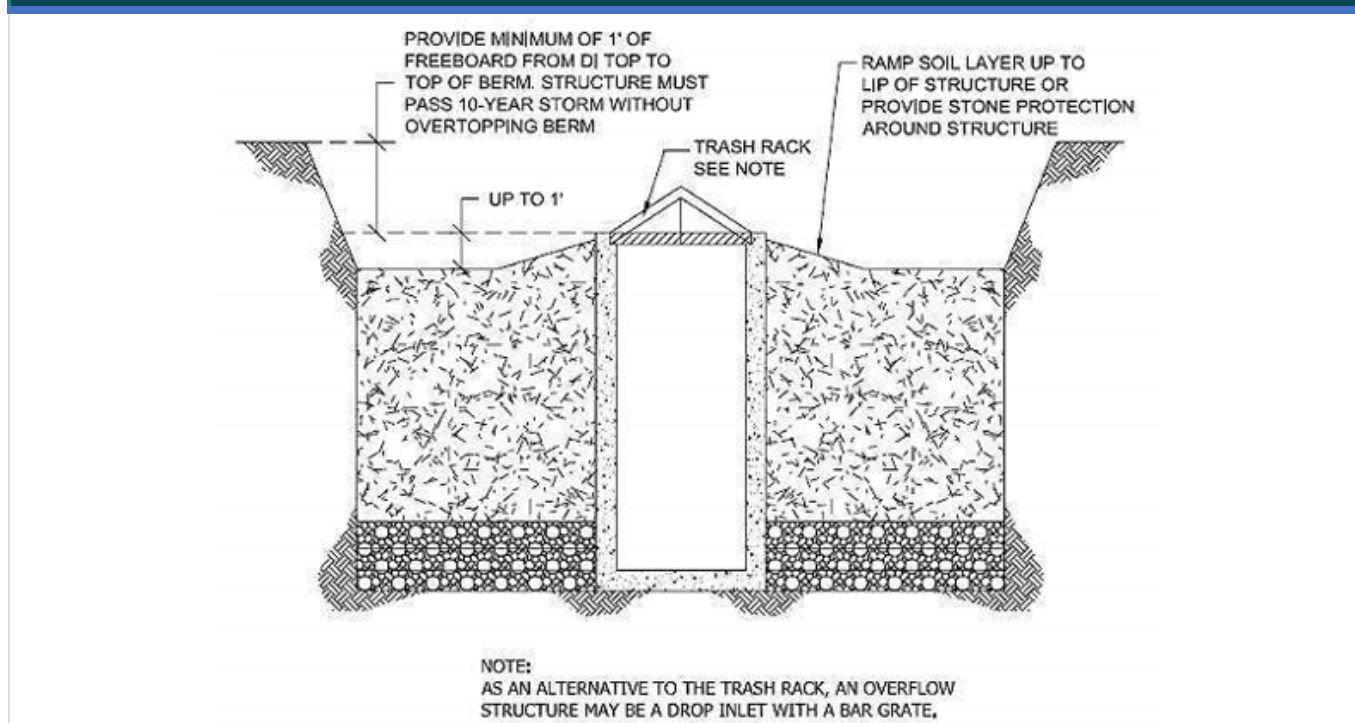


5.8.2 On-line Bioretention

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: A linear approach to bioretention, using multiple cells leading to the ditch system, helps conserve hydraulic head. 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). 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). Maintain at least 0.3% slope in the underdrain to ensure positive drainage. The underdrain should be tied into the ditch or conveyance system. 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. 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 the use of NaCl deicers be limited to prevent long-term nutrient export. 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.

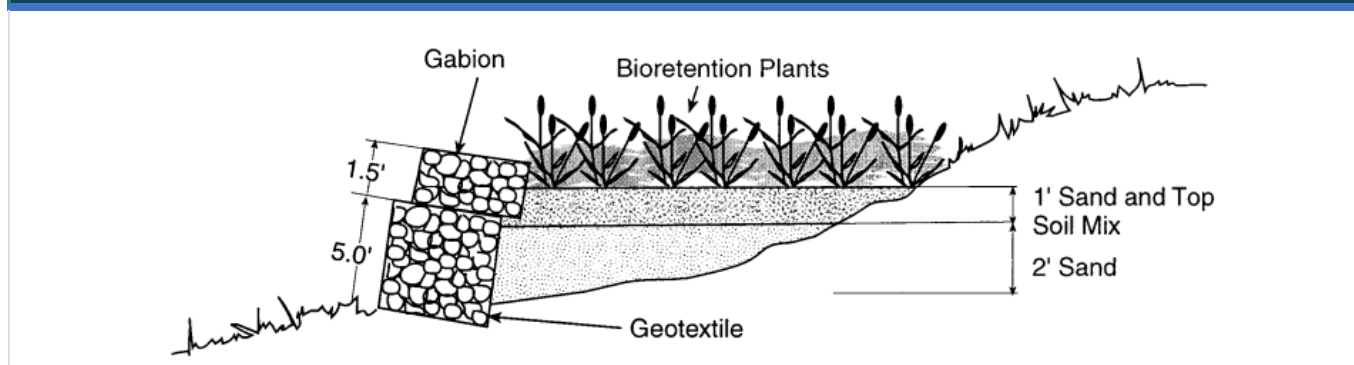
Notes:

* 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: 80% - 90% sand 10% - 20% soil fines 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.

Table P-FIL-05-11 Bioretention Materials Specifications

Material	Specification	Notes
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.
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; Up to 12 inches for the stone storage layer, if needed; 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 no 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. 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-bioretenention 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 wyees, 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. Remove invasive plants using recommended control methods. Stabilize the contributing drainage area to prevent erosion.	As needed
Perform spring inspection and cleanup. 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
Reevaluate 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-bioretenction practice is the same as that for general bioretention. Micro-bioretenction is typically applicable for treating runoff from small areas, such as sidewalks, driveways, and other on-lot features. Micro-bioretenction 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-bioretenction 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-bioretenction practices are connected and used instead of one large one because of design or space considerations.

Micro-bioretenction, 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-bioretenction can be located anywhere along the natural runoff pathway. Runoff can also be directed into a micro-bioretenction practice through pipes or swales. Micro-bioretenction 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-02-3](#) and others in the primary bioretention specification for feasibility, site selection criteria and regional and special case design adaptations.

Stormwater Performance Summary

The typical stormwater functions of an micro-bioretenction 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-Bioretenction Design Level Performance		
Pollutant Constituents	Design Level 1	Design Level 2
Total Phosphorus Removal Credit	40% RR	80% RR
	25% PR	50% PR
	55% Mass Load*	90% Mass Load*
Total Nitrogen Removal Credit	40% PR	60% PR
	64% Mass Load*	90% Mass Load*

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-bioretenention is provided in [Table P-FIL-05 A-2](#). Note certain minor variations for this application vs. [Table P-FIL-02-3](#) 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 Max $\leq$ 10 in./hr.†	Min > 0.25 in./hr. Min > 1 in./hr. to remove the underdrain requirement Max $\leq$ 10 in./hr.†
Surface Area	TV_{BMP} (cu. ft.) / ESD (ft.) Where: TV_{BMP} (cu. ft.) = (1.0 in.)(R_v)(A)/12	TV_{BMP} (cu. ft.) / ESD (ft.) Where: TV_{BMP} (cu. ft.) = (1.25 in.)(R_v)(A)/12
Drain Time	NA	Ponding Volume $\leq$ 48 hrs. Design Volume $\leq$ 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 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.	
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 Max: 36 inches§	Min: 24 inches Max: 36 inches§ 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 .

Table P-FIL-05 A-2 Summary of Design Elements

Design Element	Level 1 (RR: 40; TP: 25)	Level 2 (RR: 80; TP: 50)
Gravel Layer/Sump	Min choker stone layer: 3 in. Min gravel layer with no underdrain: 0 in. Min gravel layer with underdrain: 9 in. Max gravel layer: 12 in.‡	Min choker stone layer: 3 in. Min sump depth with underdrain: 9 in. 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. Non-concentrated flow: Distribute inflow evenly across filter surface area.	
Maintenance	Deeded Maintenance Agreement See Section 7 for routine and non-routine maintenance requirements.	

Notes:

RR = runoff reduction (%); TP = total phosphorus reduction (%); NA = not applicable.

* Micro-bioretenention 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

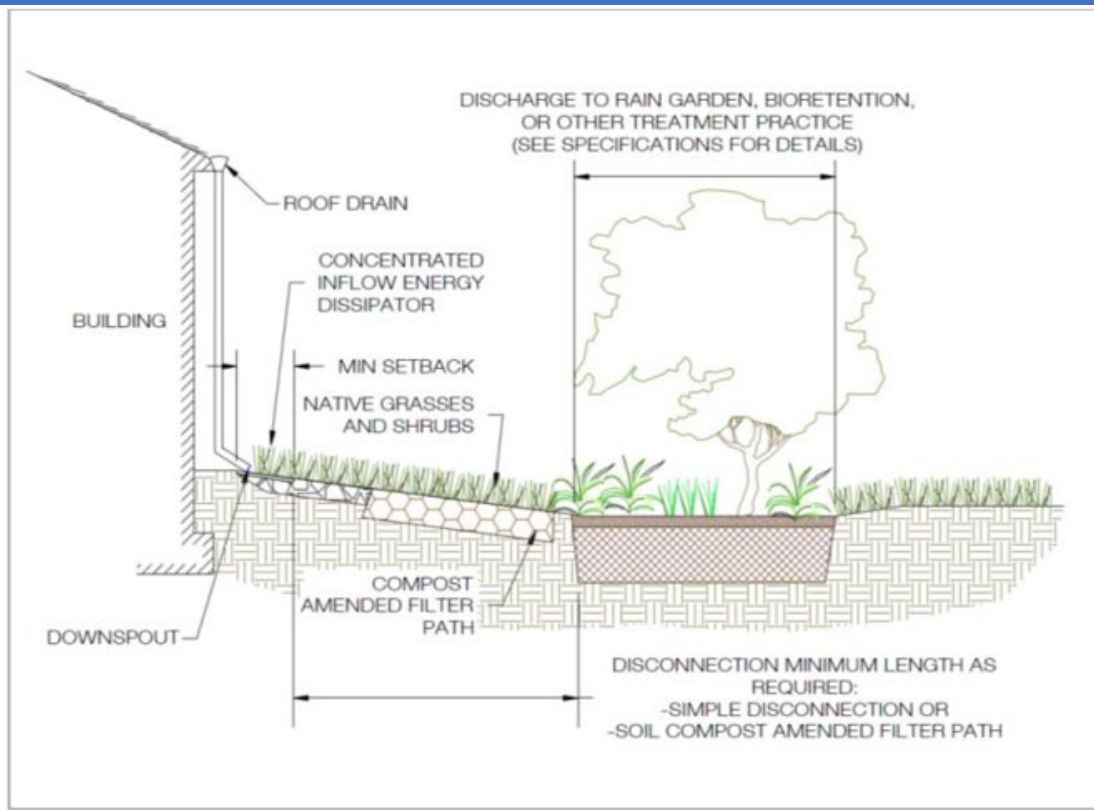
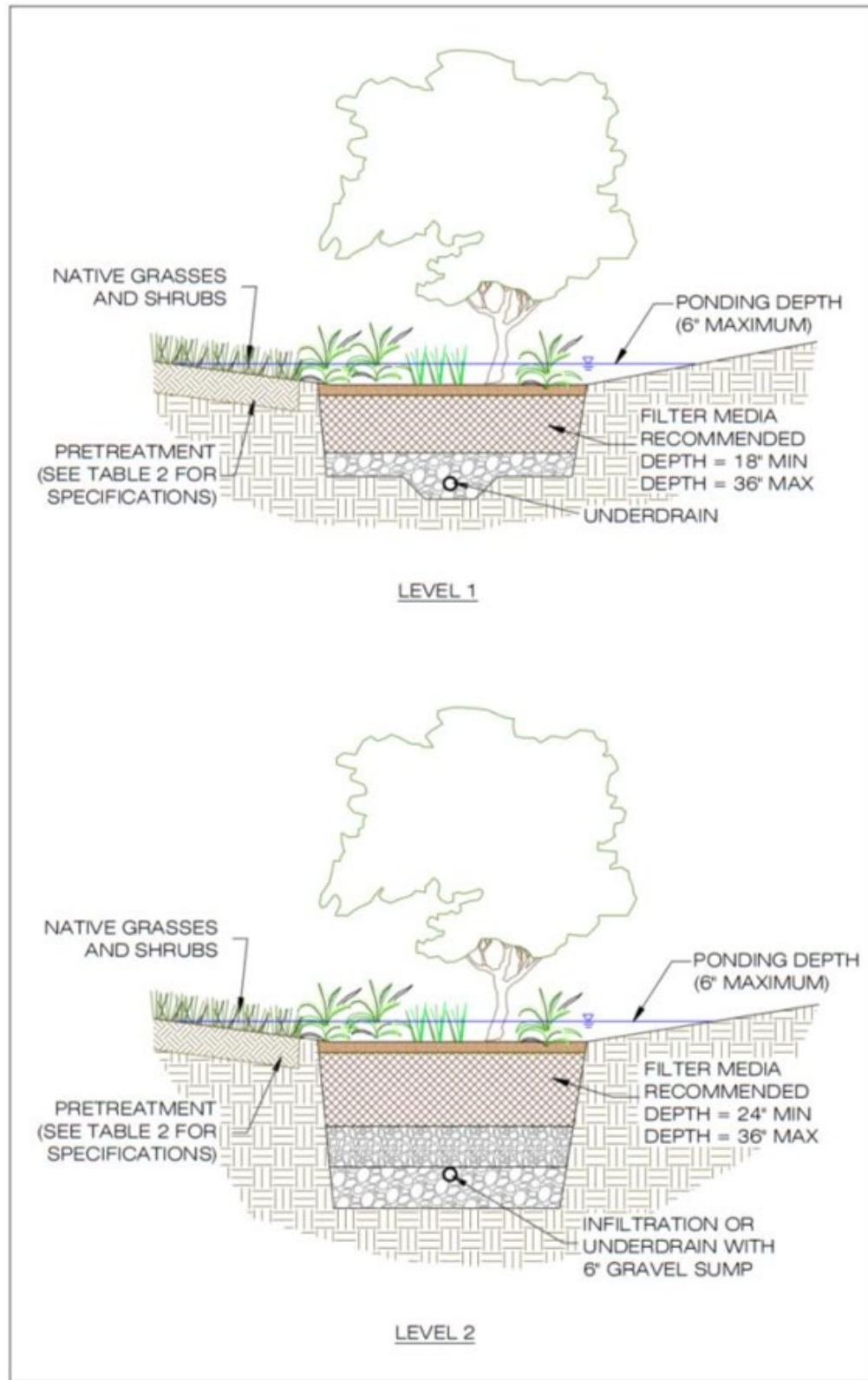


Figure P-FIL-05 A-2 Typical Micro-bioretention basis with Level 1 vs. Level 2 design



Guidance and References on Micro-bioretenention (a.k.a Rain Gardens)

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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

Table P-FIL-05 B-1 Summary of Stormwater Functions Provided by Ultra-urban Bioretention Areas

Stormwater Function	Level 1 Design	Level 2 Design
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 OR 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 :

$$T_v \text{ BMP} = [(1)(R_v)(A) / 12]$$

Maximum Ponding Depth = 6 to 12 inches ²

Filter media depth minimum = 18 inches; recommended maximum = 48 inches

Media and Surface Cover
(Refer to the Primary Bioretention Design Specification)

Underdrain = Schedule 40 PVC with clean-outs
(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)

Table P-FIL-05 B-2 Ultra-Urban Bioretention Design Criteria

Level 1 Design Only (RR: 40; TP: 25)

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-02-3).
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

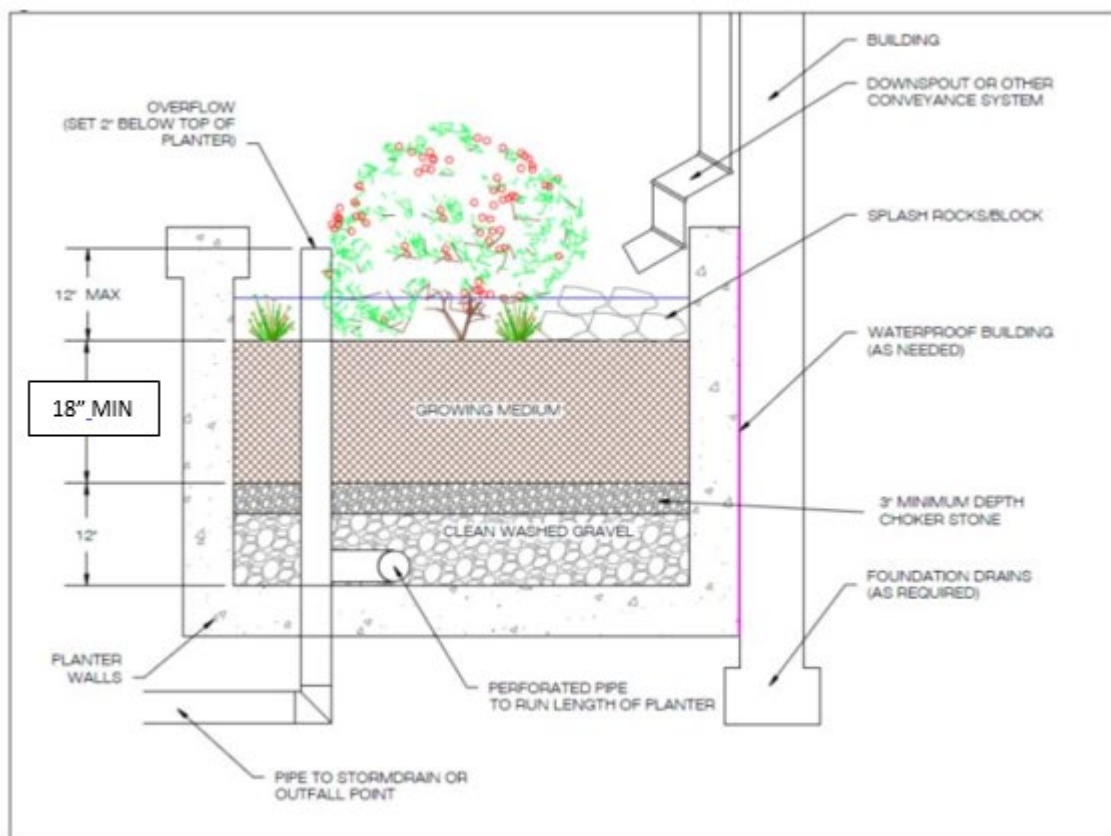
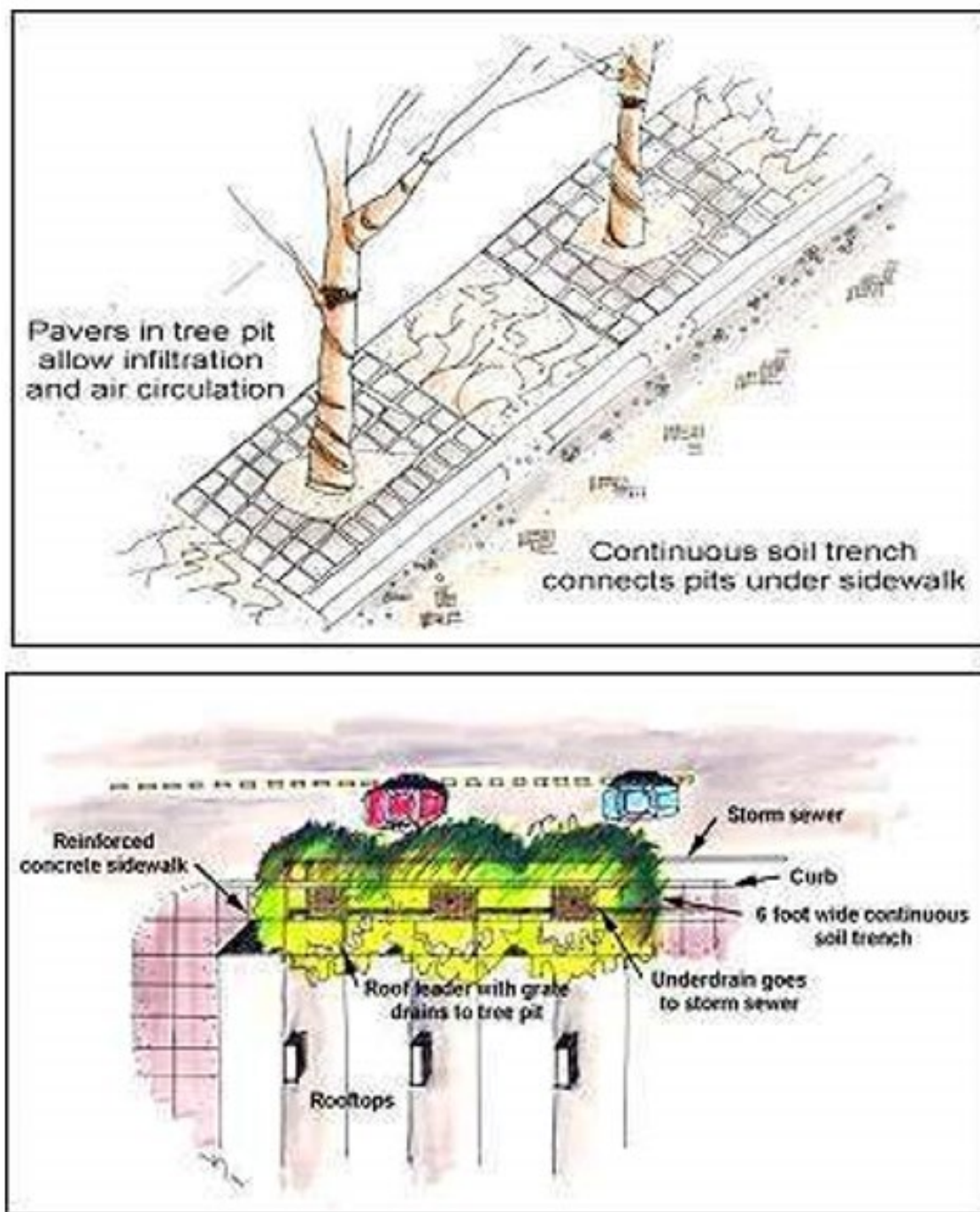


Figure P-FIL-05 B-5 Expanded tree pit details



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 design. 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-02-3](#)) 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

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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-06-5](#) , 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 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
$T_v = [(1.0)(R_v)(A)] / 12$ – the volume reduced by an upstream BMP	$T_v = [(1.25)(R_v)(A)] / 12$ – 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 T_v 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 T_v . 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 T_v , 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

$$A_f = (T_v)(df)/(K)(hf + df)(tf)$$

Where:

A_f = area of the filter surface (square feet).

T_v = 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 T_v is reduced by the upstream runoff reduction, or T_{vBMP} .*

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

$$V_s = 0.75(T_v)$$

Where:

V_s = volume of storage (cubic feet).

T_v = treatment volume (cubic feet).

A storage volume of at least 75% of the design T_v – 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 T_v) 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 T_v (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. 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.
	See BMP P-FIL-05 , Bioretention.
Underdrain and Observation Well	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. 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: • The combined depth of the underdrain and sand filter bed can be reduced to 18 inches. • The designer may wish to maximize the length of the stormwater filter or provide treatment in multiple connected cells. • 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. • 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. • 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: • 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. • Extend the filter bed below the frost line to prevent freezing within the filter bed. • Oversize the underdrain to encourage more rapid drainage and to minimize freezing of the filter bed. • 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

and [Figure P-FIL-06-5](#) provide typical schematics for a surface sand filter and organic filter, respectively. 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

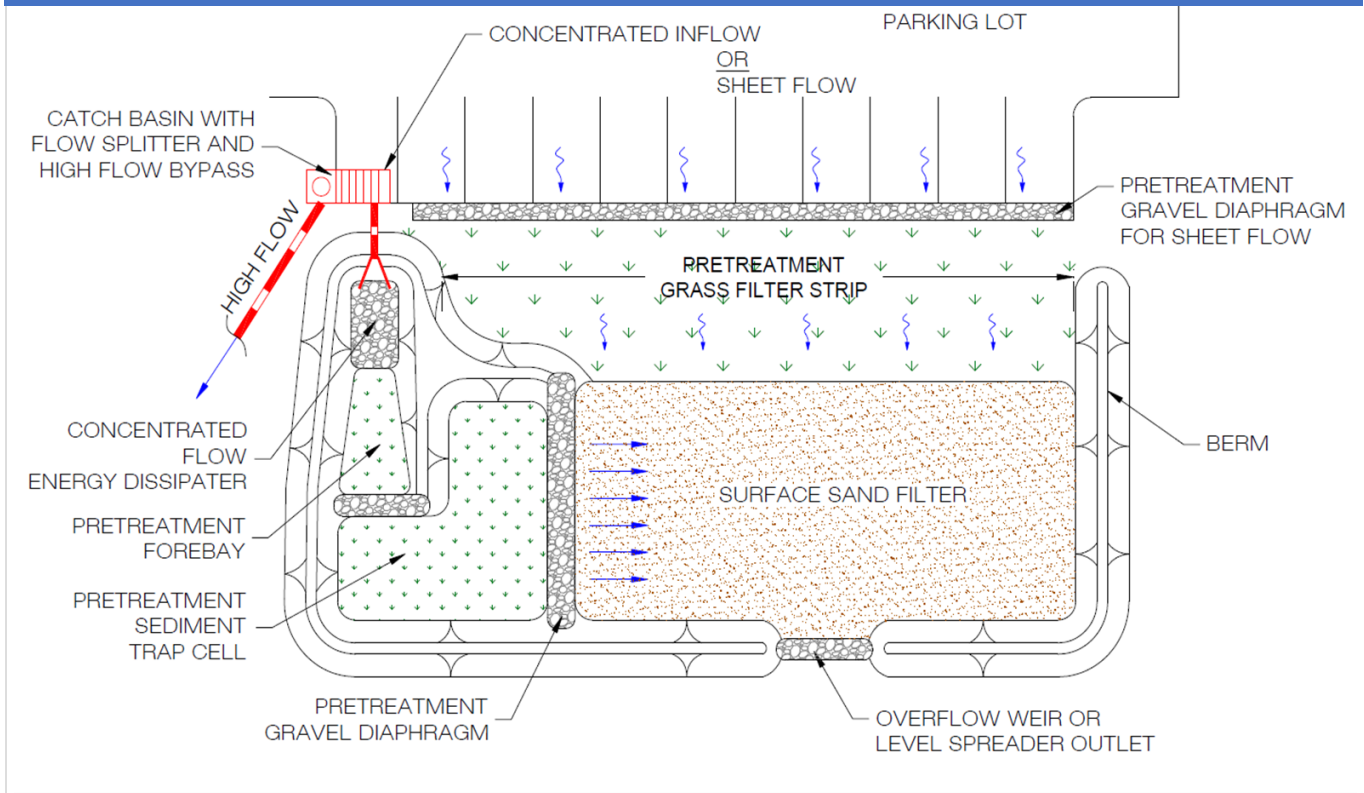


Figure P-FIL-06-5 Profile of an Organic Filter

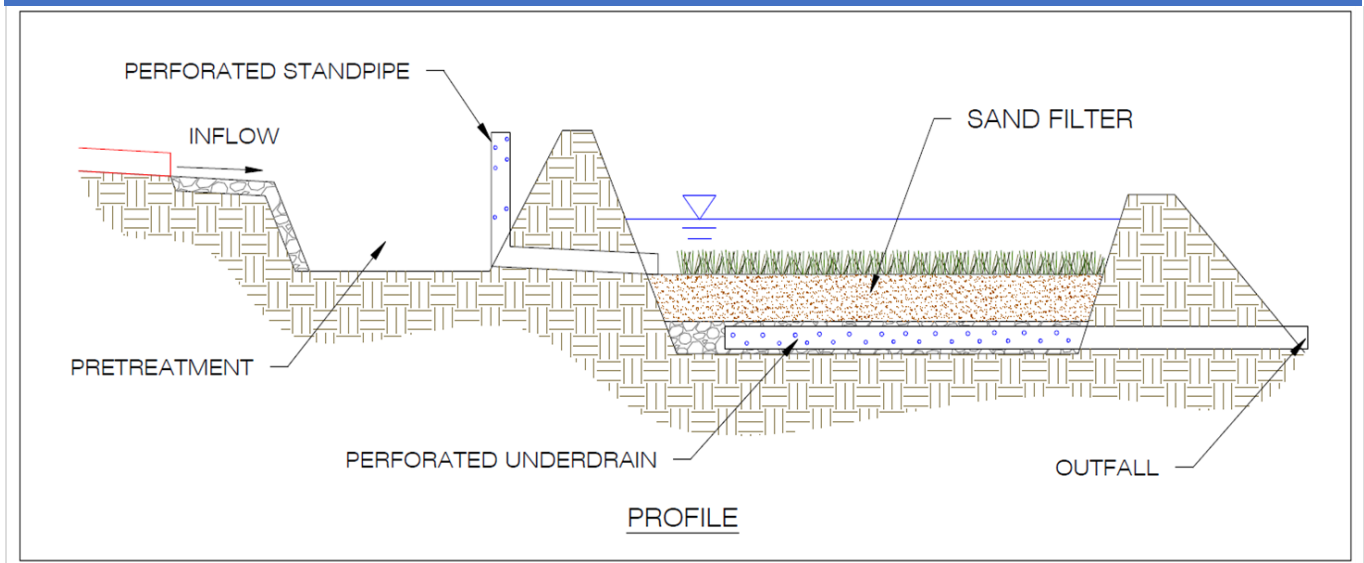


Figure P-FIL-06-6 Underground Filter Schematic

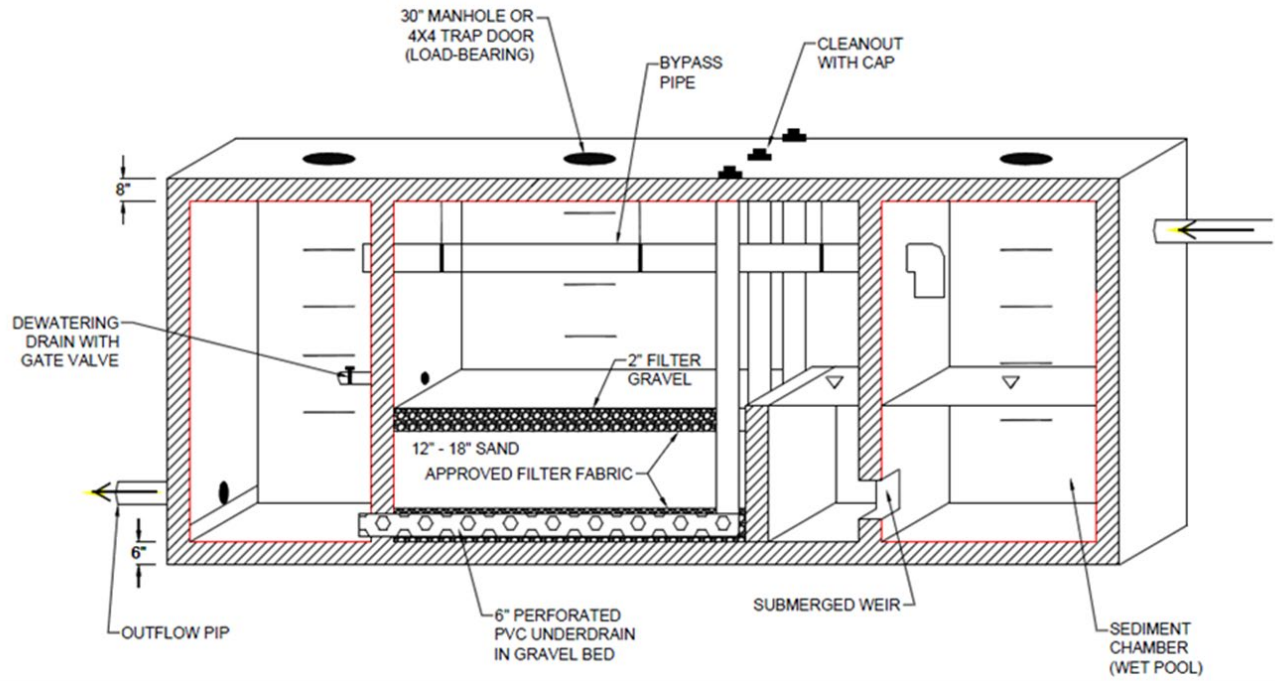
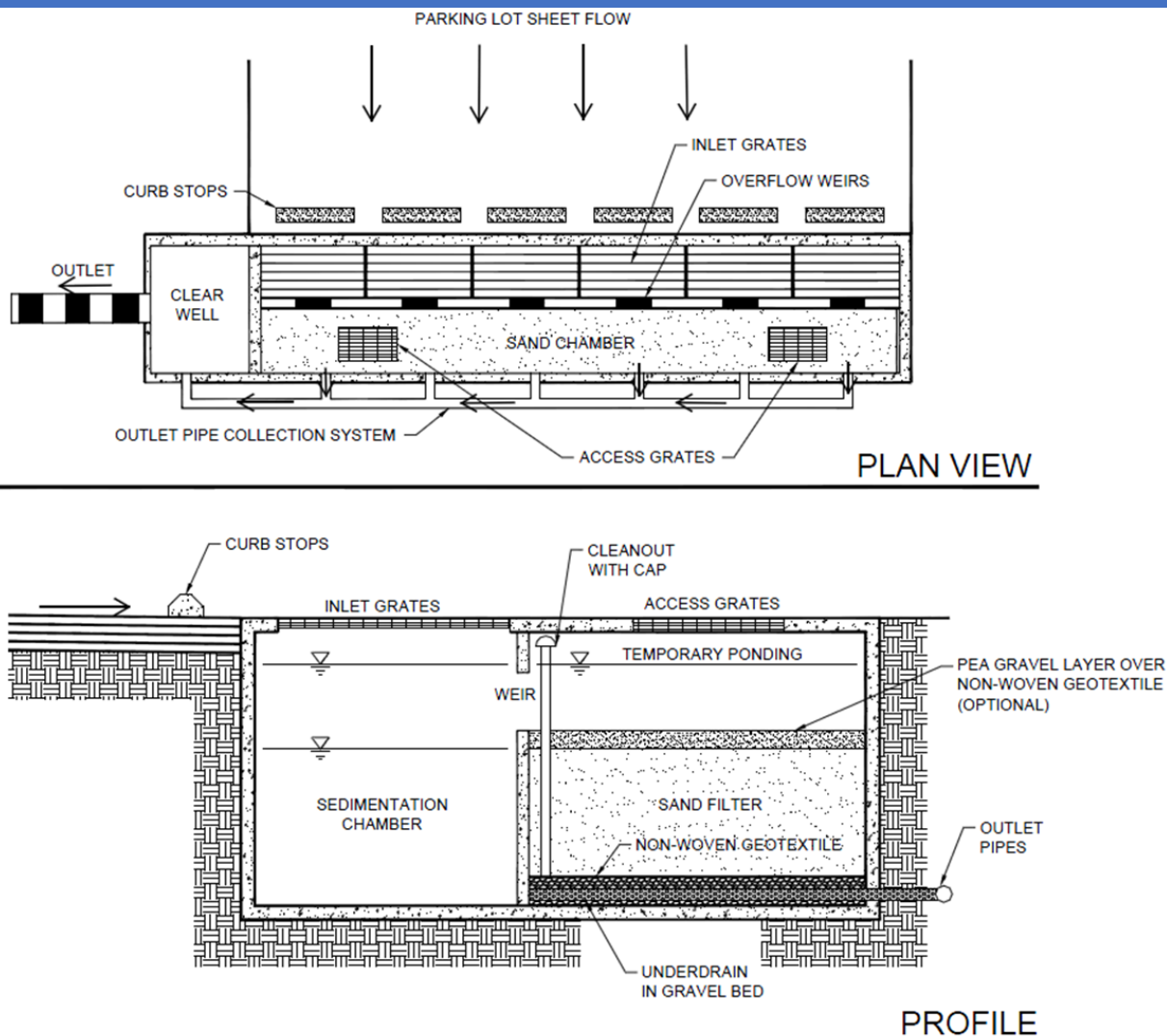


Figure P-FIL-06-7 Perimeter Filter Plan and Profile Schematic



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 wyres, 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 or 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 of 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. Stabilize CDA and side slopes to prevent erosion.	As needed
Inspect and clean up.	Annually
Clean out wet sedimentation chambers. Remove sediments from dry sedimentation chamber.	Once every 2 to 3 years or as needed
Replace top sand layer. Till or aerate surface to improve infiltration/grass cover.	Every 5 years

8.0 References

- Atlanta Regional Commission. 2001. Georgia Stormwater Management Manual, First Edition. Prepared by AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and Atlanta Regional Commission. Available online at: <http://www.georgiastormwater.com>.
- Atlanta Regional Commission. 2016. Georgia Stormwater Management Manual, Volumes 1 and 2, 2016 Edition. Prepared by AECOM, Atlanta Regional Commission, Center for Watershed Protection, Center Forward, Georgia Environmental Protection Division, and Mandel Design. Available online at: <https://atlantaregional.org/natural-resources/water/georgia-stormwater-management-manual/>.
- Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, Maryland. 329

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 . 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.
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.

Table P-FIL-07-1 Feasibility/Limitations

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%
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.			

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

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>	
	1% to 2% Slope – Minimum 25-foot length	
	2% to 4% Slope – Minimum 40-foot length	
	4% to 6% Slope – Minimum 50-foot length	
	6% to 8% Slope – Minimum 60-foot length	1% to 2% Slope – Minimum 25-foot length
	Maximum length of 100 feet	2% to 4% Slope – Minimum 50-foot length
	<u>HSG C and D</u>	4% to 6% Slope – Minimum 75-foot length
	1% to 2% Slope – Minimum 40-foot length	6% to 8% Slope – Minimum 95-foot length
	2% to 4% Slope – Minimum 50-foot length	Maximum length of 100 feet
	4% to 6% Slope – Minimum 65-foot length	
	6% to 8% Slope – Minimum 80-foot length	
	Maximum length of 100 feet	

Table P-FIL-07-3 Filter Strip Design Criteria

Design Issue	Conserved Open Space	Vegetated Filter Strip
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 Amendments ²	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.

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. 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. 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). 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. 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

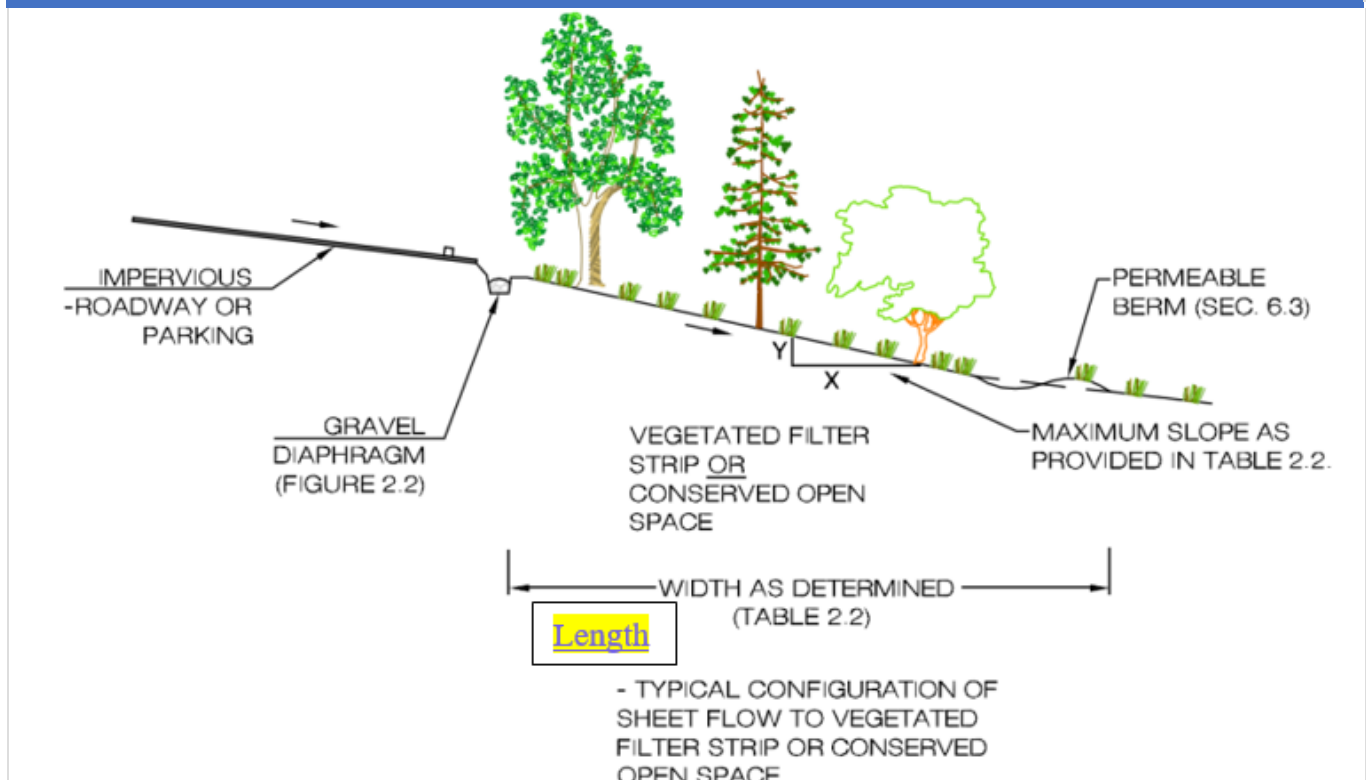


Figure P-FIL-07-2 Gravel Diaphragm – Sheet Flow Pretreatment

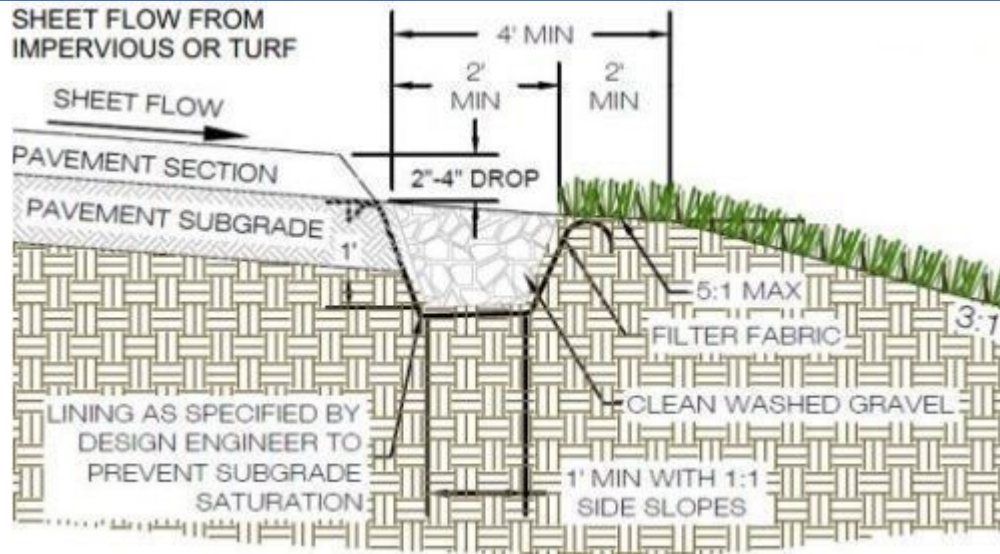


Figure P-FIL-07-3 Plan View – Level Spreaders (Rigid Lip – top; and Earthen Lip – bottom)

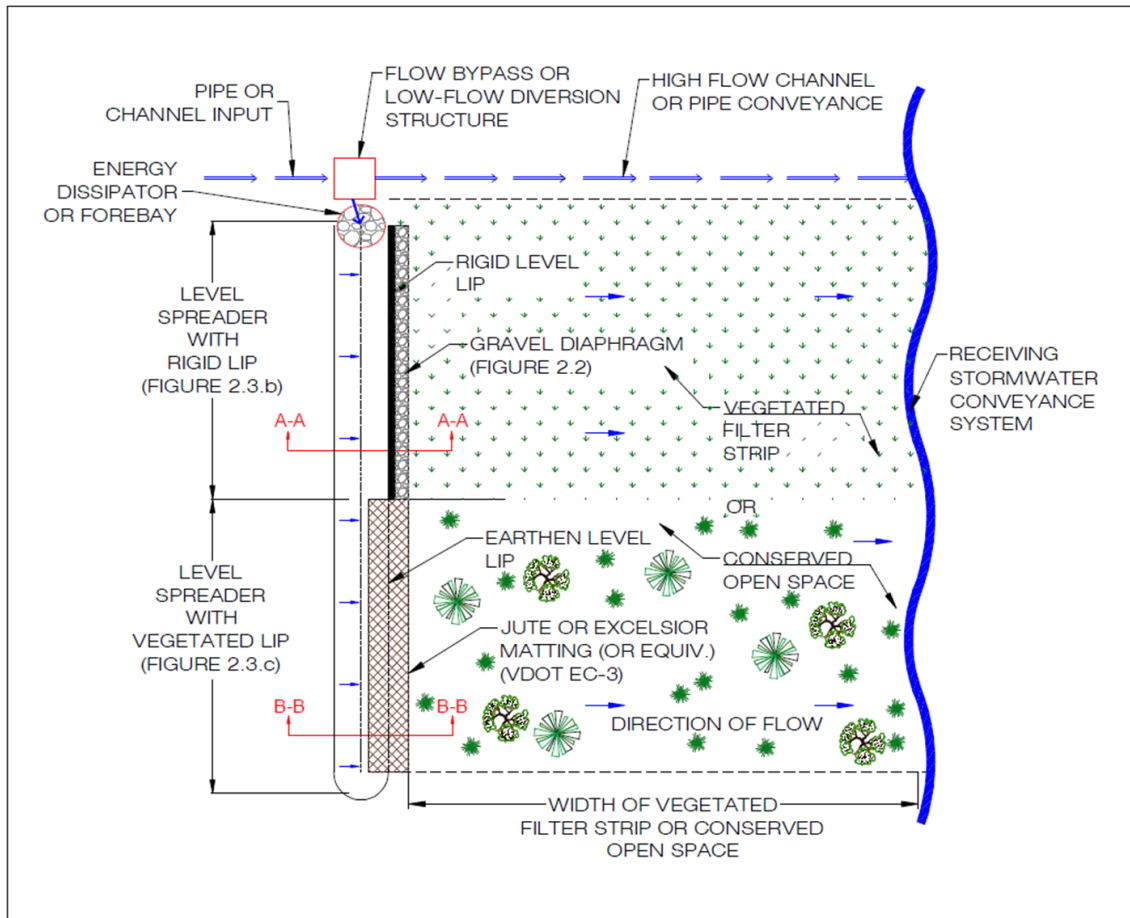
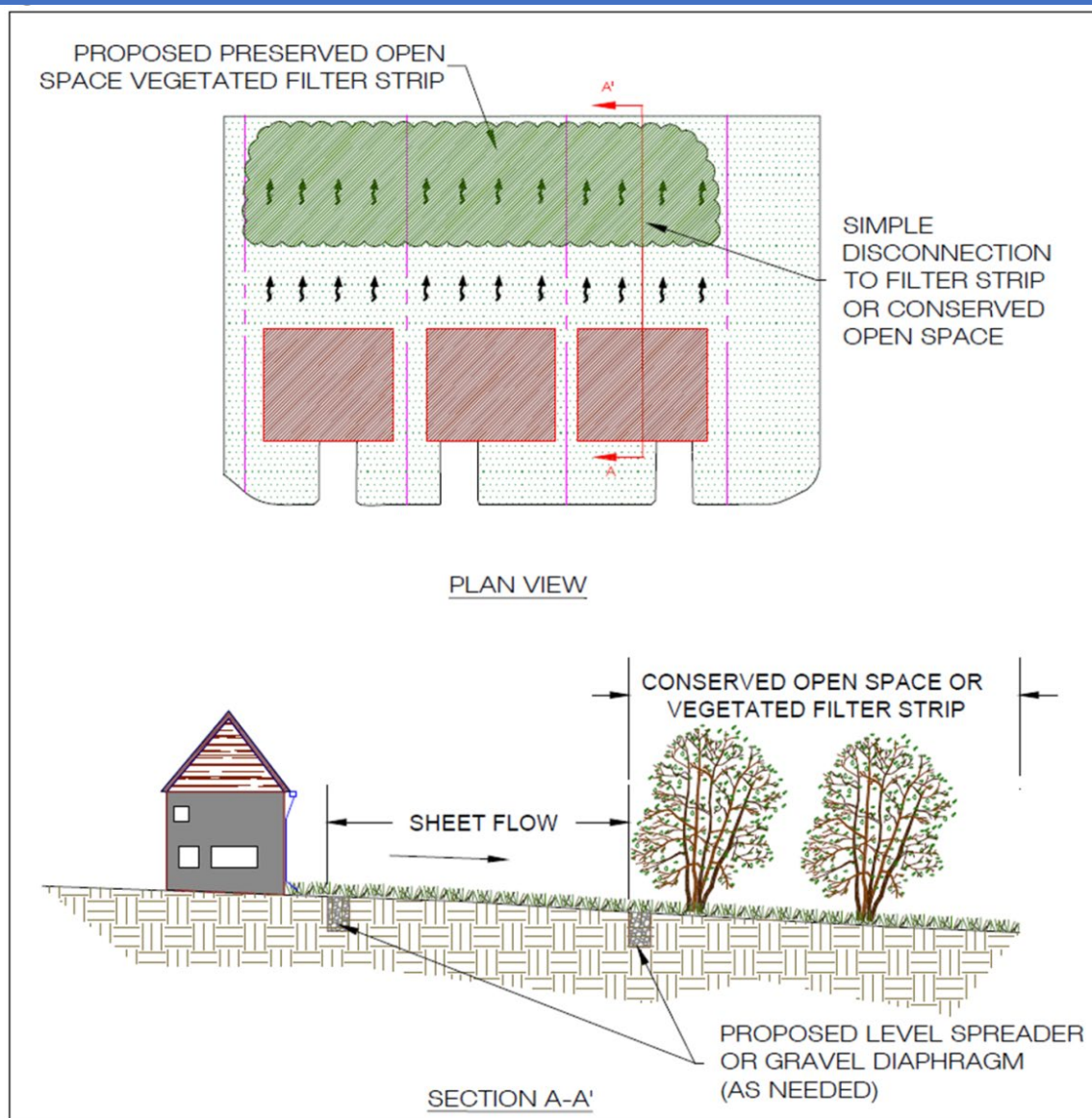


Figure P-FIL-07-4 Simple Disconnection to downstream Conserved Open Space or Vegetated Filter Strip



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 Authority 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 is 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	

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 Phosphorus Mass Load Removal	Same as for annual runoff reduction volume		Same as for annual runoff reduction volume	
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:

1. IC = contributing impervious cover (square feet) and SA = surface area of compost amendment (square feet).
2. For amendment of compacted lawns that do not receive offsite runoff.
3. In general, IC/SA ratios greater than 1 should be avoided.
4. Average depth of compost added.
5. 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 millimhos 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 receive 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 (ft²), 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)	0	0	0
Reduction by BMP Treatment Process			
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 Erosion and Stormwater Management Program (VESMP) or VDEQ when the agency is 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 forester with experience in Virginia, 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. The Virginia Department of Forestry has information about finding a forester at https://dof.virginia.gov/forest-management-health/landowner-assistance/find-a-forester/
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 VESMP or 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 VESMP or 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 ft² delineated tree canopy area.

The water quality credit area for each newly planted tree equals 144 ft² 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 ft²) 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.
- Topography: 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/invspdflist> (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 VESMP or 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.
Ensure 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 VESMP or 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
Water trees.	X	X	
Remove any supporting stakes and guywires.		X	
Implement invasive species and noxious weed control as needed.	X	X	X
Prune damaged, dead, or diseased branches.		X	X
Implement integrated pest management methods as needed.	X	X	X
Remove trash and fallen branches from area.	X	X	X
Remove any limbs damaged in storms that might pose a danger.	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 Erosion and Stormwater Management Regulation (9 VAC 875-535) specifies the circumstances under which a maintenance agreement must be executed between the owner and the VESMP or 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 VESMP Regulation 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 VESMP or 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 VESMP or VSMP Authority to access the property for inspection or corrective action.

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- U.S. EPA. 2016. Stormwater Trees: Technical Memorandum. 2016. United States Environmental Protection Agency—Great Lakes National Program Office. Chicago, IL. https://www.epa.gov/sites/default/files/2016-1/documents/final_stormwater_trees_technical_memo_508.pdf (accessed August 16, 2023).
- 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.

Virginia Department of Conservation and Recreation (DCR). 2022. Virginia Invasive Plant Species List. <https://www.dcr.virginia.gov/natural-heritage/invspdflist> (accessed August 16, 2023).

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Virginia Cooperative Extension. 2017. Planting Trees. Publication 426-702. https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/426/426-702/426-702.pdf (accessed August 16, 2023).

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, $1/0.75=1.333$.
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:

$$X_{AB}(0.64) + X_{CD}(0.36) = RR_{TOTAL}$$
$$X_{AB} = 1.33(X_{CD})$$

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 $RR_{TOTAL} = 0.29$ yields $X_{CD} = \sim 0.24$, or 24% and $X_{AB} = \sim 0.32$, 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 (§ 10.1-604 et seq., Code of Virginia) and the Virginia Dam Safety Regulations (4 VAC 50-20-10 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-01-2](#)).

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
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.
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. 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.

Parameter	Details
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

Table P-SUP-01-1 Clay Liner Specification

Property	Test Method (or equal)	Unit	Specifications
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 Geotextile Fabric Specifications

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

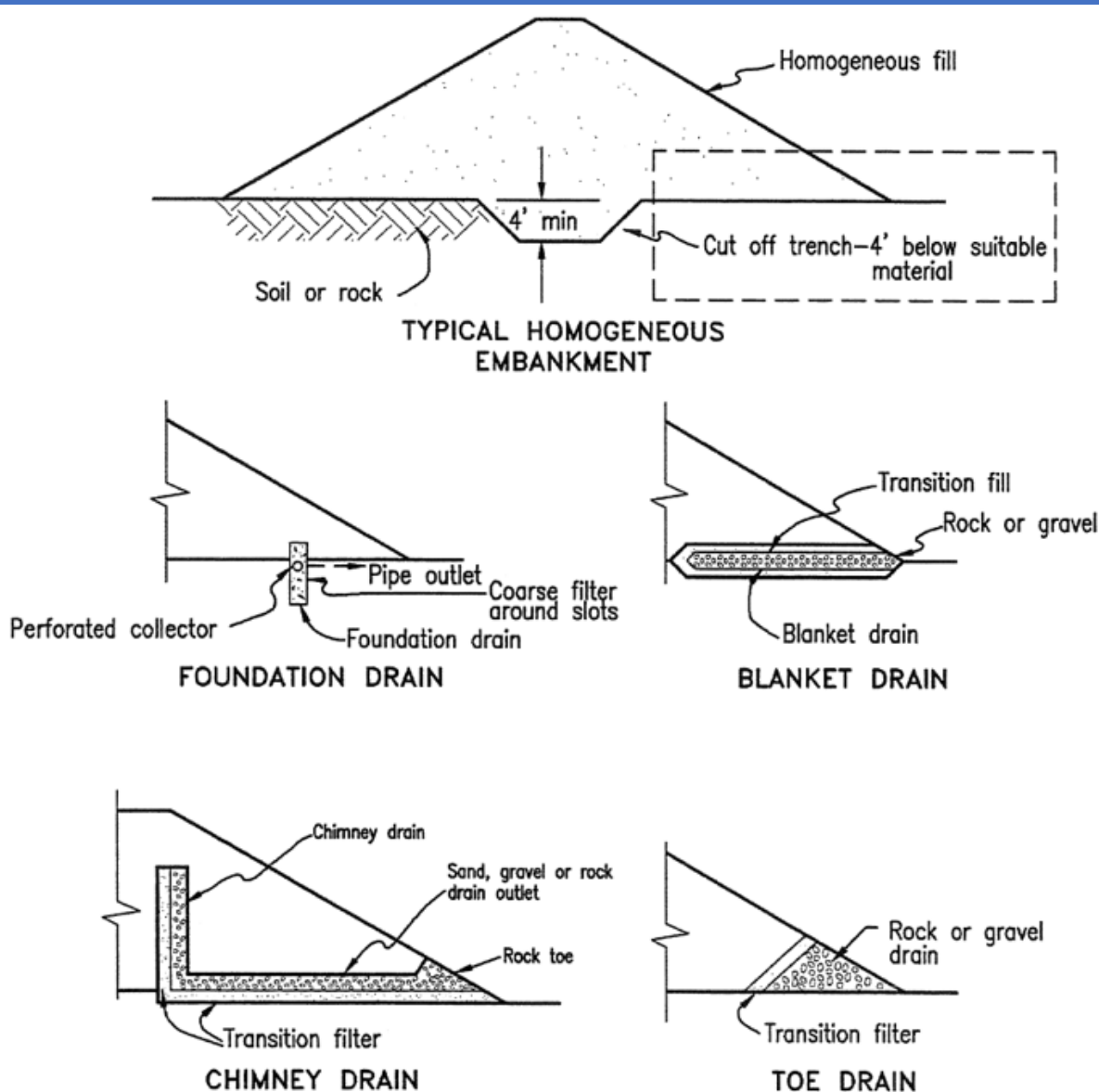
the excavated volume replaced and compacted with material similar to the surrounding area. All seedlings should be removed at the first opportunity. Similarly, any vine cover and brush should be removed from the embankment to allow for inspections.

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

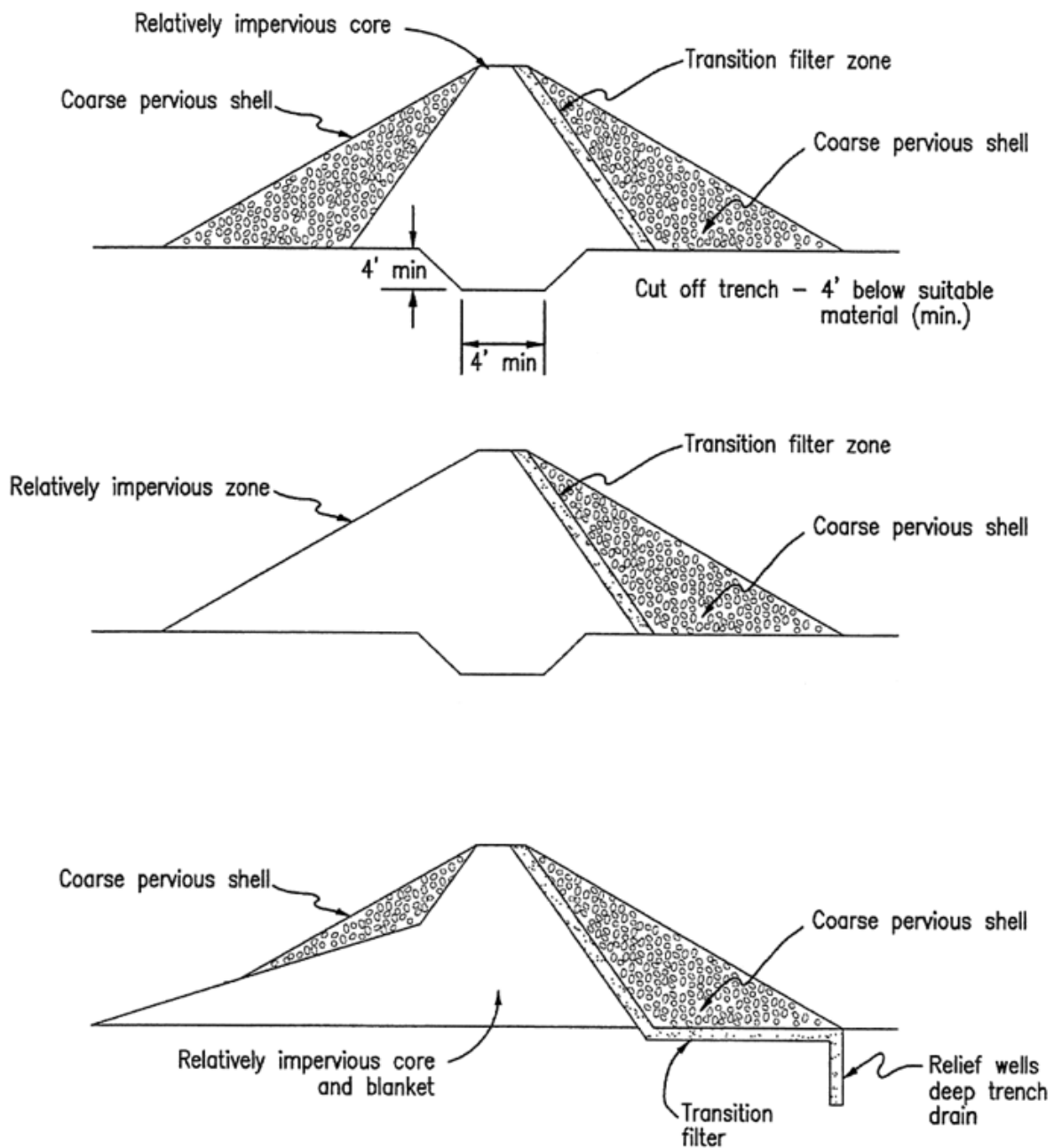


Figure P-SUP-01-3 Profile Along Centerline of Embankment

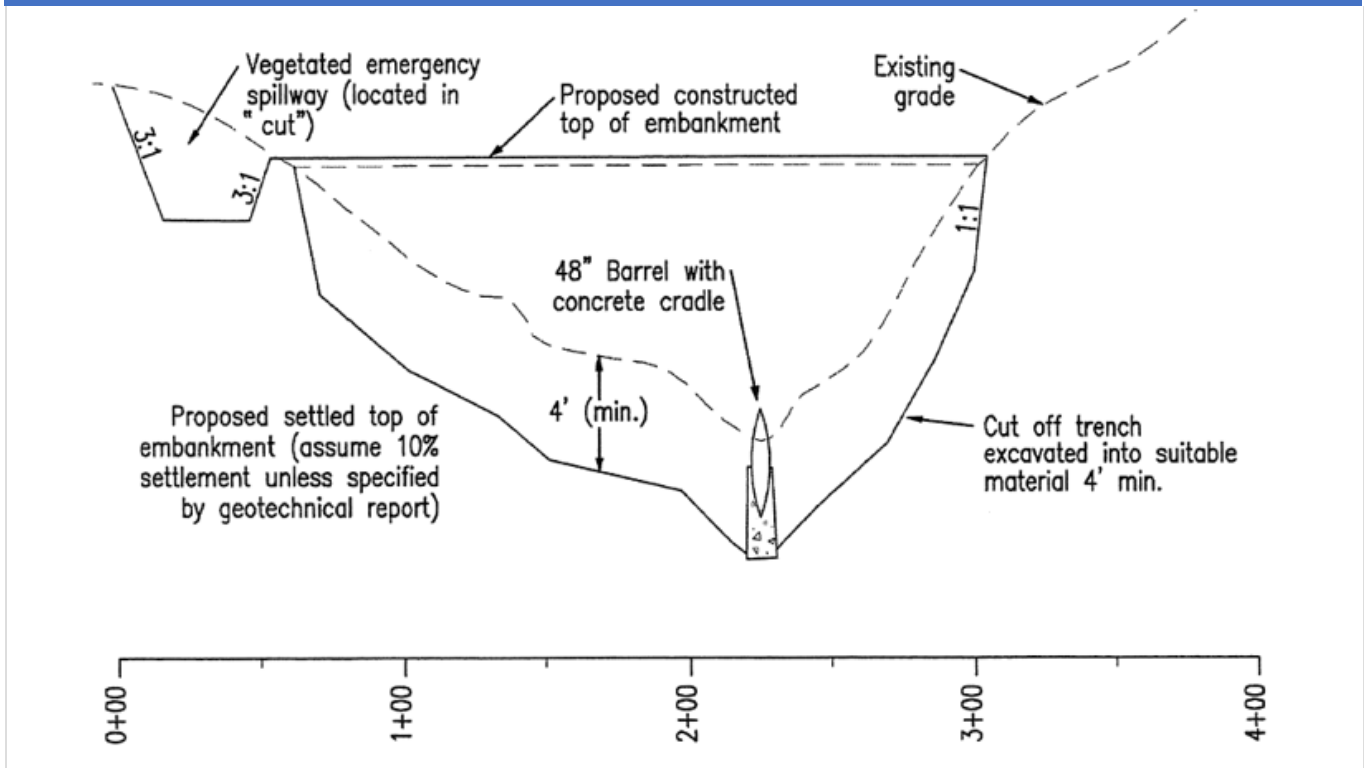
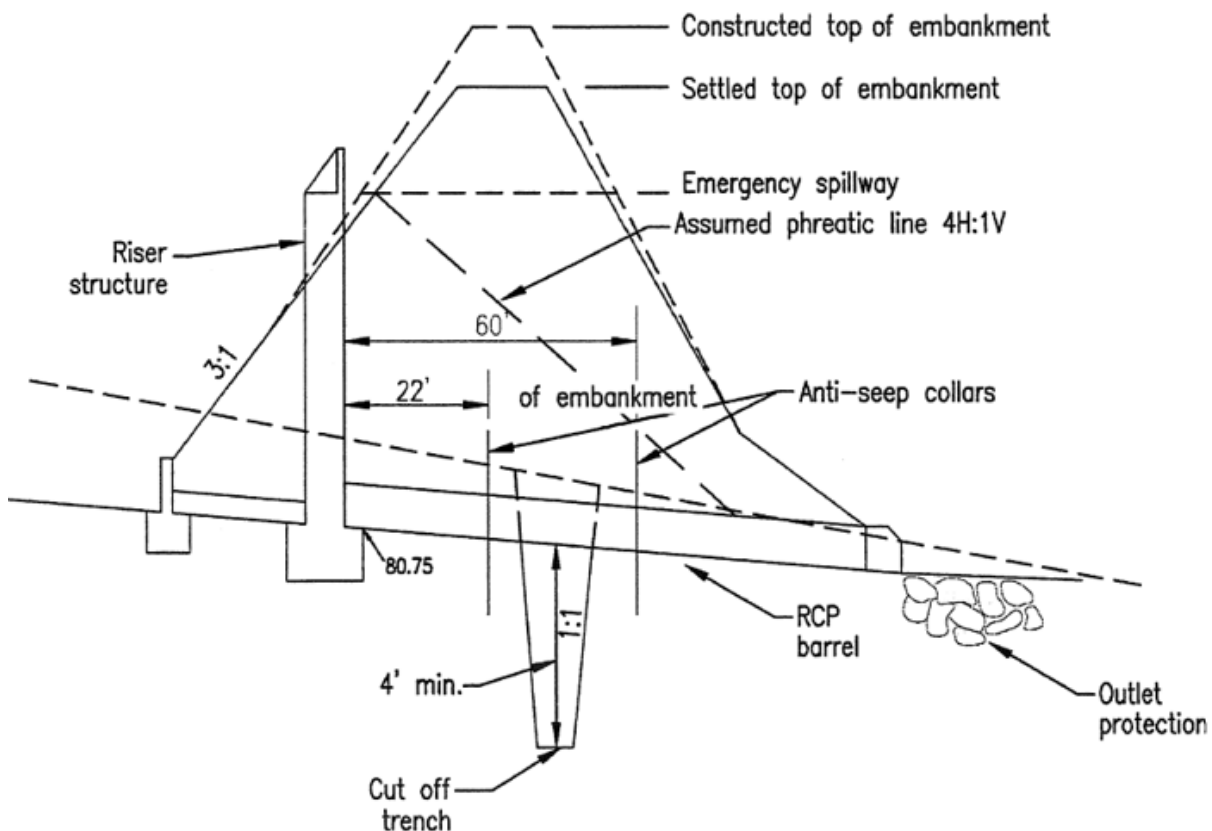


Figure P-SUP-01-4 Profile Along Centerline of Principal Spillway



7.0 References

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- 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.
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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

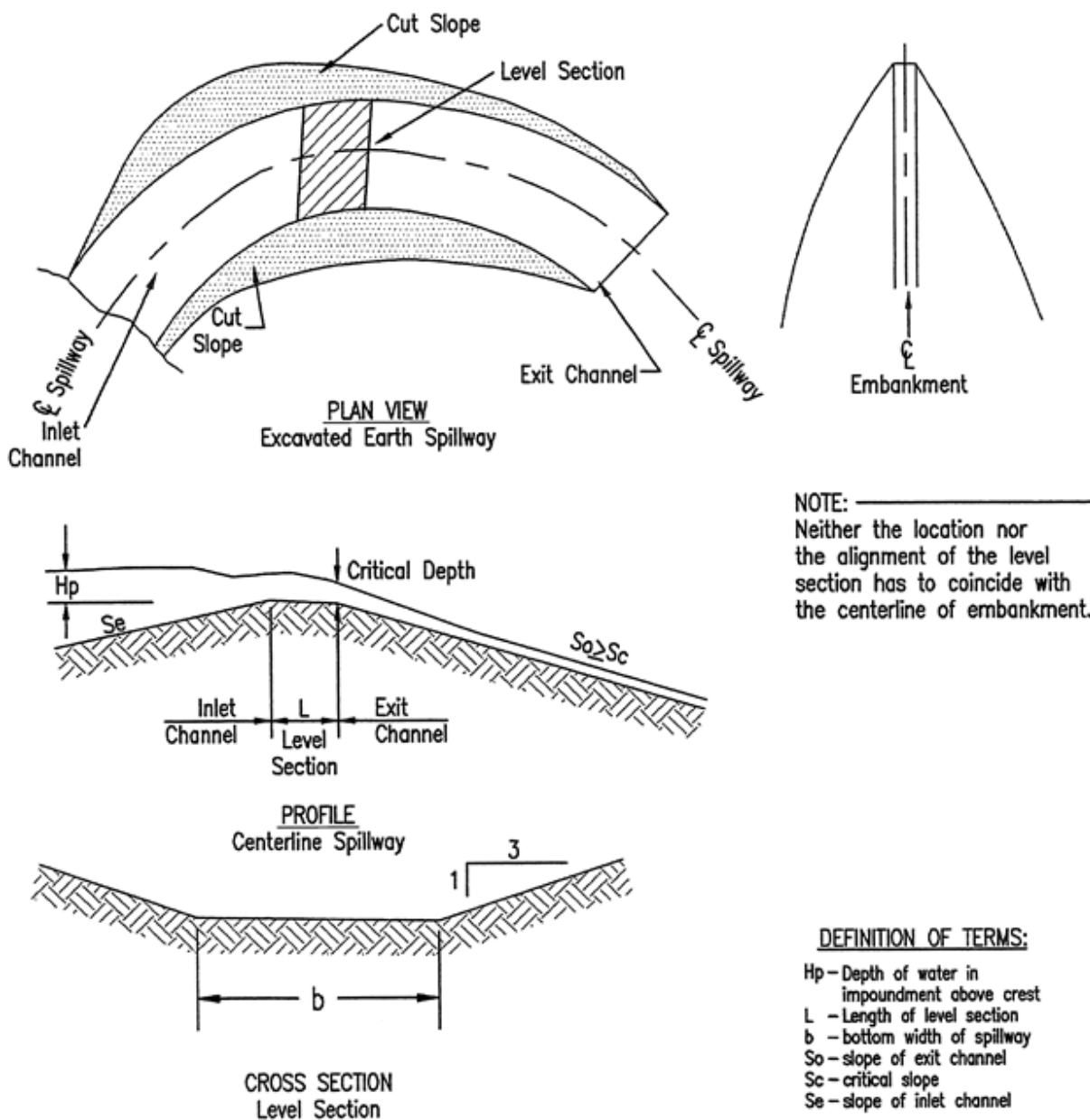
Vegetated spillways should be constructed in undisturbed earth in the abutments at one or both ends of an earthen embankment or over a topographic saddle anywhere on the periphery of the basin. The channel should be excavated into undisturbed earth or rock and the water surface, under maximum design 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). Flow enters the spillway through the inlet channel and the depth of flow (H_p) 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.

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/ft ²
EC-2 Type 2	1.5-1.75 lb/ft ²
EC-2 Type 3	1.75-2.0 lb/ft ²
EC-2 Type 4	2.0-2.25 lb/ft ²
EC-3 Type 1	2.25-6.0 lb/ft ²
EC-3 Type 2	6.0-8.0 lb/ft ²
EC-3 Type 3	8.0-10.0 lb/ft ²

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	
	Tall fescue	5 ft/second
	Kentucky bluegrass	
	Grass-legume mixture	4 ft/second

Table P-SUP-03-2 Permissible Velocities for Grass-Lined Channels

Channel Slope	Lining	Permissible Velocity*
5 – 10%	Red fescue Redtop	2.5 ft/second
	Annual lespedeza	
	Small grains (temporary)	
	Bermudagrass	5 ft/second
	Reed canarygrass	4 ft/second
	Tall fescue	
	Kentucky bluegrass	
Greater than 10%	Grass-legume mixture	3 ft/second
	Bermudagrass	4 ft/second
	Reed canarygrass	
	Tall fescue	
	Kentucky bluegrass	3 ft/second

* 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”

Table P-SUP-03-3 Retardance Classifications for Vegetative Channel Linings

Retardance	Vegetative Cover	Stand	Condition
D	Grass-legume mixture - summer	Good	Unmowed – 7”
	Kentucky bluegrass	Good	Headed – 9”
	Small grains, mixture	Poor	Uncut – 19”
	Tall fescue	Good	Mowed – 6”
	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 H_p , 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 (s_o), are known, then the bottom width (b) of the level and exit sections and the depth of flow (H_p) 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 H_p , a decrease in the outlet slope from s_o , as given in Table 16-11 (Chapter 16), decreases the spillway discharge, but increasing the outlet slope from s_o 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	.	.	.	.	.				
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).

Table P-SUP-06-2 Rooftop Isolation Design Criteria

Element	Design Criteria
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. 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: - Constructed Wetlands: 10% to 15% of the total permanent pool volume. - Wet Ponds: 10% to 15% of the total permanent pool volume. - Extended Detention Basins: 10% to 15% of volume of the 2-year/24-hour storm. - 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. - 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: - 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. - 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. - Naturalized Detention Basins: As determined to meet storage volume guidance and a minimum flow length of 10 feet. - 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. $V=Q/A$ Where: v = average velocity. Q = average flow rate. 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. 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. 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.

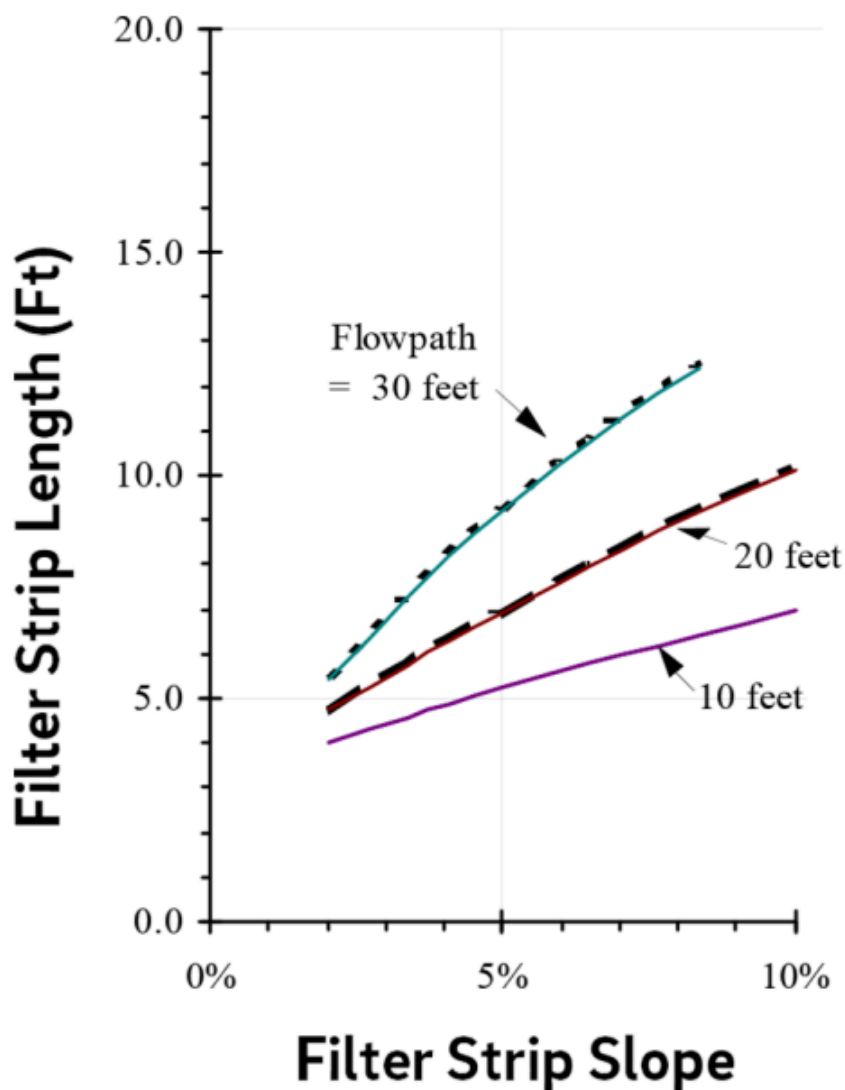
A filter strip acts as a pre-treatment for sheet flow and shallow concentrated flow entering a BMP from adjacent surfaces. Like other pre-treatment components, a filter strip works by reducing runoff velocity and trapping sediment and pollutants. Filter strips may provide limited infiltration, but the 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. 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. 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. 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. The filter strip should be installed perpendicular to flow. 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)



Adapted from: Seattle Stormwater Manual Vol. 3, 2009

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. 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. 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

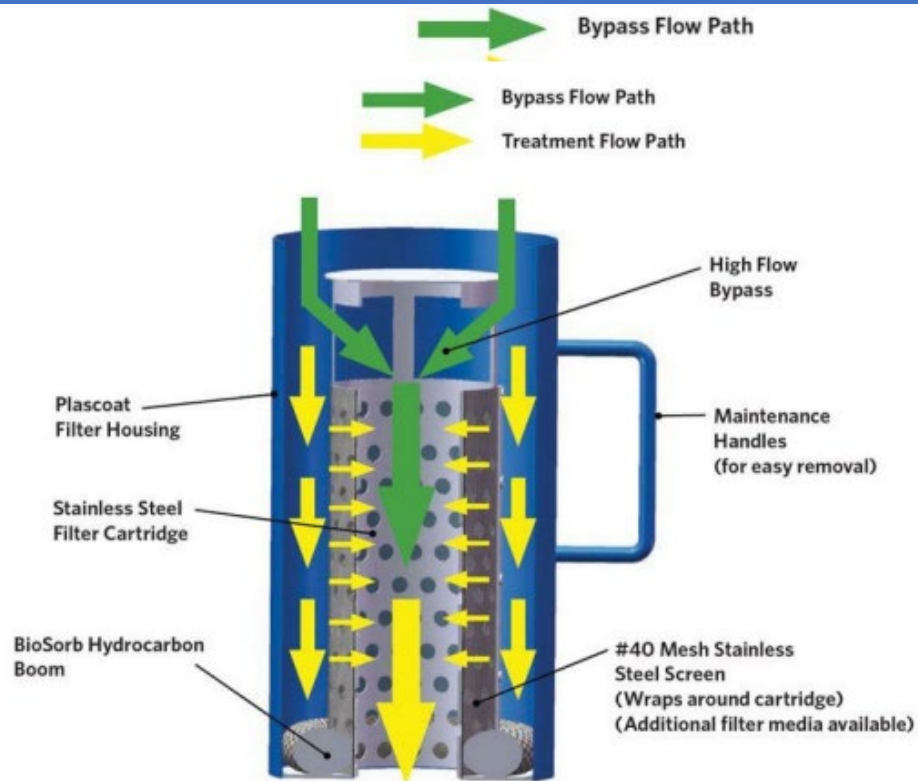


Table P-SUP-06-7 Trash Capture Device Design Specifications

Parameter	Specifications
Material	Material should be durable and resistant to photo-degradation, weathering, oxidation, or other corrosive conditions. 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. 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. 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

Table P-SUP-06-9 Sumped Inlet with Traps or Filter

Element	Design Consideration
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. 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	

Table P-SUP-07-2 Detention Basin Offset Guidance

Feature	Offset*	Notes
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. 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.

Table P-SUP-07-3 Underground Detention Basin Feasibility Criteria

Parameter	Details
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. Designers should also be aware that even modest changes in inundation frequency can kill upstream trees (Wright et al. 2007).

Table P-SUP-07-5 Detention Basin Community and Environmental Concerns

Concern	Details
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.
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: • Be designed with a maximum 24-hour detention time (to avoid excessive warming of runoff); • Have a minimum outlet micro-pool volume sufficient to prevent clogging; • Be planted with trees so it becomes fully shaded; and • 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. Underground detention should be designed so that overflow drains away from buildings to prevent damage to building foundations. 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: • 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. • Fencing of basins is not generally desirable; however, it may be required by local review authority depending on site location and basin configuration. • Safety benches should be landscaped with vegetation that hinders or prevents access to the pool. • 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 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. • 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. 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. 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 Spillway for design criteria.

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. 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 Embankment 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. Pipe should be installed observing manufacturer's pipe spacing, minimum cover, and maximum cover recommendations. A minimum of 4 inches of stone bedding under pipe or chamber structure should be provided. Multiple pipe sizes can be used to maximize storage. Provide access to pipes larger than 36 inches in diameter. Proprietary chambers should be installed in accordance with manufacturer's recommendations.
	Underground vaults	Provide human access to vaults. Proprietary vaults should be installed in accordance with manufacturer's recommendations.
	Underground plastic grid storage	Various structure types can be stacked and interlocked. Grid systems are commonly known for their ability to provide a high void space efficiently for storage of stormwater. 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 pondscape 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 pondscape 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 Appendix G Plant Selection
Outlet Orifices and Spillway	P-SUP-02 Principal Spillways
Inlet and Outlet Protection	C-ECM-15 Outlet Protection C-ECM-13 Riprap
Erosion Control Blankets	C-SSM-05 Soil Stabilization Blankets and Matting 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 of 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.	
Remove sediment, trash, and oil/grease from pre-treatment devices as well as from overflow structures.	Quarterly
Repair undercut and eroded areas at inflow and outflow structures.	
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.	Semi- annually
Inspect pre-treatment devices, diversion structures, and outlets for sediment buildup and structural damage.	
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.

Pennsylvania Department of Environmental Protection. 2023. Pennsylvania Post-Construction Stormwater Management (PCSM) Manual. Draft ed. 374

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).

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

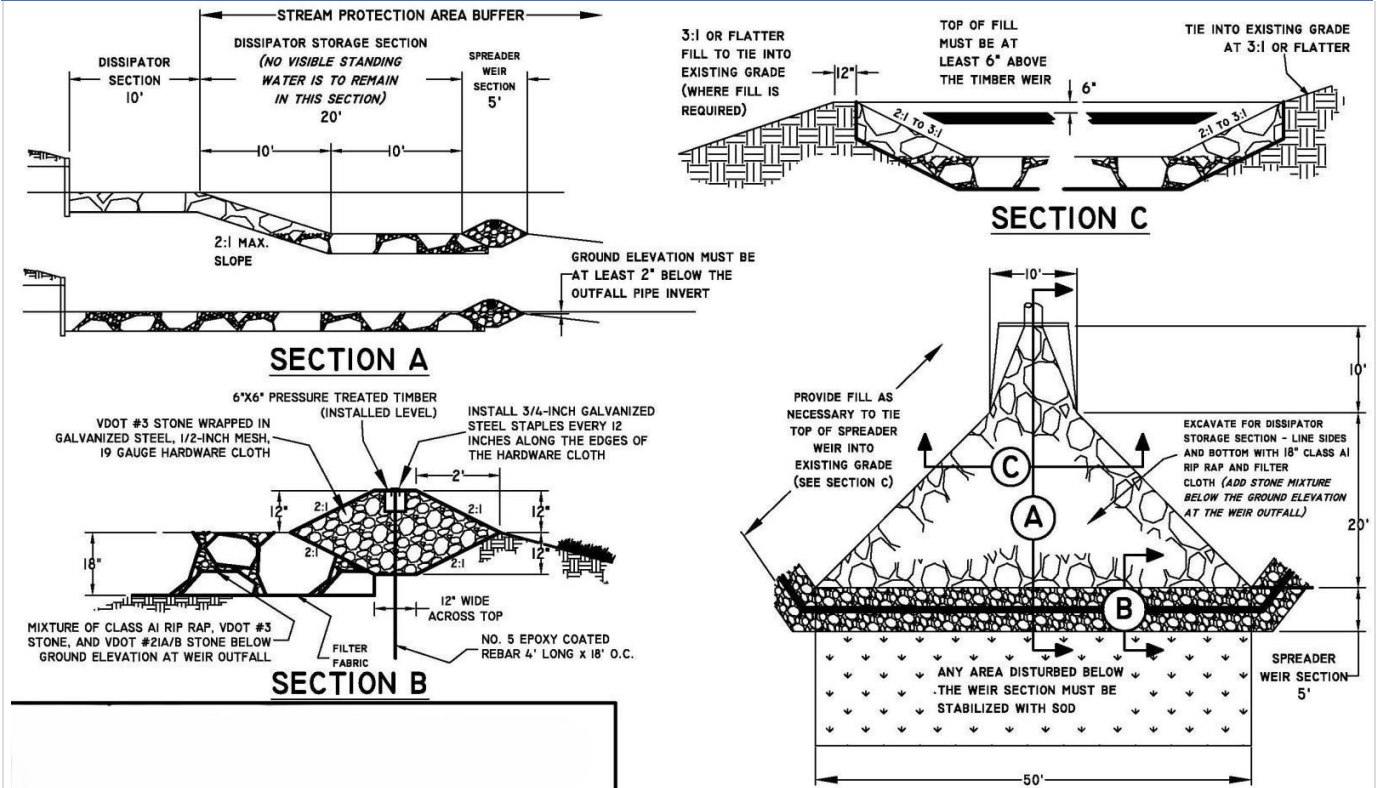
Erosion Control Efficiency: Moderate

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. Specify the remediation of any active erosion, sedimentation, or flooding in the sheet flow path on the plans. 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. 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.
	Sheet Flow Length: Compute maximum design length of sheet flow path to the downgradient stormwater conveyance system: $L_{SF} = \frac{100\sqrt{S}}{n}$
	where: L_{SF} = maximum length of sheet flow (feet) S = slope (feet/foot) n = Manning's roughness coefficient (U.S. Department of Agriculture, Natural ResourceConservation Service [USDA-NRCS] National Engineering Handbook, Table 15-1 [2008])
	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: $V = \frac{1.486}{n} R^{2/3} S^{1/2}$

**Table P-SUP-08-1 Level Spreaders as a
Permanent Best Management Practice Design Criteria**

Permanent Level Spreaders	
Topic	Requirement
	where: V = Velocity (feet per second) n = Manning's roughness coefficient (USDA-NRCS National Engineering Handbook, Table 15-1 [2008]) R = Hydraulic radius (feet) = A / P S = Land slope (feet/foot) A = Flow area (square feet) = Length of Level Spreader x 0.1 foot P = Wetted perimeter (feet) = Length of Level Spreader + 0.1 foot + 0.1 foot 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.
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. Orient level spreaders to be parallel to downgradient contours. 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. Construct level spreaders of concrete or other non-erodible material (e.g., rock). Provide a maintenance plan on the plans. 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): $L_{LS} = \frac{Q}{C_W \times H^{3/2}}$ where: LLS = Length of level spreader (feet) Q = 10-year 24-hour post-development peak flow rate (cfs) CW = Weir coefficient (assume 3.3 for rectangular weir) 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. <i>Rigid spreader lips should have a maximum design flow of 30 cfs.</i>

**Table P-SUP-08-1 Level Spreaders as a
Permanent Best Management Practice Design Criteria**

Permanent Level Spreaders	
Topic	Requirement
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 A1 riprap in accordance with BMP [C-ECM-13](#).

Construct the spreader weir section by excavating a trench to the depth and configuration shown on , 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 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.

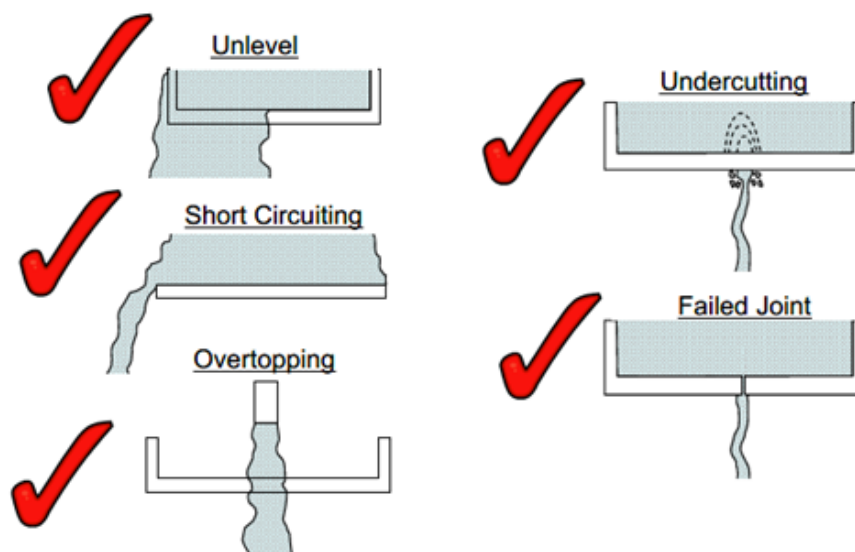
Immediately repair any damage to the level spreader. Inspect the level spreader in the same conditions for subsidence along the perimeter of the measure.

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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