Technical Memorandum:

The Runoff Reduction Method

Developed for the Following Projects:

Extreme BMP Makeover – Enhancing Nutrient Removal Performance for the Next Generation of Urban Stormwater BMPs in the James River Basin

Virginia Stormwater Regulations & Handbook Technical Assistance

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List Of Acronyms

BMP	best management practice
CDA	contributing drainage area
CSN	Chesapeake Stormwater Network
CWP	Center for Watershed Protection, Inc.
DCR	Virginia Department of Conservation & Recreation
ED	extended detention
EMC	event mean concentration
ESD	environmental site design
IC	impervious cover
HSG	hydrologic soil group
LID	low impact development
NPRPD	National Pollutant Removal Performance Database
NSQD	National Stormwater Quality Database
P-index	phosphorus index for soils
PR	pollutant removal
Q3	75^{th} percentile value – or third quartile
RR	runoff reduction
SA	surface area
SNDS	stormwater nutrient design supplement
TN	total nitrogen
TP	total phosphorus
TR	total (mass) removal
Tv	treatment volume

1. INTRODUCTION & BACKGROUND

Through the convergence of various projects, the Center for Watershed Protection, Inc. (CWP) and the Chesapeake Stormwater Network (CSN) have been working to articulate the next generation of stormwater best management practices (BMPs) in the Chesapeake Bay Watershed. These practices must have the following characteristics:

- Achieve superior pollutant removal performance compared to current practices, particularly for the removal of nutrients.
- Support nutrient reduction targets outlined in Tributary Strategies.
- Be accessible and understandable to design professionals who prepare plans and local government staff who review them.
- Offer a broader menu of BMPs, including both conventional and innovative practices.
- Be based on sound science and the most up-to-date research on BMP design and performance.
- Address, through design features, long-term maintenance obligations.

CWP and CSN are collaborating on this work through the following projects:

> <u>Extreme BMP Makeover: Enhancing the Nutrient Removal Performance of the Next Generation of Urban Stormwater BMPs in the James River Watershed</u>
> This multi-year effort is supported by a grant from the National Fish and Wildlife Foundation (NFWF). The project aims to collect the best stormwater BMP science and apply to the creation of a Stormwater Nutrient Design Supplement (SNDS). Several "Early Adopter" communities within the James River Basin will apply various components of the SNDS and provide feedback to improve BMP design and implementation. The project also includes training for design professionals and local government staff, and dissemination of the SNDS to communities in the James River Basin and Chesapeake Bay Watershed.
>
> Besides CWP and CSN, project partners include the James River Association and the Hampton Roads Planning District Commission. The project will continue through 2010
>
> <u>Technical Assistance for Virginia Stormwater Management Regulations & Handbook</u>
> As a related project, CWP and CSN are working with the Virginia Department of Conservation & Recreation (DCR) on the development of technical support material for the updated stormwater regulations and handbook. The technical part of this work focuses on the creation of a "Runoff Reduction Method" for compliance with proposed regulations for new development and redevelopment. CWP and CSN are also participating in several site design charettes around the State to introduce the method and apply it on a trial basis to various real-world site plans. These charettes are sponsored by DCR and the Virginia Chapter of the American Society of Civil Engineers.

National Pollutant Removal Performance Database, Version 3
Over the years, CWP has been active in compiling and analyzing BMP pollutant removal performance data from research across the nation. CWP's National Pollutant Removal Performance Database was one of the first efforts in the country to systematically compile this type of data. Version 2 of the database (Winer, 2000) consisted of 139 individual BMP performance studies published through 2000. The database was recently updated to include an additional 27 studies published through 2006 (CWP, 2007).

These three projects will be instrumental in bringing research, field experience, and stakeholder involvement together to define key elements for future BMP design and implementation. This technical memorandum is the first step in the process. The memorandum outlines the results of BMP research and distills this information into a framework that can be used by design professionals and plan reviewers to verify compliance with proposed stormwater regulations in Virginia. The resulting "Runoff Reduction Method" is a system that incorporates site design, stormwater management planning, and BMP selection to develop the most effective stormwater approach for a given site.

Following the release of this memorandum, work will continue on both the Extreme BMP Makeover and Virginia DCR projects. This work will involve continued vetting the method with various stakeholder groups and technical advisory committees, conducting a field study of BMPs, developing the SNDS, conducting trainings on BMP design, installation, and maintenance, and disseminating the results within the James River and Chesapeake Bay watersheds. DCR will also continue with its process to update the stormwater regulations and handbook, with the assistance of various technical advisory committees.

One particular emphasis for future work will be to define how water quality and quantity criteria can be integrated in the BMP computation and design process. The current version of this technical memorandum outlines a method to account for water quality (nutrient) reductions. However, "full" stormwater compliance at a site includes other components, such as channel protection and flood control. CWP will be working with DCR and other stakeholders to help better define the relationship between quality and quantity, and future versions of this memorandum will include proposed methods.

The technical memorandum includes the following sections:

1. Introduction & Background: A brief review of the project background and framework.

2. The Runoff Reduction Method – A Three-Step Process for Better Stormwater Design: An overview of the rational and process outlined in the Runoff Reduction Method.

3. Documenting Runoff Reduction (RR) and Pollutant Removal (PR) Capabilities of BMPs: Key definitions and data tables to assign RR and PR values to BMPs.

4. Site-Based Nutrient Load Limits: A brief description of Virginia's proposed approach to stormwater compliance based on Tributary Strategy goals.

5. Runoff Coefficients – Moving Beyond Impervious Cover: An introduction to new runoff coefficients to better reflect land cover conditions that affect water quality.

6. Treatment Volume – The Common Currency for Site Compliance: An introduction to the Treatment Volume computation and rational.

7. Runoff Reduction Practices: A brief explanation of the research basis for assigning runoff reduction rates to BMPs.

8. Pollutant Removal Practices: Similar to Section 7, a brief explanation of the research basis for assigning pollutant removal rates to BMPs.

9. Level 1 and 2 Design Factors – Accountability for Better BMP Design: The resources and reasoning for identifying design factors that lead to better BMP performance.

Appendix A: BMP Planning Spreadsheet & Guidelines
Appendix B: Derivation of Runoff Reduction Rates for Select BMPs
Appendix C: Derivation of EMC Pollutant Removal Rates for Select BMPs
Appendix D: Level 1 & 2 BMP Design Factors
Appendix E: Minimum Criteria for Selected ESD Practices
Appendix F: BMP Research Summary Tables
Appendix G: Derivation of Event Mean Concentrations for Virginia

2. THE RUNOFF REDUCTION METHOD: A THREE-STEP PROCESS FOR BETTER STORMWATER DESIGN

The Runoff Reduction Method ("RR Method") was developed in order to promote better stormwater design and as a tool for compliance with Virginia's proposed regulations. There several shortcomings to existing stormwater design practices that the method seeks to overcome:

- Levelling the BMP Playing Field: The suite of BMPs that can be used to comply with the existing regulations is limited to those listed in the *Virginia Stormwater Management Handbook*. For many site designers, this leaves out many innovative practices that have proven effective at reducing runoff volumes and pollutant loads. In particular, good site design practices, that reduce stormwater impacts through design techniques, are not "credited" in the existing system. The RR Method puts conventional and innovative BMPs on a level playing field in terms of BMP selection and site compliance.
- Meeting the Big-Picture Goals: The existing stormwater compliance system does not meet Tributary Strategy goals for urban land. As sites are developed, the total urban land load increases at a rate that exceeds urban land targets. The RR Method uses better science and BMP specifications to help with the job of incrementally attaining the Tributary Strategy goals for phosphorus and nitrogen.
- Beyond Impervious Cover: Existing computation procedures use impervious cover as the sole indicator of a site's water quality impacts. More recent research indicates that a broad range of land covers – including forest, disturbed soils, and managed turf – are significant indicators of water quality and the health of receiving streams. The RR Method accounts for these land covers and provides built-in incentives to protect or restore forest cover and reduce impervious cover and disturbed soils.
- Towards Total BMP Performance: The current system for measuring BMP effectiveness is based solely on the pollutant removal functions of the BMP, but does not account for a BMP's ability to reduce the overall volume of runoff. Recent research has shown that BMPs are quite variable in terms of runoff reduction, and that some are quite promising. Runoff reduction has benefits beyond pollutant load reductions. BMPs that reduce runoff volumes can do a better job of replicating pre-development hydrologic conditions, protecting downstream channels, recharging groundwater, and, in some cases, reducing overbank (or "nuisance") flooding conditions. The RR Method uses recent research on runoff reduction to better gage total BMP performance.
- Accountability for Design: Currently, it can be difficult for site designers and plan reviewers to verify BMP design features – such as sizing, pretreatment, and vegetation – that should be included on stormwater plans in order to achieve a target level of pollutant removal. Clearly, certain BMP design features either enhance or diminish overall pollutant removal performance. The RR Method provides clear guidance that links design features with performance by distinguishing between "Level 1" and "Level 2" designs.

The RR Method relies on a three-step compliance procedure, as described below.

Step 1: Apply Site Design Practices to Minimize Impervious Cover, Grading and Loss of Forest Cover. This step focuses on implementing Environmental Site Design (ESD) practices during the early phases of site layout. The goal is to minimize impervious cover and mass grading, and maximize retention of forest cover, natural areas and undisturbed soils (especially those most conducive to landscape-scale infiltration). The RR Method uses a spreadsheet to compute runoff coefficients for forest, disturbed soils, and impervious cover and to calculate a site-specific target treatment volume and phosphorus load reduction target.

Step 2: Apply Runoff Reduction (RR) Practices. In this step, the designer experiments with combinations of nine Runoff Reduction practices on the site. In each case, the designer estimates the area to be treated by each Runoff Reduction practice to incrementally reduce the required treatment volume for the site. The designer is encouraged to use Runoff Reduction practices in series within individual drainage areas (such as rooftop disconnection to a grass swale to a bioretention area) in order to achieve a higher level of runoff reduction.

Step 3: Compute Pollutant Removal (PR) By Selected BMPs. In this step, the designer uses the spreadsheet to see whether the phosphorus load reduction has been achieved by the application of Runoff Reduction practices. If the target phosphorus load limit is not reached, the designer can select additional, conventional BMPs -- such as filtering practices, wet ponds, and stormwater wetlands -- to meet the remaining load requirement.

In reality, the process is iterative for most sites. When compliance cannot be achieved on the first try, designers can return to prior steps to explore alternative combinations of Environmental Site Design, Runoff Reduction practices, and Pollutant Removal practices to achieve compliance.

A possible Step 4 would involve paying an offset fee (or fee-in-lieu payment) to compensate for any load that cannot feasibly be met on particular sites. The local government or program authority would need to have a watershed or regional planning structure for stormwater management in order to make this option available for sites within the jurisdiction. The fee would be based on the phosphorus "deficit" – that is, the difference between the target reduction and the actual site reduction after the designer makes his or her best effort to apply Runoff Reduction and Pollutant Removal practices. A related, but simpler option would be to allow a developer to conduct an off-site mitigation project in lieu of full on-site compliance.

Figure 1 illustrates the step-wise compliance process described above, and **Table 1** includes a list of site design and stormwater practices that can be used for each step.

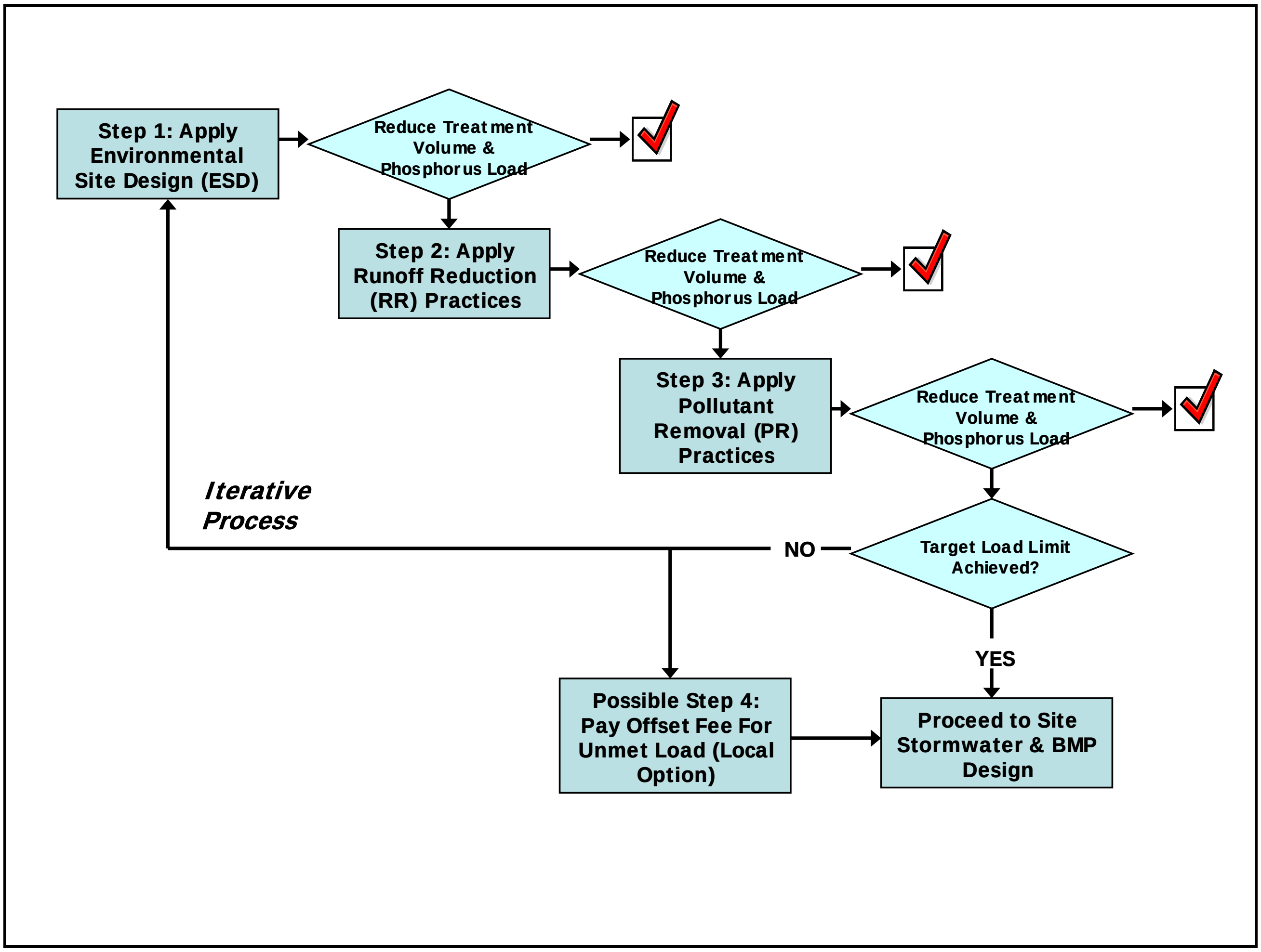

Figure 1. Step-Wise Process for Site Compliance

<table>
<tr><th colspan="3">Table 1. Practices Included in the Runoff Reduction Method</th></tr>
<tr><th>Step 1: Environmental Site Design (ESD)</th><th>Step 2: Runoff Reduction (RR) Practices</th><th>Step 3: Pollutant Removal (PR) Practices</th></tr>
<tr><td>Forest Conservation</td><td>Sheetflow to Conserved Open Space</td><td>Filtering Practice</td></tr>
<tr><td rowspan="2">Site Reforestation</td><td rowspan="3">Rooftop Disconnection:
▪ Simple
▪ To Soil Amendments
▪ To Rain Garden or Dry Well
▪ To Rain Tank or Cistern</td><td>Constructed Wetland</td></tr>
<tr><td>Wet Swale</td></tr>
<tr><td>Soil Restoration (combined with or separate from rooftop disconnection)</td><td rowspan="2">Wet Pond</td></tr>
<tr><td rowspan="7">Site Design to Minimize Impervious Cover & Soil Disturbance</td><td>Green Roof</td></tr>
<tr><td colspan="2">Grass Channels</td></tr>
<tr><td colspan="2">Permeable Pavement</td></tr>
<tr><td colspan="2">Bioretention</td></tr>
<tr><td colspan="2">Dry Swale (Water Quality Swale)</td></tr>
<tr><td colspan="2">Infiltration</td></tr>
<tr><td colspan="2">Extended Detention (ED) Pond</td></tr>
<tr><td colspan="3">Practices in shaded cells achieve both Runoff Reduction (RR) and Pollutant Removal (PR) functions, and can be used for Steps 2 and 3 depicted in Figure 1. See Appendices B and C for documentation.</td></tr>
</table>

3. DOCUMENTING RUNOFF REDUCTION (RR) & POLLUTANT REMOVAL (PR) CAPABILITIES OF BMPs

CWP and CSN made a significant effort to identify the capabilities of various BMPs to reduce overall runoff volume (Runoff Reduction) in addition to pollutant concentrations (Pollutant Removal). Since various terms are used in this technical memorandum, it is useful to supply some definitions for the purpose of their use within this document.

- *Runoff Reduction (RR)* is defined as the total annual runoff volume reduced through canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration.

- *Event Mean Concentration (EMC)* is defined as the average concentration of a pollutant in runoff for a monitored storm event.

- *Pollutant Removal (PR)* is defined as the change in EMC as runoff flows into and out of a BMP. Pollutant removal is accomplished via processes such as settling, filtering, adsorption, and biological uptake. This does not account for changes in the overall volume of runoff entering and leaving the BMP.

- *Total Removal* (TR) is the nutrient mass reduction, which is the product of both Runoff Reduction (RR) and Pollutant Removal (PR).

- *Eligibility Criteria* are defined as design factors – such as sizing, pretreatment, flow path geometry, vegetative condition, and treatment processes – that allow a BMP to achieve the RR and PR rates assigned in this document.

Tables 2 and **3** provide a comparative summary of how the combination of Runoff Reduction and Pollutant Removal translate into Total Removal for the range of practices. **Table 2** addresses the values for Total Phosphorus (TP) and **Table 3** for Total Nitrogen (TN). Details on the methodology and derivation of the RR and PR rates are found in **Appendices B and C**, respectively.

Where a range of values is presented in **Tables 2** and **3**, the first number is for Level 1 design and second for Level 2 design. The levels account for the variable Runoff Reduction and Pollutant Removal capabilities based on BMP design features. The concept of design levels is addressed in more detail in **Section 9.** In addition, eligibility criteria for Level 1 and 2 designs are contained in **Appendix E**.

The biggest caveat to the data in **Tables 2** and **3** is the limited number of studies available that reported BMP runoff reduction or EMC based nutrient removal efficiencies. As a result, some of the numbers listed in the tables will be subject to change are more studies and data become available. The numbers in the tables are the authors' best judgment based on currently-available information.

Table 2. Comparative Runoff Reduction, Pollutant Removal, and Total Removal for Total Phosphorus				
Practice	**Runoff Reduction (RR) (%)** (Appendix B)	**Pollutant Removal (PR)[1] - Total Phosphorus (%)** (Appendix C)	**Total Removal (TR) [2]**	**NPRPD -- Median to 3rd quartile (Q3)**
Green Roof	*45 to 60*	*0*	*45 to 60*	*NR*
Rooftop Disconnection	*25 to 50*	*0*	*25 to 50*	*NR*
Raintanks and Cisterns	*40*	*0*	*40*	*NR*
Permeable Pavement	*45 to 75*	*25*	*59 to 81*	*NR*
Grass Channel	*10 to 20*	*15*	*23 to 32*	*24 to 46* [3]
Bioretention	*40 to 80*	*25 to 50*	*55 to 90*	*5 to 30*
Dry Swale	*40 to 60*	*20 to 40*	*52 to 76*	*NR*
Wet Swale	*0*	*20 to 40*	*20 to 40*	*NR*
Infiltration	*50 to 90*	*25*	*63 to 93*	*65 to 96*
ED Pond	*0 to 15*	*15*	*15 to 28*	*20 to 25*
Soil Amendments[4]	*50 to 75*	*0*	*50 to 75*	*NR*
Sheetflow to Open Space	*50 to 75*	*0*	*50 to 75*	*NR*
Filtering Practice	*0*	*60 to 65*	*60 to 65*	*59 to 66*
Constructed Wetland	*0*	*50 to 75*	*50 to 75*	*48 to 76*
Wet Pond	*0*	*50 to 75*	*50 to 75*	*52 to 76*
Range of values is for Level 1 and Level 2 designs – see Section 9 & Appendix D				

[1] EMC based pollutant removal
[2] TR = RR + [(100-RR) * PR]
[3] Includes data for Grass Channels, Wet Swales and Dry Swales
[4] Numbers are provisional and are not fully accounted for in Version 1 of the BMP Planning spreadsheet (Appendix A); however future versions of the spreadsheet will resolve any inconsistencies.
NR= Not Researched

Table 3. Comparative Runoff Reduction, Pollutant Removal, and Total Removal for Total Nitrogen				
Practice	**Runoff Reduction (RR) (%)** (Appendix B)	**Pollutant Removal (PR)[1] - Total Nitrogen (%)** (Appendix C)	**Total Removal (TR) [2]**	**NPRPD -- Median to 3rd quartile (Q3)**
Green Roof	*45 to 60*	*0*	*45 to 60*	*NR*
Rooftop Disconnection	*25 to 50*	*0*	*25 to 50*	*NR*
Raintanks and Cisterns	*40*	*0*	*40*	*NR*
Permeable Pavement	*45 to 75*	*25*	*59 to 81*	*NR*
Grass Channel	*10 to 20*	*20*	*28 to 36*	*56 to 76* [3]
Bioretention	*40 to 80*	*40 to 60*	*64 to 92*	*46 to 55*
Dry Swale	*40 to 60*	*25 to 35*	*55 to 74*	*NR*
Wet Swale	*0*	*25 to 35*	*25 to 35*	*NR*
Infiltration	*50 to 90*	*15*	*57 to 92*	*42 to 65*
ED Pond	*0 to 15*	*10*	*10 to 24*	*24 to 31*
Soil Amendments[4]	*50 to 75*	*0*	*50 to 75*	*NR*
Sheetflow to Open Space	*50 to 75*	*0*	*50 to 75*	*NR*
Filtering Practice	*0*	*30 to 45*	*30 to 45*	*32 to 47*
Constructed Wetland	*0*	*25 to 55*	*25 to 55*	*24 to 55*
Wet Pond	*0*	*30 to 40*	*30 to 40*	*31 to 41*
Range of values is for Level 1 and Level 2 designs – see Section 9 & Appendix D				
[1] EMC based pollutant removal [2] TR = RR + [(100-RR) * PR] [3] Includes data for Grass Channels, Wet Swales and Dry Swales [4] Numbers are provisional and are not fully accounted for in Version 1 of the BMP Planning spreadsheet (Appendix A); however future versions of the spreadsheet will resolve any inconsistencies. NR= Not Researched				

For comparative purposes, data from the National Pollutant Removal Performance Database (NPRPD v.3; CWP, 2007) is shown in the last column of **Tables 2** and **3**. The NPRPD analyzes pollutant removal efficiencies of BMPs. The database defines pollutant removal efficiency as the pollutant reduction from the inflow to the outflow of a system. The values included in the NPRPD were derived from two fundamentally different computation methods for pollutant removal efficiency: (1) event mean concentration (EMC) efficiency, and (2) mass or load efficiency. For this reason, the NPRPD mixes analysis for RR and PR capabilities, which does not allow for distinguishing which BMPs may be particularly good for RR versus PR. The analysis done for this document, as portrayed in **Tables 2** and **3,** attempted to better tease out RR and PR results from the research studies.

Despite the differing analysis techniques, Total Removal values provided in **Tables 2** and **3** closely match numbers previously set forth in the NPRPD, with the exception of the total removal rate of Total Phosphorus for bioretention. The discrepancy with the bioretention removal rate is likely due to a disproportionate number of early studies in the NPRPD that tested bioretention media having a high Phosphorus Index (P-index greater than 30), which results in phosphorus leaching. The PR analysis used in this memorandum excluded bioretention practices having a P-index greater than 30.

4. SITE-BASED NUTRIENT LOAD LIMITS

The Runoff Reduction Method for Virginia is focused on site compliance to meet site-based load limits. This means that the proposed Virginia stormwater regulations are aimed at limiting the total load leaving a new development site. This is a departure from water quality computations of the past, in which the analysis focused on comparing the post-development condition to the pre-development, or an average land cover condition (the existing water quality procedures are explained in the *Virginia Stormwater Management Handbook, Volume II, Chapter 5;* VA DCR, 1999).

The chief objective of instituting a site-based load limit is so that land, as it develops, can still meet the nutrient reduction goals outlined in the Tributary Strategies. With the site-based limit, newly-developed land will maintain loadings that replicate existing loading from agricultural, forest, and mixed-open land uses. This is not to say that all developing parcels will maintain the pre-development loading rates, but that the rates, averaged across all development sites, will not increase compared to all categories of non-urban land.

An operational advantage to using site-based load limits is that it simplifies computations by focusing on the post-development condition. This, it is hoped, will reduce sources of contention between site designers and local government plan reviewers by eliminating confusion and conflict about what best constitutes the pre-development condition for a particular site.

The load limit calculations for the proposed Virginia stormwater regulations were performed by Virginia DCR staff, based on model outputs from the U.S. EPA Chesapeake Bay Program Watershed Model Scenario Output Database (Phase 4.3) (Commonwealth of Virginia, 2005). The DCR calculations led to proposed load limits of 0.28 pounds/acre/year for Total Phosphorus and 2.68 pounds/acre/year for Total Nitrogen.

5. RUNOFF COEFFICIENTS – MOVING BEYOND IMPERVIOUS COVER

The negative impacts of increased impervious cover (IC) on receiving water bodies have been well documented (CWP 2003, Walsh et al. 2004; Shuster et al. 2005; Bilkovic et al. 2006). Due to widespread acceptance of this relationship, IC has frequently been used in watershed and site design efforts as a chief indicator of stormwater impacts.

More recent research, however, indicates that other land covers, such as disturbed soils and managed turf, also impact stormwater quality (Law et al, 2008). Numerous studies have documented the impact of grading and construction on the compaction of soils, as measured by increase in bulk density, declines in soil permeability, and increases in the runoff coefficient (OCSCD et al, 2001; Pitt et al, 2002; Schueler and Holland, 2000). These areas of compacted pervious cover (lawn or turf) have a much greater hydrologic response to rainfall than forest or pasture.

Further, highly managed turf can contribute to elevated nutrient loads. Typical turf management activities include mowing, active recreational use, and fertilizer and pesticide applications (Robbins and Birkenholtz 2003). An analysis of Virginia-specific data from the National Stormwater Quality Database (Pitt et al. 2004) found that runoff from monitoring sites with relatively low IC residential land uses contained significantly higher nutrient concentrations than sites with higher IC non-residential uses (CWP & VA DCR, 2007). This suggests that residential areas with relatively low IC can have disturbed and intensively managed pervious areas that contribute to elevated nutrient levels.

The failure to account for the altered characteristics of disturbed urban soils and managed turf can result in an underestimation of stormwater runoff and pollutant loads generated from urban pervious areas. Therefore, the computation and compliance system for nutrients should take into account impervious cover as well as other land cover types.

The runoff coefficients provided in **Table 4** were derived from research by Pitt et al (2005), Lichter and Lindsey (1994), Schueler (2001a), Schueler, (2001b), Legg et al (1996), Pitt et al (1999), Schueler (1987) and Cappiella et al (2005). As shown in this table, the effect of grading, site disturbance, and soil compaction greatly increases the runoff coefficient compared to forested areas.

Table 4. Site Cover Runoff Coefficients (Rv)

Soil Condition	Runoff Coefficient
Forest Cover	0.02 to 0.05*
Disturbed Soils/Managed Turf	0.15 to 0.25*
Impervious Cover	0.95
*Range dependent on original Hydrologic Soil Group (HSG) Forest A: 0.02 B: 0.03 C: 0.04 D: 0.05 Disturbed Soils A: 0.15 B: 0.20 C: 0.22 D: 0.25	

The advantage of a computation system for nutrients that takes into account a range of land covers is that site stormwater designs will have a higher likelihood of treating all relevant land uses that contribute nutrients to waterways. In addition, such a system can incorporate site design incentives, such as maintaining or restoring forest cover, as a means of reducing site compliance requirements.

6. TREATMENT VOLUME – THE COMMON CURRENCY FOR SITE COMPLIANCE

Treatment Volume (Tv) is the central component of the Runoff Reduction method. By applying site design, structural, and nonstructural practices, the designer can reduce the treatment volume by reducing the overall volume of runoff leaving a site. In this regard, the Treatment Volume is the main “currency” for site compliance.

Treatment Volume is a variation of the 90% capture rule that is based on a regional analysis of the mid-Atlantic rainfall frequency spectrum. In Virginia, the 90^{th} percentile rainfall event is defined approximately as one-inch of rainfall. Additional rainfall frequency analyses across the State will further refine the one-inch rule.

Figure 2 illustrates a representative rainfall analysis for Reagan Airport in Washington, D.C. (DeBlander, et al., 2008). The figure provides an example of a typical rainfall frequency spectrum and shows the percentage of rainfall events that are equal to or less than an indicated rainfall depth. As can be seen, the majority of storm events are relatively small, but there is a sharp upward inflection point that occurs just above one-inch of rainfall (90^{th} percentile rainfall event).

The rational for using the 90^{th} percentile event is that it represents the majority of runoff volume on an annual basis, and that larger events would be very difficult and costly to control for the same level of water quality protection (as indicated by the upward inflection at 90%). However, these larger storm events would likely receive partial treatment for water quality, as well as storage for channel protection and flood control.

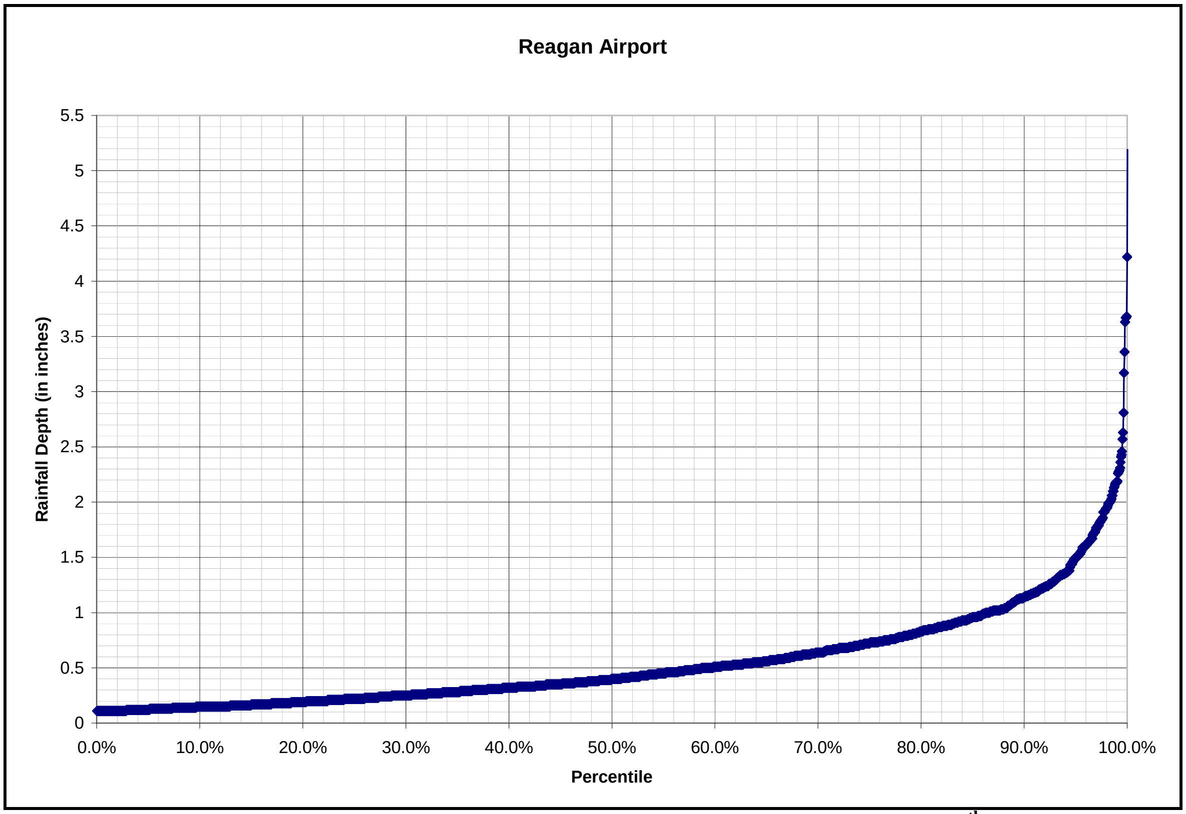

Figure 2. Rainfall Frequency Curve for Reagan Airport in Washington, D.C. The 90th percentile storm event is slightly more than 1" (DeBlander, et al., 2008).

A site's Tv is calculated by multiplying the "water quality" rainfall depth (one-inch) by the three site cover runoff coefficients (forest, disturbed soils, and impervious cover) present at the site, as shown in **Table 5**.

Table 5: Determining the Stormwater Treatment Volume
$$Tv = \frac{P * (Rv_I * \%I + Rv_T * \%T + Rv_F * \%F) * SA}{12}$$
Where Tv = Runoff reduction volume in acre feet P = Depth of rainfall for "water quality" event Rv_I = runoff coefficient for impervious cover[1] Rv_T = runoff coefficient for turf cover or disturbed soils[1] Rv_F = runoff coefficient for forest cover[1] % I = percent of site in impervious cover (fraction) %T = percent of site in turf cover (fraction) %F = percent of site in forest cover (fraction) SA = total site area, in acres [1] Rv values from **Table 4.**

The proposed Treatment Volume has several distinct advantages when it comes to evaluating runoff reduction practices and sizing BMPs:

- The Tv provides effective stormwater treatment for approximately 90% of the annual runoff volume from the site, and larger storms will be partially treated.

- Storage is a direct function of impervious cover and disturbed soils, which provides designers incentives to minimize the area of both at a site

- The 90% storm event approach to defining the Treatment Volume is widely accepted and is consistent with other state stormwater manuals (MDE, 2000, ARC, 2002, NYDEC, 2001, VTDEC, 2002, OME, 2003, MPCA, 2005)

- The Tv approach provides adequate storage to treat pollutants for a range of storm events. This is important since the first flush effect has been found to be modest for many pollutants (Pitt et al 2005).

- Tv provides an objective measure to gage the aggregate performance of environmental site design, LID and other innovative practices, and conventional BMPs together using a common currency (runoff volume).

- Calculating the Tv explicitly acknowledges the difference between forest and turf cover and disturbed and undisturbed soils. This creates incentives to conserve forests and reduce mass grading and provides a defensible basis for computing runoff reduction volumes for these actions.

7. RUNOFF REDUCTION PRACTICES

Various BMPs are capable of reducing the overall volume of runoff based on the post-development condition. Historically, BMP performance has been evaluated according to the pollutant removal efficiency of a practice. However, in some cases, this underreported the full capabilities of BMPs to reduce pollutant loads. More recent BMP performance research has focused on runoff reduction as well as overall pollutant removal.

A literature search was performed to compile data on the Runoff Reduction capabilities for different BMPs. Runoff Reduction data were limited for most practices. However, many recent studies have started documenting Runoff Reduction performance. Based on the research findings, Runoff Reduction rates were assigned to various BMPs, as shown in **Table 6**. A range of values represents the median and 75th percentile runoff reduction rates based on the literature search. Several BMPs reflected moderate to high capabilities for reducing annual runoff volume. Others – including filtering, wet swales, wet ponds, and stormwater wetlands -- were found to have a negligible affect on runoff volumes, and were not assigned runoff reduction rates.

Table 6. Runoff Reduction for various BMPs (from Table 2)

Practice	**RR (%)**
Green Roof	*45 to 60*
Rooftop Disconnection	*25 to 50*
Raintanks and Cisterns	*40*
Permeable Pavement	*45 to 75*
Grass Channel	*10 to 20*
Bioretention	*40 to 80*
Dry Swale	*40 to 60*
Wet Swale	*0*
Infiltration	*50 to 90*
ED Pond	*0 to 15*
Soil Amendments	*50 to 75*
Sheetflow to Open Space	*50 to 75*
Filtering Practice	*0*
Constructed Wetland	*0*
Wet Pond	*0*

Range of values is for Level 1 and Level 2 designs – see Section 9 & Appendix D

Runoff Reduction data for several practices were limited, so some of the values are considered provisional. Documentation for the recommended Runoff Reduction rates can be found in **Appendix B**. Practice eligibility for the range of Runoff Reduction rates is included in **Appendix E**.

8. POLLUTANT REMOVAL PRACTICES

Pollution removal occurs through a variety of mechanisms, including filtering, biological uptake, adsorption, and settling. There is wide variability in the ability of BMPs to remove nutrients through these mechanisms.

Some of the studies in the National Pollutant Removal Performance Database (version 3; CWP, 2007) reported EMC-based pollutant removal rates. Reporting EMC-based efficiencies can help to isolate the pollutant removal mechanisms of a BMP and offers an approach to assessing BMP performance apart from Runoff Reduction. In this regard, the Runoff Reduction function of a BMP can be seen as the "first line of defense" and the Pollutant Removal mechanisms help to treat the remaining runoff that "passes through" the BMP.

The literature search was expanded to refine EMC-based pollutant removal efficiencies. Studies reporting EMCs were isolated from the NPRPD. The search was then broadened to include more recent studies and studies not included the NPRPD. **Table 7** summarizes the EMC pollutant removal rates of TP and TN for various BMPs. A range of values represents the median and 75th percentile pollutant removal rates. **Appendix C** provides further documentation on the methodology and recommended Pollutant Removal rates.

Table 7. EMC based pollutant removal for various BMPs (from Tables 2 and 3)

Practice	**Total Phosphorus PR (%)**	**Total Nitrogen PR (%)**
Green Roof	*0*	*0*
Disconnection	*0*	*0*
Raintanks and Cisterns	*0*	*0*
Permeable Pavement	*25*	*25*
Grass Channel	*15*	*20*
Bioretention	*25 to 50*	*40 to 60*
Dry Swale	*20 to 40*	*25 to 35*
Wet Swale	*20 to 40*	*25 to 35*
Infiltration	*25*	*15*
ED Pond	*15*	*10*
Soil Amendments	*0*	*0*
Sheetflow to Open Space	*0*	*0*
Filtering Practice	*60 to 65*	*30 to 45*
Constructed Wetland	*50 to 75*	*25 to 55*
Wet Pond	*50 to 75*	*30 to 40*
Range of values is for Level 1 and Level 2 designs – see Section 9 & Appendix D		

9. LEVEL 1 & 2 DESIGN FACTORS – ACCOUNTABILITY FOR BETTER BMP DESIGN

Two levels of design are introduced in the Runoff Reduction Method (see values provided in **Tables 2, 3, 6 and 7**). Level 1 can be considered a "standard" design (achieves the median value of Runoff Reduction and Pollutant Removal from the research), and Level 2 an enhanced design (achieves the 75^{th} percentile values).

Based on the evaluation of BMP performance in the literature, design factors that enhance nutrient pollutant removal and runoff reduction of BMPs were isolated. This section documents the scientific rationale and assumptions used to assign sizing and design features to the Level 1 and Level 2 BMPs that are presented in **Appendix D**.

Standard Design Features. The first step involved identifying the "standard" design features that should be included in all designs (i.e., not directly related to differential nutrient removal or runoff reduction rates). These include any features needed to maintain proper function of the BMP, as well as its safety, appearance, safe conveyance, longevity, standard feasibility constraints, and maintenance needs. These standard features will be outlined in the detailed design specifications to be developed by CSN and others later in 2008.

Design Point Tables. The *Stormwater Retrofit Manual, Appendix B* (Schueler et al, 2007) contains a series of tables that describe design factors that increase or decrease overall pollutant removal rates. These were used initially to assign design features into Level 1 and 2. It should be acknowledged that the design point tables were developed primarily to evaluate removal rates for stormwater retrofits that may lack the full range of design features (and design opportunities) present in a new development setting. Also, the original design point method was established to estimate removal for eight different pollutants. Modifications were made in this document to reflect the more specific goal of nutrient removal for BMPs in both new development and redevelopment settings.

Review of 2007 NPRD Rates. The updated NPRPD (CWP, 2007) recently added 27 new performance monitoring studies, mostly for under-represented practices such as bioretention, infiltration and water quality swales. Even so, nearly 80% of the performance entries in the NPRPD were built and monitored from 1980 to 2000, so many of the older designs may not reflect modern design features (particularly for ponds and wetlands).

Review of Individual Studies. To gain additional insight into the value of different sizes and design features, 50 stormwater technical notes were reviewed that provided a more in-depth analysis of more than 70 studies included into the NPRPD (Schueler and Holland, 2000). In addition, selected references were reviewed from the 2000 to 2008 stormwater literature, with an emphasis on design enhancements for infiltration, bioretention, and water quality swales. Greater emphasis was placed on studies in close geographic proximity to Virginia.

Based on the foregoing analysis, five primary design factors were used to define Level 1 and Level 2 design features: (1) increased treatment volume, (2) increased runoff reduction volumes, (3) enhanced design geometry and hydraulics, (4) vegetative condition, and (5) use of multiple treatment methods. More on the basis for each split are provided below.

> *1. Increased Treatment Volume:* Increasing the treatment volume can enhance nutrient removal rates, up to a point. The existing treatment volume approach captures about 90% of the annual runoff volume, so further increases can only result in modest improvements, unless the larger volumes increase the residence time, or rate of nutrient uptake (which has been documented for ponds and wetlands). Therefore, three incremental levels of greater treatment volume were considered for each BMP: 110%, 125% and 150% of the base Tv.
>
> *2. Increased Runoff Reduction Volume:* The second strategy to enhance nutrient removal rates is to increase the proportion of the treatment volume that is achieved by runoff reduction. In this instance, design features that could significantly enhance runoff reduction volumes were generally assigned to Level 2 practices.
>
> *3. Enhanced Design Geometry & Hydraulics:* A third strategy to split BMPs according to nutrient removal is to isolate geometry factors that are known to influence either hydraulic performance or create better treatment conditions. Examples include flow path, depth of filter media, multiple cells, BMP surface area to contributing drainage area ratio, and minimum extended detention time.
>
> *4. Vegetative Condition:* A fourth splitting strategy involves the ultimate type and cover of vegetation within the BMP insofar as it influences nutrient uptake, increases the evapotranspiration pump, stabilizes trapped sediments or enhances the filter bed. Landscape designs that maximize tree canopy or otherwise increase the ultimate vegetative cover for a practice were often used to support Level 2 designs.
>
> *5. Multiple Treatment Methods:* The last major strategy is to combine several treatment options within a single practice to increase the reliability of treatment. For instance, a practice that incorporates settling, filtering, soil adsorption, and biological uptake will have a higher level of performance than one that relies on only one of these mechanisms.

Based on the assumptions, **Tables 4** through **13** in **Appendix B** assign Level 1 and 2 design factors and associated expected average runoff reduction, phosphorus removal, and nitrogen removal rates. Importantly, it should be understood that the assigned rates are based on the assumption that BMP designs will meet certain "eligibility criteria." That is, the BMPs will be located and designed based on appropriate site conditions and limitations with regard to soils, slopes, available head, flow path, and other factors. **Appendix E** details these eligibility criteria for the various BMPs.

10. TRANSFERABILITY OF THE RUNOFF REDUCTION CONCEPT

While the Runoff Reduction Method was originally developed in tandem with Virginia DCR's efforts to update the stormwater regulations and handbook, the concept is widely applicable to other state and local stormwater planning procedures. The focus on runoff volume as the common currency for BMP evaluation is gaining wider acceptance across the county (U.S. EPA, 2008).

Currently, within the Chesapeake Bay Watershed, the States of Delaware, Maryland, Virginia, and the District of Columbia are considering incorporating the concept of runoff reduction into updated stormwater regulations and design manuals (Capiella et al., 2007; DeBlander et al., 2008; MSC, 2008). The *Pennsylvania Stormwater Best Management Practices Manual* (PA DEP, 2006) already incorporates standards for volume control achieved by structural and nonstructural BMPs. The Georgia Coastal Program is also working on a Coastal Stormwater Supplement to the *Georgia Stormwater Management Manual* that will incorporate runoff reduction principles (Novotney, 2008).

Clearly, the concept of runoff reduction marks an important philosophical milestone that will help define the next generation of stormwater design. The promise of runoff reduction is that the benefits go beyond water quality improvement. If site and stormwater designs can successfully implement runoff reduction strategies, then they will do a better job at replicating a more natural (or pre-development) hydrologic condition. This goes beyond peak rate control to address runoff volume, duration, velocity, frequency, groundwater recharge, and protection of stream channels. Important future work will involve integrating the runoff reduction concept with stormwater requirements for channel protection and flood control, so that stormwater criteria can be presented in a unified approach.

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APPENDICES

Appendix A: BMP Planning Spreadsheet & Guidelines

Appendix B: Derivation of Runoff Reduction Rates for Select BMPs

Appendix C: Derivation of EMC Pollutant Removal Rates for Select BMPs

Appendix D: Level 1 & 2 BMP Design Factors

Appendix E: Minimum Criteria for Selected ESD Practices

Appendix F: BMP Research Summary Tables

Appendix G: Derivation of Event Mean Concentrations for Virginia

APPENDIX A:
BMP Planning Spreadsheet and Guidelines
04/18/08

NOTE: The Spreadsheet Tool referenced here is Version 1. Subsequent versions of the spreadsheet will be developed and released in response to stakeholder feedback, including the site plan charettes sponsored by ASCE and DCR. This guidance will be updated as new versions of the spreadsheet become available.

Click here for Version 1 of the Spreadsheet

NOTES ON THE METHOD

- **Total Phosphorus (TP)** used as keystone pollutant. Total Nitrogen (TN) can also be calculated and BMP designs can address TN removal, but compliance is based on TP.
- Each site also has a **Treatment Volume (Tv)** that is based on post-development land covers. The method uses more than just impervious cover to compute the Tv.
- BMPs are assigned **Runoff Reduction (RR)** and **Pollutant Removal (PR)** rates. Rates vary for Level 1 and Level 2 designs, based on ongoing research (these rates are provisional). Level 2 BMPs have design enhancements to boost performance (see Table 1).
- BMPs are sized and designed based on Level 1 and Level 2 design guidelines (see Tables 2 through 16). The applicable RR and PR rates are based on these sizing and design rules.

OVERVIEW OF METHOD

1. Utilize environmental site design (ESD) techniques to reduce impervious cover and maximize forest and open space cover. This will affect the post-development treatment volume and pollutant load.
2. For the site, measure post-development impervious, managed turf, and forest/open space land cover. If there is more than one Hydrologic Unit for the site, the land cover analysis should be done for each HU. The approval authority may define a planning area for the site where the land cover analysis should be done (e.g., a concentrated area of development within a larger parcel), although this should be based on equitable criteria. Guidance for various land covers is as follows:
    a. Impervious = roads, driveways, rooftops, parking lots, sidewalks, and other areas of impervious cover
    b. Managed Turf = land disturbed and/or graded for turf, including yards, rights-of-way, and turf intended to be maintained and mowed within commercial and institutional settings

c. Forest/Open Space = pre-existing forest and open land, plus land to be reforested (according to standards), that will remain undisturbed and protected in an easement, deed restriction, protective covenant, etc. If land will be disturbed during construction, but treated with soil amendments, reforested according to the standards, and protected as noted above, then it may also qualify for forest cover.

3. Calculate weighted turf and weighted forest runoff coefficients based on hydrologic soil groups. Combined with impervious cover, the result will be a weighted site runoff coefficient. STEP 1 IN THE SPREADSHEET.

Rv Coefficients				
	A soils	**B Soils**	**C Soils**	**D Soils**
Forest/Reforested	0.02	0.03	0.04	0.05
Managed Turf	0.15	0.20	0.22	0.25
Impervious Cover	0.95			

4. Calculate post-development TP loading & Treatment Volume for the site or each HU on the site. STEP 1 IN THE SPREADSHEET.
5. Apply **Runoff Reduction (RR)** Practices on the site to reduce post-development treatment volume and load. The site designer should select the most strategic locations on the site to place RR practices (e.g., drainage areas with the most developed land). This will likely be an iterative process. Runoff reduction "volume credits" are based on the contributing drainage area (CDA) to each selected BMP. STEP 2 IN THE SPREADSHEET.
6. Based on the RR practices selected, **Pollutant Removal (PR)** rates will be applied to BMPs that achieve both runoff reduction and pollutant removal functions. STEP 3 IN THE SPREADSHEET.
7. If there is still a TP load to remove after applying RR and PR credits to the selected BMPs, the designer can:
    a. Select additional **RR** BMPs in STEP 2 OF THE SPREADSHEET,
    b. Select additional **PR** BMPs in STEP 3 OF THE SPREADSHEET.

RR and PR credits are applied to the BMP's CDA.
The ultimate goal is to reduce the load to the "terminal load" (0.28 pounds/acre).

APPENDIX B:
DERIVATION OF RUNOFF REDUCTION RATES FOR SELECT BMPs

Runoff reduction (RR) is defined as the average annual reduction in stormwater runoff volume. For stormwater best managment practices (BMPs) runoff can be reduced via canopy interception, soil infiltration, evaporation, transpiration, rainfall harvesting, engineered infiltration, or extended filtration. Extended filtration includes bioretention or dry swales with underdrains that delay the delivery of stormwater from small sites to the stream system by six hours or more.

Prior to 2003, very few research studies reported flow reductions in the literature, reporting instead on the change in inflow and outflow event mean concentrations (EMCs). Recently, more studies have been reporting flow reductions, particularly for LID projects, although data are still limited. For the purposes of this document, studies documenting the runoff reduction of individual BMPs were compiled, and are included in Appendix F. Summaries of the runoff reduction performance for individual BMPs are discussed in this section.

From a design standpoint, the runoff reduction rates are appropriate for use in the Virginia spreadsheet up to the water quality storm event. Runoff reduction rates were generally an annual average based on the study site water balance. These rates may not apply at their full values to storm events larger than the typical “water quality storm,” or approximately one-inch of rainfall (but it is likely that some reduction for larger events will occur). The runoff reduction numbers are dependent on meeting the Level 1 and 2 design criteria (Appendix D) or the eligibility criteria for ESD (Appendix E). Given the limited number of runoff reduction performance studies available, the recommended rates were selected using conservative assumptions and best professional judgment, and some of the numbers are considered provisional until more data become available (these are noted in each subsection below).

Green Roofs
Considerable research has been conducted in recent years to define the runoff reduction capability of extensive green roofs (Table B-1). Reported rates for runoff reduction have been shown to be a function of media depth, roof slope, annual rainfall and cold season effects. Based on the prevailing climate for the region, a conservative runoff reduction rate for green roofs of 45 to 60% is recommended for initial design.

Table B-1. Volumetric Runoff Reduction by Green Roof			
LID Practice	**Location**	**Runoff Reduction**	**Reference**
Green Roof	USA	40 to 45%	Jarrett et al (2007)
Green Roof	Germany	54%	Mentens et al (2005)
Green Roof	MI	30 to 85%	Getter et al (2007)
Green Roof	OR	69%	Hutchinson (2003)
Green Roof	NC	55 to 63%	Moran and Hunt (2005)
Green Roof	PA	45%	Denardo et al (2005)
Green Roof	MI	50 to 60%	VanWoert et al (2005)
Green Roof	ONT	54 to 76%	Banting et al (2005)
Green Roof	GA	43 to 60	Carter and Jackson (2007)
RR Estimate		45 to 60%	

Rooftop Disconnection
Very limited research has been conducted on the runoff reduction rates for rooftop disconnection, so initial estimates are drawn from research on filter strips, which operate in a similar manner. The research indicates that runoff reduction is a function of soil type, slope, vegetative cover and filtering distance. Table B-2 summarizes filter strip runoff reduction rates within the first 45 feet (where a range is given, the first number is for filtering distance of 5 to 15 ft and the second for 25 to 45 ft). A conservative runoff reduction rate for rooftop disconnection is 25% for HSG C and D soils and 50% for HSG A and B soils. These values apply to disconnection that meet the feasibility criteria, and do not include any further runoff reduction due to the use of compost amendments along the filter path.

Table B-2. Volumetric Runoff Reduction Achieved by Rooftop Disconnection			
LID Practice	**Location**	**Runoff Reduction**	**Reference**
Filter Strip	USA	20 to 62	Abu-Zreig et al (2004)
Filter Strip	USA	40%	Strecker at al (2004)
Filter Strip	CA	40 to 70	Barrett (2003)
Runoff Reduction Estimate		25 to 50%	

Raintanks and Cisterns
The runoff reduction capability of rain tanks and cisterns has not been extensively monitored, but numerous modeling efforts have assigned a runoff reduction rate. Dual use rain tanks provide indoor potable or grey water and outdoor landscaping irrigation. Modeling research indicates that their runoff reduction capability is limited by tank capacity, and the rate of de-watering between storms, which is strongly influenced by indoor and outdoor water demand and overflows (Table

B-3). The actual rate of runoff reduction for an individual project will require simulation modeling of rainfall and the tank. Based on the prevailing climate for this region, a conservative runoff reduction estimate of 40% is recommended for initial design. For the purposes of the Virginia spreadsheet, the actual storage volume is used multiplied by a discount factor of 75% (to account for water that is not used or drained between storm events).

Table B-3. Volumetric Runoff Reduction by Raintanks and Cisterns

LID Practice	**Location**	**Runoff Reduction**	Reference
Dual Use Rain Tanks [1]	AUS (semi-arid)	60 to 90%	Hardy et al (2004)
Dual Use Rain Tanks	AUS (arid)	40 to 45%	Coombes et al (2002)
Dual Use Rain Tanks	NZ	35 to 40%	Kettle et al (2004)
	RR Estimate	40%	

Permeable Pavement

More than a dozen studies are now available to characterize the runoff reduction potential for permeable pavers that are designed with the requisite amount of storage to enable infiltration beneath the paver. The research studies have been classified into two categories: permeable paver applications that have underdrains and those that do not (Table B-4). Assuming the permeable paver is designed with adequate pretreatment and soil infiltration testing, a conservative runoff reduction rate of 75% is assigned to designs that rely upon full infiltration. Permeable paver applications on HSG C and D soils that typically require underdrains should use the lower runoff reduction rate of 45%.

Table B-4. Volumetric Runoff Reduction by Permeable Pavement

LID Practice	**Location**	**Runoff Reduction**	**Reference**
Pervious Pavement *	ONT	99	Van Seters et al (2006)
Pervious Pavement *	PA	94	Traver et al (2006)
Pervious Pavement *	FRA	98	Legret and Colandini (1999)
Pervious Pavement *	NC	100	Bean et al (2007)
Pervious Pavement *	NC	95 to 98%	Collins et al (2007)
Pervious Pavement *	WA	97 to 100	Brattebo and Booth (2003)
Pervious Pavement *	CT	72	Gilbert and Clausen (2006)
Pervious Pavement *	UK	78	Jefferies (2004)
Pervious Pavement #	NC	38 to 66	Collins et al (2007)
Pervious Pavement #	PA	25-45	Pratt et al (1989)
Pervious Pavement #	NC	66	Bean et al (2007)
Pervious Pavement #	UK	53	Jefferies (2004)
Pervious Pavement #	MD	45 to 60	Schueler et al (1987)
Pervious Pavement #	Lab	30 to 55	Andersen et al (1989)
Runoff Reduction Estimate		45# to 75*	
* no underdrain collection/infiltration design; # underdrain collection			

Grass Channels
Runoff reduction by grass channels is generally low, but is influenced strongly by soil type, slope, vegetative cover, and the length of channel (Table B-5). Recent research indicates that a conservative runoff reduction rate of 10 to 20% can be used, depending on whether soils fall in HSG A/B or C/D. The runoff reduction rates can be doubled if the channel is modified to incorporate compost soil amendments.

Table B-5. Volumetric Runoff Reduction Achieved by Grass Channels

LID Practice	**Location**	**% Runoff Reduction**	Reference
Grass Channel	VA	0	Schueler (1983)
Grass Channel	USA	40	Strecker at al (2004)
Grass Channel	NH	0	UNHSC (2007)
Grass Channel	OR	27 to 41	Liptan and Murase (2000)
Runoff Reduction Estimate		10 to 20	

Bioretention
More than 10 studies are now available to characterize the runoff reduction rates for bioretention areas. The research can be classified into bioretention applications that possess underdrains and those that do not (and therefore rely on full infiltration into underlying soils) (Table B-6). A conservative runoff reduction rate of 80% is assigned to designs that rely on full infiltration. Bioretention areas located on HSG C and D soils that typically require underdrains should use the lower runoff reduction rate of 40%.

Table B-6. Volumetric Runoff Reduction Achieved by Bioretention

LID Practice	**Location**	**% Runoff Reduction**	Reference
Bioretention *	CT	99%	Dietz and Clausen (2006)
Bioretention *	PA	86%	Ermilio (2005)
Bioretention *	FL	98%	Rushton (2002)
Bioretention *	AUS	73%	Lloyd et al (2002)
Bioretention #	ONT	40%	Van Seters et al (2006)
Bioretention #	Model	30%	Perez-Perdini et al (2005)
Bioretention #	NC	40 to 60%	Smith and Hunt (2007)
Bioretention #	NC	20 to 29%	Sharkey (2006)
Bioretention #	NC	52 to 56%	Hunt et al. (2006)
Bioretention #	NC	20 to 50%	Passeport et al. (2008)
Bioretention #	MD	52 to 65%	Davis (2008)
Runoff Reduction Estimate		40# to 80*	
*infiltration design; # underdrain design			

Dry Swales
Only a handful of data are available to define the runoff reduction rate for dry swales, but research indicates that they perform as well as, or better than, bioretention with underdrains (Table B-7). Since an underdrain is an integral design feature for dry swales, a conservative runoff reduction of 40% is assigned to dry swales, a value equivalent to the rate assigned to bioretention with underdrains. If a dry swale lacks an underdrain due to highly permeable soils, or is designed with an underground stone storage layer, the runoff reduction rate can be increased to 60%.

Table B-7. Volumetric Runoff Reduction Achieved by Dry Swales

LID Practice	**Location**	**% Runoff Reduction**	Reference
Dry Swale	WA	98%	Horner et al (2003)
Dry Swale	MD	46 to 54%	Stagge (2006)
Dry Swale	TX	90%	Barrett et al (1998)
Runoff Reduction Estimate		40 to 60%	

Wet Swales
Limited runoff reduction data are available on wet swales. Wet swales function similarly to wet ponds and wetlands, retaining a permanent pool of water due to intersection with ground water or siting in poorly drained soils. No runoff reduction rate is recommended for wet swales.

Infiltration
The runoff reduction capability of infiltration practices is presumed to be high, given that infiltration is the design intent of the practice. Some surface overflows do occur when the infiltration storage capacity is exceeded. Assuming the practice is designed with adequate pretreatment and soil infiltration testing, a conservative runoff reduction rate of 90% is assigned to infiltration practices. If an underdrain must be utilized, the recommended runoff reduction rate drops to 50% (Table B-8).

Table B-8. Volumetric Runoff Reduction Achieved by Infiltration

LID Practice	**Location**	**Runoff Reduction**	Reference
Infiltration	NH	90%	UNHSC (2005)
Infiltration	VA	60%	Schueler (1983)
Infiltration	PA	90%	Traver et al (2006)
Infiltration	NC	96-100%	Bright et al (2007)
Runoff Reduction Estimate		50 to 90%	

Extended Detention
In lined extended detention (ED) basins, evaporation reduces a small portion of the runoff volume, and in unlined basins, runoff is further reduced via seepage. Strecker et al. (2004) analyzed the runoff reduction rates for 11 dry extended detention basins in the EPA/ASCE

National Stormwater BMP Database and found a mean runoff volume reduction of 30%; however, more recent research indicates lower reductions (Strecker, 2008). Additionally, two ED basins in NC had negligible runoff reduction rates (Hathway et al, 2007e), and a basin in FL sited in very well drained soils had a 70% runoff reduction rate (Harper et al, 1999). Based on the prevailing climate for the region, a conservative runoff reduction estimate of 0% for lined basins, and 15% for unlined basins is recommended for initial design.

Soil Amendments

Several studies have examined the effect of soil compost amendments to reduce the volume of runoff produced by lawn runoff from compacted soils (Table B-9). This practice can be combined with rooftop disconnection as a complementary strategy (see Table B-2). A runoff reduction rate of 50% is given when compost amended soils receive runoff from an appropriately designed rooftop disconnection or grass channel. A 75% runoff reduction rate can be used for the runoff from lawn areas that are compost amended, but do not receive any off-site runoff from impervious surfaces (in other words, runoff is reduced from the lawn area itself).

Table B-9. Volumetric Reduction in Lawn Runoff Due to Compost Amendments

LID Practice	**Location**	**Runoff Reduction**	Reference
Compost Amendment	WI	74 to 91%	Balusek (2003)
Compost Amendment	AL	84 to 91%	Pitt et al (1999 and 2005)
Compost Amendment	WA	29 to 50%	Kolsti et al (1995)
Compost Amendment	WA	53 to 74%	Hielima (1999)
Runoff Reduction Estimate		50 to 75%	

Sheetflow to Conserved Open Space

Limited data are available to characterize the runoff reduction associated with sending sheet flow to conserved open space, although the process is very similar to using a filter strip (see Table B-2 and the discussion for Rooftop Disconnection). However, the surface area, flow path, and vegetative condition of conserved open space would be greater – and likely provide greater runoff reduction -- than an engineered filter strip. A runoff reduction rate of 50 to 75% can be used provisionally and conditionally, depending on whether the soils in the conserved areas fall in HSG A/B or C/D.

Filtering Practices, Constructed Wetlands, and Wet Ponds

Very little individual performance data are available on the runoff reduction capabilities of sand filters, wet pond, and wetland practices. In pond and wetland applications, evapo-transpiration may occur; however, research suggests that the amount of runoff reduced is very low to negligible (Strecker et al, 2004 ; Hathaway et al, 2007a-d). Therefore, a conservative runoff reduction rate of 0% is recommended for filters, wet ponds, and wetlands.

Stormwater Planters, Tree Pits, and Tree Clusters

Only one study has measured the hydrologic capacity of stormwater planters or tree pits to reduce runoff, and it found they had relatively low capability (UNHSC, 2007). The actual runoff reduction capability for these practices is related to their contributing drainage area, runoff storage capacity and rate of overflow or underdrain. Consequently, these practices are assigned a modest runoff reduction capability of 15%. No specific research has been conducted on the runoff reduction rates for tree clusters as set forth in Cappiella et al (2005), although the value of trees in reducing runoff has been established by Portland BES (2003) and PA DEP (2006). These manuals assign a runoff reduction rate of 6 cubic feet per qualifying deciduous tree and 10 cubic feet per evergreen tree. If planting bed is compost amended, or tree cluster is designed to accept off-site runoff, a higher rate of runoff reduction may be used.

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APPENDIX C:
DERIVATION OF EMC POLLUTANT REMOVAL RATES FOR SELECT BMPs

Pollutant removal efficiency refers to the pollutant reduction from the inflow to the outflow of a system. Pollutant removal efficiency can be calculated using variety of computations, but the two most common methods are event mean concentration (EMC) efficiency and mass or load efficiency. EMC efficiency is derived by averaging the influent and effluent concentrations for storm events, and then calculating the median change. Mass efficiency is calculated by determining the pollutant load reduction from the influent to effluent, and is influenced by the volume of water reduced by the practice (runoff reduction – see Appendix B).

Depending on the method used, reported removal efficiencies of stormwater best management practices (BMPs) can vary widely and are often inconsistent. Further, removal efficiencies do not always address runoff volume reductions in BMPs (Strecker et al, 2004; Jones et al, 2008). However, for the purposes of the analysis in this document, reported EMC based pollutant removal efficiencies can help to isolate the pollutant removal mechanisms of a BMP and offers a better approach to assessing BMP performance apart from runoff reduction (Appendix B).

The following sections discuss the derivation of EMC based pollutant removal efficiencies of BMPs. The NPRPD (CWP, 2007) details the pollutant removal efficiencies of several BMPs that were derived using several different methods. Studies reporting EMC pollutant removal in the NPRPD were isolated and included in the analysis. Further, EMC pollutant removal numbers were compiled from recent studies, which are detailed in Appendix F. When possible, a median and 75th percentile value for nutrient PR was determined.

The EMC nutrient removal rates are appropriate for use in the Virginia spreadsheet (Appendix A). It should be noted that the data used to estimate pollutant removal were derived from practices in good condition; most studies focused on BMPs that were constructed within three years of monitoring. Further, the actual EMC pollutant removal performance can be strongly influenced by the influent quality. Since pollutant removal rates are usually dependent on site characteristics and BMP geometry, the EMC based pollutant removal numbers are dependent on meeting the Level 1 or 2 design criteria (Appendix D) and the eligibility criteria for ESD (Appendix E). Due to the limited number of performance studies, conservative EMC pollutant removal rates were selected. In several cases, provisional numbers are set forth until more data become available.

Green Roofs

In recent years, several studies have been conducted on the nutrient removal capabilities of green roofs. Results confirm that green roofs initially leach nutrients from the compost contained in the growth media used to support initial plant growth (Table C-1). Several studies have suggested that the leaching may subside over time; however, the extent to which nutrient leaching decreases has not been quantified. Media with high initial compost content will leach more nutrients than media with lower compost content. Therefore, to minimize the export of nutrients, media should be selected with the lowest compost content that adequately supports the growth of the desired roof vegetation (unless other factors for overall green roof success supersede this factor). No pollutant removal credit for nitrogen or phosphorus is recommended.

Table C-1. Pollutant Removal Achieved by Green Roofs

LID Practice: Green Roof[1]	**Location**	**Pollutant Removal (TP)**	**Pollutant Removal (TN)**	**Study**
Green Roof	NC	negative	negative	Moran et al, 2005
Green Roof	OR	negative	negative	Hutchinson, 2003
Green Roof	CAN	negative	negative	Banting et al, 2005
EMC PR estimate		0%	0%	

[1]Pollutant removal values are EMC based for all studies
[+] Study included in NPRPD (CWP, 2007)

Disconnection (Vegetated Filter Strips)
Limited research has been conducted on the pollutant removal rates for rooftop disconnection. Initial estimates are drawn from research on filter strips, which operate in a similar manner. The research indicates that nutrient reduction is a function of filtering distance and vegetative cover (Abu-Zreig et al, 2003; Barrett et al, 1998; CALTRANS, 2004; Goel et al, 2004). Since very little information regarding the EMC based nutrient removal rates of vegetated filter strips has been published, no pollutant removal rate for TP or TN is recommended at this initial stage. Pollutant removal rates for downspout disconnection may likely change as more data become available.

Raintanks and Cisterns
Limited research has been conducted to evaluate the pollutant removal capabilities of rain tanks and cisterns. However, it is generally understood that no primary pollutant removal benefits exist (MPAC, ND). Based on this assumption, no pollutant removal credit for TP and TN is recommended for raintanks and cisterns.

Permeable Pavement
While several studies have documented high heavy metal and TSS removal efficiencies of permeable pavements, few studies have evaluated permeable pavement nutrient removal capabilities. Limited results indicate that permeable pavement TP and TN removal rates vary widely (Table C-2). TP can potentially be reduced by adsorption to the aggregate and soils in the pavement subbase layers, but may also leach from underlying soils or surface fill material in pavement void spaces. Provisional EMC pollutant removal rates of 25% for both TP and TN are recommended.

Table C-2. Pollutant Removal Achieved by Permeable Pavements				
LID Practice: Permeable Pavement[1]	**Location**	**Pollutant Removal (TP)**	**Pollutant Removal (TN)**	**Study**
Permeable Pavement#	Lab	60%		Day et al, 1981
Permeable Pavement#	CAN	0%		James and Shahin, 1998
Permeable Pavement#	GA	10%	negative	Dreelin et al, 2006
Permeable Pavement#	NC	65%	36%	Bean et al, 2007[+]
Permeable Pavement#	NC	negative	negative	Bean, 2005[+]
Permeable Pavement#	NH	38%		UNH, 2007
Permeable Pavement#	NC	0%	25%*	Collins et al., 2008
Permeable Pavement#	CT	34%	88%	Gilbert and Clausen, 2006
EMC PR estimate		25%	25%	

[1]Pollutant removal values are EMC based for all studies
[+] Study included in NPRPD (CWP, 2007)
* for one pavement type only
# underdrain design

Grass Channels (Drainage Swales)
Several studies have documented the nutrient removal rates of grass channels (Table C-3). Nutrient removal is generally low, but is influenced by vegetative cover and flow velocity. The removal of mowed grass clippings may also increase nutrient removal. Fertilization of channel vegetation should be avoided. Conservative pollutant removal rates of 15% for TP and 20% for TN are recommended.

Table C-3. Pollutant Removal Achieved by Grass Channels				
LID Practice: Drainage Swale[1]	**Location**	**Pollutant Removal (TP)**	**Pollutant Removal (TN)**	**Study**
Grass Channel	MD	0%	37%	OWML, 1983[+]
Grass Channel	MD	0%	negative	OWML, 1983 [+]
Grass Channel	TX	34 to 44%	38%	Walsh et al, 1995 [+]
Grass Channel	TX	negative	negative	Welborn and Veehuis, 1987 [+]
Grass Channel	FL	13%	21%	Harper, 1988[+]
Grass Channel	FL	25%	11%	Yousef et al, 1986[+]
Grass Channel	WA	29 to 45		Seattle Metro, 1992 [+]
Grass Channel	CA	negative	30%	CALTRANS, 2004
Grass Channel	USA	29		Schueler and Holland, 2000 (article 116)
EMC PR estimate		15%	20%	

[1]Pollutant removal values are EMC based for all studies except NPRPD
[+] Study included in NPRPD (CWP, 2007)

Bioretention

Several recent studies have indicated that bioretention practices are effective at removing nutrients, as well as metals, pathogens, oil and grease. Much of this research has reported mass based pollutant removal rates, but ten studies reporting EMC based removal rates were examined (Table C-4). The extent of TP removal is related to bioretention cell depth, mulching, plant cover, and the organic matter content of the soil media. The primary phosphorus removal mechanism is soil adsorption. It is imperative that the P-index of the media be tested to ensure a low number (less than 30), as earlier studies have found that soil media with a high P-index will leach phosphorus.

Nitrogen is removed through mineralization and denitrification near the surface of bioretention cells and also by denitrification in anaerobic zones that often develop deeper in the cells. Design of an internal water storage zone (sump) using an upturned underdrain (or stone sump below the underdrain pipes) may increase TN removal. A summary of bioretention mass removal included in the NPRPD lists lower median and 75th percentile pollutant removal rates for TP; however, many of these earlier studies tested practices with high P-index media. Conservative EMC pollutant removal rates of 25 to 50% for TP removal and 40 to 60% for TN removal are recommended. TP removal is credited only if the media is tested to ensure that the media P-index is less than 30.

Table C-4. Pollutant Removal Achieved by Bioretention

LID Practice: Bioretention[1]	Location	Pollutant Removal (TP)	Pollutant Removal (TN)	Study
NPRPD (N=10)		5[a]-30[b]	46[a]-55[b]	CWP, 2007
Bioretention#	MD	81%		Davis et al., 2001
Bioretention#	MD	65%	49%	Davis et al., 2006
Bioretention#	MD	87%	59%	Davis et al., 2006
Bioretention#	Lab	81%	60%	Davis et al., 2006
Bioretention#	PA	1%	48%	Ermilio, 2005[+]
Bioretention#	NC	8%	61%	Smith and Hunt, 2006[+]
Bioretention#	NC	32%	38%	Hunt et al. 2008
Bioretention#	NC	60%	54%	Passeport et al. 2008
Bioretention#	NC	66%	62%	Sharkey, 2006
Bioretention#	VA	13%		Yu and Stopinski, 2001[+]
EMC PR estimate		25 to 50%	40 to 60%	

[1]Pollutant removal values are EMC based for all studies

[a] Median pollutant removal rate

[b] 75th Percentile pollutant removal rate

[+] Study included in NPRPD (CWP, 2007)

underdrain design

Water Quality Swales

Compared to bioretention, fewer monitoring studies are available to define the EMC pollutant removal rate for water quality swales, which include wet swales and dry swales with an underdrain. Research suggests that pollutant removal mechanisms of dry swales are similar to those of a bioretention cell with an underdrain, because a portion of water is filtered through a soil media. Wet swales, which typically contain a shallow permanent pool, may function similar to, but less efficient than, wetlands or wet ponds with respect to pollutant removal. Conservative and provisional EMC pollutant removal rates of 20 to 40% for TP and 25 to 35% for TN are recommended for both wet and dry swales (Table C-5).

Table C-5. Pollutant Removal Achieved by Water Quality Swales

LID Practice: Water Quality Swales[1]	Location	Pollutant Removal (TP)	Pollutant Removal (TN)	Study
Wet swale	FL	17%	40%	Harper, 1988[+]
Wet swale	WA	39		Koon, 1995[+]
Dry swale	AUS	65%	52%	Fletcher et al, 2002
Dry swale with Underdrain	TX	31		Barrett et al, 1997
Wet Ponds		50 to 75%	30 to 40%	This study
Bioretention with Underdrain		25 to 50%	25%	This study
EMC PR estimate		20 to 40%	25 to 35%	

[1]Pollutant removal values are EMC based for all studies
[+] Study included in NPRPD (CWP, 2007)

Infiltration

Because of the difficulty associated with monitoring infiltration practices, very limited data are available on EMC nutrient removal capability. Studies have indicated that stormwater pollutants, including nutrients, can be filtered out in the soils underlying infiltration basins (Mikkelson et al, 1994; Barraud et al, 1999; Dechesne et al, 2003). A summary of 12 infiltration practices included in the NPRPD lists the median and 75th percentile mass pollutant removal rates as 65 to 96 for total phosphorus (TP), and 42 to 65 for total nitrogen (TN). However, the majority of mass removal in infiltration practices occurs in the form of runoff reduction (Appendix B). Therefore, provisional EMC pollutant removal rates of 25% for TP removal and 15% for TN removal are specified until more research becomes available.

Extended Detention

Extensive research on ED ponds has indicated that these practices can effectively remove particulate pollutants, primarily thorough sedimentation. Documented nutrient removal rates are variable (Table C-6). Based on several studies, conservative EMC pollutant removal rates of 15% for TP and 10% for TN are recommended. The EMC pollutant removal differs from the removal rates in the NPRPD, which did not include any ED studies that analyzed EMC based pollutant removal.

Table C-6. Pollutant Removal Achieved by Extended Detention

LID Practice: Extended Detention[1]	Location	Pollutant Removal (TP)	Pollutant Removal (TN)	Study
NPRPD (N=10)		20[a]-25[b]	24[a] -31[b]	CWP, 2007
Dry ED pond	CA	15 to 39%	14%	CALTRANS, 2004
Dry ED pond	NC	0%	10 to 13%	Hathaway et al, 2007e,f
Dry ED pond	NJ	34%	0%	Harper et al, 1999[+]
Dry ED pond	TX	7%		Middleton and Barrett, 2006
EMC PR estimate		15%	10%	

[1]Pollutant removal values are EMC based for all studies except NPRPD
[a] Median pollutant removal rate
[b] 75th Percentile pollutant removal rate
[+] Study included in NPRPD (CWP, 2007)

Soil Amendments

Few studies have reported on the pollutant removal capabilities of amended soils. Both Glanville, et al. (2003) and Pitt et al, (2005) found that the pollutant concentrations in runoff from compost amended soils were higher than in runoff from un-amended soils. Pitt et. al. (2005) found that subsurface flows had an increased amount of nitrogen and phosphorus as compared to un-amended soils. This difference was present at newly constructed sites but was less prominent at older sites. Due to the high compost or organic matter content that is added to amended soils, it can be assumed that negligible removal of nutrients would occur, and nutrients may, in fact, leach from soil runoff, similar to documented pollutant dynamics of green roof media containing compost. As such, no pollutant removal credit for TP and TN is recommended for soil amendments.

Sheet Flow to Open Space

Limited research has been conducted on the pollutant removal rates for sheetflow to open space. Initial estimates may be drawn from research on filter strips or buffer areas, which demonstrate pollutant removal via plant uptake and soil filtering (Abu-Zreig et al, 2003; Desbonnet et al, 1994). For initial design, no pollutant removal rate for TP or TN is recommended for open space; however, pollutant removal rates may likely change as more data become available.

Filtration

Numerous studies have evaluated the nutrient removal capabilities of various stormwater filtration practices (Table C-7). Phosphorus is removed via chemical precipitation in the filter bed media, and although organic filters may export nitrates, studies have indicated that TN is typically reduced. The use of some organic materials in the filter bed, which can improve heavy metal removal rates, may cause nutrient leaching (Leif, 1999). An analysis of individual studies in which the EMC pollutant removal rates were reported yielded EMC removal rates for TP (N=7 studies) and TN (N=4 studies) similar to the pollutant removal rates in the NPRPD (N=18 studies). Since runoff reduction in filtration practices is negligible (Appendix B), mass removal and EMC removal rates are roughly equivalent. Due to the limited number of filtration studies reporting EMC pollutant removal rates, filtration practices are therefore assigned EMC pollutant removal rates based on the values in the NPRPD, since the NPRPD contains more studies. These rates are 60 to 65% for TP, and 30 to 45% for TN.

Table C-7. Pollutant Removal Achieved by Filtration

LID Practice: Sand Filters[1]	Location	Pollutant Removal (TP)	Pollutant Removal (TN)	Study
NPRPD (N=18)		59[a]-66[b]	32[a]-47[b]	CWP, 2007
Sand Filter	TX	39 %	22%	Barrett, 2003
Sand Filter	VA	66%	47%	Bell et al, 1995[+]
Peat Sand Filter	TX	48%	30 to 51%	LCRA, 1997[+]
Sand Filter	WA	20 to 41%		Horner, 1995[+]
Sand Filter	TX	45%	15%	Barton Springs, 1996[+]
Organic filter	WI	88%		Corsi and Greb, 1997[+]
Compost filter	TX	41%		Stewart, 1992[+]
EMC PR estimate		60 to 65%	30 to 45%	

[1]Pollutant removal values are EMC based for all studies except NPRPD
[a] Median pollutant removal rate
[b] 75th Percentile pollutant removal rate
[+] Study included in NPRPD (CWP, 2007)

Wetlands

Studies indicate that wetlands can effectively remove TP and TN, primarily through sedimentation and plant nutrient uptake (Table C-8). Nutrient removal is related to the vegetative covering, wetland geometry, and the drawdown time of the temporary storage volume.

An analysis of individual studies in which the EMC pollutant removal rates were reported yielded EMC removal rates for TP (N=8 studies) and TN (N=4 studies) similar to the pollutant removal rates in the NPRPD (N=40 studies). Since runoff reduction in wetland practices is negligible (Appendix B), mass removal and EMC removal rates can be evaluated equivalently. Due to the smaller number of studies reporting wetland EMC pollutant removal rates, wetlands are assigned EMC pollutant removal rates based on the values in the NPRPD: 50 to 75% for TP, and 25 to 55% for TN.

Table C-8. Pollutant Removal Achieved by Wetlands				
LID Practice: Wetlands[1]	**Location**	**Pollutant Removal (TP)**	**Pollutant Removal (TN)**	**Study**
NPRPD (N=40)		48[a]-76[b]	24[a]-55[b]	CWP, 2007
Wetland	FL	28%	10%	Martin, 1988[+]
Wetland	FL	48%	13%	Blackburn et al, 1986[+]
Wetland	WA	33%		Koon, 1995[+]
Wetland	FL	57%		Rushton and Dye, 1993[+]
Wetland	VA	69%		Yu et al, 1998[+]
Wetland	VA	15%		Yu et al, 1998[+]
Submerged gravel wetland	CA	46%	negative	Reuter et al, 1992[+]
Wetland	NC	45%	35 to 45%	Hathaway et al, 2007a,b
EMC PR estimate		50 to 75%	25 to 55%	

[1]Pollutant removal values are EMC based for all studies except NPRPD
[a] Median pollutant removal rate
[b] 75th Percentile pollutant removal rate
[+] Study included in NPRPD (CWP, 2007)

Wet Ponds

Numerous studies have evaluated the nutrient removal capabilities of wet ponds (Table C-9). Several factors appear to affect removal rates, such as the treatment volume captured, presence of emergent vegetation, and length of the flow path in the pond. The establishment of a diverse, dense plant community around the perimeter of the pond may increase nutrient removal, and may also discourage water fowl activity, potentially reducing organic nutrient and pathogen inputs. An analysis of individual studies in which the EMC pollutant removal rates were reported yielded EMC removal rates for TP (N=16 studies) and TN (N=12 studies) similar to the pollutant removal rates in the NPRPD (N=46 studies). Since runoff reduction in wet pond practices is negligible (Appendix B), mass removal and EMC removal rates can be evaluated equivalently. Due to the smaller number of studies reporting wet pond EMC pollutant removal rates, these practices are assigned EMC pollutant removal rates based on the values in the NPRPD: 50 to 75% for TP, and 30 to 40% for TN.

Table C-9. Pollutant Removal Achieved by Wet Ponds

LID Practice: Wet Ponds[1]	**Location**	**Pollutant Removal (TP)**	**Pollutant Removal (TN)**	**Study**
NPRPD (N=46)		52[a]-76[b]	31[a]-41[b]	CWP, 2007
Wet Pond	TX	87%	50%	City of Austin, TX 1996[+]
Wet Pond	WA	19%		Comings et al, N.D [+]
Wet Pond	FL	55%	12%	Cullum, 1984 [+]
Wet Pond	FL	30%	16%	Gain, 1996 [+]
Wet Pond	FL	40%		Kantrowitz and Woodham, 1995[+]
Wet Pond	FL	22%	15%	Martin, 1988 [+]
Wet Pond	CAN	72%		SWAMP, 2000 [+]
Wet Pond	CA	29%	0%	Taylor et al, 2001
Wet Pond	NC	57%	40%	Mallin et al, 2002
Wet Pond	CA	5%	51%	CALTRANS, 2004
Wet Pond	NC	15 to 41%	19 to 23%	Hathaway et al, 2007c,d
Wet ED pond	CAN	37%	28%	Fellows et al, 1999[+]
Wet ED pond	CO	52%	55%	LCRA, 1997 [+]
Wet ED pond	FL	75%	28%	Rushton et al, 1995[+]
Wet ED pond	FL	50%	25%	Rushton et al, 2002[+]
Wet ED pond	CAN	56 to 65%		SWAMP, 2000
EMC PR estimate		50 to 75%	30 to 40%	

[1]Pollutant removal values are EMC based for all studies except NPRPD
[a] Median pollutant removal rate
[b] 75th Percentile pollutant removal rate
[+] Study included in NPRPD (CWP, 2007)

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APPENDIX D:
LEVEL 1 AND 2 BMP DESIGN FACTORS

Based on the assumptions in Section 9 of the technical memorandum, the following tables assign design factors to Level 1 or 2 that will achieve the indicated average runoff reduction and nutrient removal rates.

- D-1 Green Roof
- D-2 Permeable Pavement
- D-3 Bioretention
- D-4 Dry Swale
- D-5 Wet Swale
- D-6 Infiltration
- D-7 Extended Detention Pond
- D-8 Filtering Practice
- D-9 Constructed Wetland
- D-10 Wet Pond

The base pollutant removal and runoff reduction are the median values for Level 1, whereas Level 2 corresponds to the 75th percentile values. These tables do not include the standard setbacks, restrictions, feasibility constraints and minimum design features that apply to each practice for all site applications.

Table D-1. Green Roof Design Guidance

Level 1 Design (RR:45; TP:0; TN:0)	**Level 2 Design (RR: 60; TP:0; TN:0)**
Depth of media four to six inches[1]	Media depth greater than six inches
Soil media not tested for P-index	Soil media with P index less than 10
Green roof receives roof runoff	Green roof does not receive roof runoff or is designed with additional media depth
All Designs: shall be in conformance to ASTM (2005) International Green Roof Standards. Appropriate media and plant selection for harsh rooftop conditions and shallow media depths. Filter media mix should have the minimum organic matter/nutrient content to maintain fertility for plant growth but not contribute to nutrient leaching. [1]If media depth is less than 4 inches, the runoff reduction credit is adjusted so that each inch of media provides a 10% reduction in runoff volume.	

Table D-2. Permeable Pavement Design Guidance

Level 1 Design (RR:45; TP:25; TN:25)	**Level 2 Design (RR: 75 TP:25; TN:25)**
TV= (1.0)(Rv)(A)	TV = (1.1)(Rv) (A)
Soil infiltration less than one-inch/hr	Soil infiltration rate exceeds one-inch/hr
Underdrain needed	Underdrain not required
CDA ≥ The pervious paver area	CDA = The pervious paver area
Slopes from 2 to 5%	Slopes less than 2%

Table D-3. Bioretention Design Guidelines

Level 1 Design (RR:40; TP:25; TN:40)	Level 2 Design (RR:80; TP:50; TN:60)
TV= (1.0)(Rv)(A)	TV= (1.25) (Rv)(A)
SA of filter exceeds 3% of CDA	SA of filter bed exceeds 5% of CDA
Filter media at least 24” deep	Filter media at least 36” deep
One form of accepted pretreatment	Two or more forms of accepted pretreatment
At least 75% plant cover w/ mulch	At least 90% plant cover, including trees.
One cell design	Two cell design
Underdrain needed	Infiltration design or underground stone sump
All Designs: acceptable media mix tested for phosphorus index, does not treat stormwater hotspot or baseflow.	

Table D-4. Dry Swale Design Guidance

Level 1 Design (RR:40; TP:20; TN:25)	Level 2 Design (RR:60; TP:40; TN: 35)
TV= (1.0)(Rv)(A)	TV= (1.1)(Rv)(A)
Swale slopes from <0.5% or >2.0%	Swale slopes from 0.5% to 2.0%
Soil infiltration rates less than 0.5 in	Soil infiltration rates exceed one inch
Swale served by underdrain	Lacks underdrain or uses underground stone sump
On-line design	Off-line or multiple treatment cells
Media depth less than 18 inches	Media depth more than 24 inches
Turf cover	Turf cover, with trees, shrubs, or herbaceous plantings
All Designs: acceptable media mix tested for phosphorus index	

Table D-5. Wet Swale Design Guidance

Level 1 Design (RR:0; TP:20; TN:25)	Level 2 Design (RR:0; TP:40; TN:35)
TV= (1.0)(Rv)(A)	TV= (1.25)(Rv)(A)
Swale slopes more than 1%	Swale slopes less than 1%
On-line design	Off-line swale cells
No planting	Wetland planting within swale cells
Turf cover in buffer	Trees and shrubs planted within swale cells
Note: Generally recommended only for flat coastal plain conditions with high water table. Linear wetland always preferred to wet swale	

Table D-6. Infiltration Design Guidelines

Level 1 Design (RR:50; TP:25; TN:15)	Level 2 Design (RR:90; TP:25; TN:15)
TV= (1.0)(Rv)(A)	TV= (1.1)(Rv)(A)
Maximum CDA of one acre	Max CDA of 0.5 acre, nearly 100% IC
At least one form of pretreatment	At least two forms of pretreatment
Soil infiltration rate of 0.5 to 1.0 in/hr	Soil infiltration rates of 1.0 to 4.0 in/hr
Underdrain needed due to soils	No underdrain utilized
All Designs: no hotspot runoff	

Table D-7. Extended Detention (ED) Pond Guidance	
Level 1 Design (RR:0; TP:15; TN:10)	**Level 2 Design (RR:15; TP:15; TN:10)**
TV= (1.0)(Rv)(A)	TV = (1.25)(Rv) (A)
At least 15% of TV in permanent pool	More than 40% of TV in deep pool or wetlands
Flow path at least 1:1	Flow path at least 1:5 to 1
Average ED time of 24 hours or less	Average ED time of 36 hours
vertical ED fluctuation exceeds 4 feet	Maximum vertical ED limit of 4 feet
Turf Cover on floor	Trees and wetlands in the planting plan
Forebay and micropool	Additional cells or treatment methods within areas of pond floor (e.g., sand filter, biotretention soils or plantings)
CDA less than ten acres	CDA greater than ten acres

Table D-8. Filtering BMP Design Guidance	
Level 1 Design (RR:0; TP:60; TN:30)	**Level 2 Design (RR:0 [1]; TP:65; TN:45)**
TV= (1.0)(Rv)(A)	TV= (1.25)(Rv)(A)
One cell design	Two cell design
Sand media	Sand media w/ organic layer
CDA contains pervious area	CDA is nearly 100% impervious
Not a confirmed stormwater hotspot	Site is a confirmed stormwater hotspot
[1] can be increased to up to 50% if or second cell is used for infiltration	

Table D-9. Constructed Wetland Design Guidance	
Level 1 Design (RR:0; TP:50; TN:25)	**Level 2 Design (RR:0; TP:75; TN:55)**
TV= (1.0)(Rv)(A)	TV = (1.5)(Rv)(A)
Single cell (with forebay)	Multiple cells or pond/wetland design
ED wetland	No ED in wetland
Uniform wetland depth	Diverse microtopography
Mean wetland depth more than one foot	Mean wetland depth less than one foot
Wetland SA/CDA ratio less than 3%	Wetland SA/CDA ratio more than 3%
Flow path 1:1 or less	Flow path 1.5:1 or more
Emergent wetland design	Combined emergent and wooded wetland design

Table D-10. Wet Pond Design Guidance	
Level 1 Design (RR:0; TP:50; TN:30)	**Level 2 Design (RR:0; TP:75; TN:40)**
TV= (1.0)(Rv)(A)	TV = (1.5)(Rv) (A)
Single Pond Cell (w/ forebay)	Wet ED or Multiple Cell Design
Pool Depth Range of 3 to 12 feet	Pool Depth Range of 4 to 8 feet
Flow path 1:1 or less	Flow path 1.5:1 or more
Pond intersects with groundwater	Adequate water balance
CDA less than 15 acres	CDA greater than 15 acres

APPENDIX E: MINIMUM CRITERIA FOR SELECT ESD PRACTICES

From a design standpoint, it is still important to establish qualifying criteria for the following ESD practices:

- Site Reforestation
- Soil Restoration
- Sheetflow to Conserved Open Space
- Rooftop Disconnection
- Grass Channels

The updated design criteria for these ESD practices are provided in the tables below. In most cases, the design criteria were based on the original qualifying credit criteria contained in the 2000 MDE Manual, but they have been updated to reflect local experience and credit details in other manuals produced since 2000 (e.g., Minnesota, Credit River, DCR). The soil restoration and site reforestation criteria were drafted using recent research.

Table E-1. Site Reforestation
Description: 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 evapo-transpiration and enhance soil infiltration rates. Reforestation areas at larger development sites and for individual trees for smaller development sites are eligible under certain qualifying conditions.
Computation: A runoff coefficient of twice the forest runoff coefficient may be used for the entire combined areas of reforestation in the contributing drainage area, since it may take several decades for the replanted area to mature and provide full hydrologic benefits. If reforestation is combined with soil amendments, then the forest cover coefficient area can be used instead (see Table E-2 for soil restoration criteria). The runoff reduction calculation for individual qualifying trees or tree clusters is 6 cubic feet per deciduous tree and 10 cubic feet per evergreen tree [1]
Eligibility for Reforestation Practice (sites greater than one acre in size) • The minimum contiguous area of reforestation must be greater than 5000 square feet • A long term vegetation management plan must be prepared and filed with the local review authority to maintain the reforestation area in a natural forest condition • The reforestation area must be protected by a perpetual stormwater easement or deed restriction that indicates that no future development or disturbance can occur within the area • Reforestation methods should be designed to achieve 75% forest canopy within ten 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

Table E-1. Site Reforestation
extending at least three growing seasons to ensure adequate growth and survival of the plant community • The reforestation area shall be shown on all construction drawings and ESC plans, and adequately protected during construction **Eligibility for Individual Tree Practice (Sites less than one acre in size).** • Qualifying trees on small sites include native tree at less two inches in caliper planted in expanded tree pits with adequate soil volume to ensure future growth and survival
[1] The individual tree runoff credits were developed from data contained in Portland BES(2004), PA DEP (2006) and Cappiella et al (2005a and 2005b)

Table E-2. Soil Restoration Criteria
Application: Compost amended soils can be used to reduce the generation of runoff from compacted urban lawns and may also be used to enhance the runoff reduction performance of downspout disconnections and grass channels.
Computation: A runoff reduction rate of 50% is given when compost amended soils receive runoff from an appropriately designed rooftop disconnection (Table E-4) or grass channel (Table E-5). A 75% runoff reduction rate can be used for the runoff from lawn areas that are compost amended, but do not receive any off-site runoff from impervious surfaces (e.g., rooftops). [1]
Suitability for Soil Restoration: Compost amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. They are particularly well suited when existing soils have low infiltration rates (HSG C and D) and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Compost amendments are not recommended where: • Existing soils have high infiltration rates • The water table or bedrock is located within 1.5 feet of the soil surface. • Slopes exceed ten percent • Existing soils are saturated or seasonally wet • They would harm roots of existing trees (stay outside the tree drip line) • The downhill slope runs toward an existing or proposed building foundation
Sizing: Several simple sizing criteria are used when soil compost amendments are used to enhance the performance of a downspout disconnection • Flow from the downspout should be spread over a 10 foot wide strip extending down-gradient from the building to the street or conveyance system. • Existing soils in the strip will be scarified or tilled to a depth of 12 to 18 inches and amended with well-aged compost to achieve a organic matter content in the range of 8 to 13%.

Table E-2. Soil Restoration Criteria
• The depth of compost amendment is based on the relationship of the contributing rooftop area to the area of the soil amendment strip, using the following general guidance (RA is the contributing roof area in square feet, and SA is the surface area (sf) of compost amendments on the lawn): o RA/SA= 1, use 4 inches of compost, o RA/SA= 2, use 8 inches of compost, o RA/SA= 3, use 12 inches of compost, till to 18 to 24 inches depth Similar sizing criteria are used when soil compost amendments are used to enhance the performance of a grass channel • Flow in the grass channel should be spread over a 10-foot long strip at the appropriate channel dimension • Existing soils in the strip will be scarified or tilled to a depth of 12 inches and soils mixed with 6 to 8 inches of well-aged compost to achieve an organic matter content in the range of 8 to 13%. • The amended area will need to be rapidly stabilized with perennial, salt tolerant grass species. For grass channels on relatively steep slopes, it may be necessary to install a protective biodegradable geotextile fabric • Designers will need to ensure that the final elevation of the grass channel meets original hydraulic capacity
Design Specifications: Leaf compost should be made exclusively of fallen deciduous leaves with less than 5% dry weight of woody or green yard debris materials. The compost shall contain less than 0.5% foreign material such as glass or plastic contaminants and be certified as pesticide free. The use of leaf mulch, composted mixed yard debris, biosolids, mushroom compost or composted animal manures is prohibited. The compost shall be matured and been composted for a period of at least one year and exhibit no further decomposition. Visual appearance of leaf matter in the compost is not acceptable. The compost should have a dry bulk density ranging from 40 to 50 lbs/ft^3, a pH between 6 to 8 and a CEC in excess 50 meq/100 grams dry weight.
Construction Sequence: The construction sequence for compost amendments differs depending 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 follows. 1. Prior to building, the proposed area should be deep tilled to a depth of 2 to 3 feet using a tractor with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. 2. A second deep tilling is needed after final building lots have been graded to a depth 12 to 18 inches 3. An acceptable compost mix is then incorporated into the soil using a rototiller or similar equipment at the volumetric rate of one part compost to two parts soils 4. The site should be leveled and seed or sod used to establish a vigorous grass

Table E-2. Soil Restoration Criteria
cover. Lime or irrigation may initially be needed during start 5. Compost amendment areas exceeding 2500 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion 6. If the compost amendment area is receiving any runoff from upslope, then erosion control measures are needed to keep upslope runoff and sediment from compromising the amended area, particularly during any land disturbance in the upslope area. 7. 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 first step is usually omitted when compost is used for narrower filter strips.
[1] The computation is not consistent with Version 1 of the BMP Planning spreadsheet (Appendix A); however future versions of the spreadsheet will resolve this discrepancy

Table E-3. Sheetflow To Conserved Open Space
Description: Sending sheetflow from developed areas of the site to protected conservation areas
Computation: The runoff coefficient for conservation area will be forest or restoration area, depending on predevelopment land cover. Qualifying contributing areas include any turf and impervious cover that is hydrologically connected to the protected conservation area and is effectively treated by it. A 75% runoff reduction practice is given for qualifying HSG A and B soils (within the conservation area), and a 50% runoff reduction is given for qualifying HSG C and D soils.
Basic Eligibility for the Conservation Area • The minimum combined area of all natural areas conserved within the appropriate drainage area must exceed 0.5 acres. • No major disturbance may occur within the open space during or after construction (i.e., no clearing or grading allowed except temporary disturbances associated with incidental utility construction, restoration operations or management of nuisance vegetation). The conservation area shall not be stripped of topsoil. Some light grading may be needed at the boundary using tracked vehicles to prevent compaction. • The limits of disturbance should be clearly shown on all construction drawings and protected by acceptable signage and fencing. • A long term vegetation management plan must be prepared to maintain the conservation area in a natural vegetative condition. 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., ball fields and golf courses are not eligible). • The conservation area must be protected by a perpetual easement or deed restriction that assigns the responsible party to ensure no future development, disturbance or clearing can occur within the area.

Table E-3. Sheetflow To Conserved Open Space
• The practice does not apply to jurisdictional wetlands that are sensitive to increased inputs of stormwater runoff. **Basic Eligibility for the Runoff Generating Area** • The maximum contributing sheet flow path from adjacent pervious areas should not exceed 150 feet • The maximum contributing sheet flow path from adjacent impervious areas should not exceed 75 feet • For average slopes exceeding 3%, graded terraces should be placed every 20 longitudinal feet along the flow path Runoff should enter the boundary of the open space as sheetflow for the one-inch storm. A depression, berm or level spreader may be used to spread out concentrated flows generated during larger storm events.

Table E-4. Rooftop Disconnection
Description: This runoff reduction practice is offered when rooftop runoff is disconnected, and then filtered, treated, or reused before it moves from roof to the storm drain system.
Computation: Two kinds of practices are allowed. One is for simple rooftop disconnection, whereas the second involves disconnection combined with supplementary runoff treatment involving: (a) Compost amended soils in the filter path (b) Installation of rain gardens or dry wells (c) Storage and reuse in a rain tank, cistern or foundation planter. Simple disconnection is assigned a runoff reduction rate of 50% on A/B soils and 25% on C/D soils. Disconnection to amended soils is assigned a 50% reduction.[2] Disconnection to rain gardens or dry wells is assigned a 75% reduction on A/B soils and 50% for C/D soils.[2] The runoff reduction for rain tanks and cisterns is 40%, but varies depending on design and the degree of water reuse. See Figure E-1 to determine the most appropriate rooftop disconnection option.

Table E-4. Rooftop Disconnection

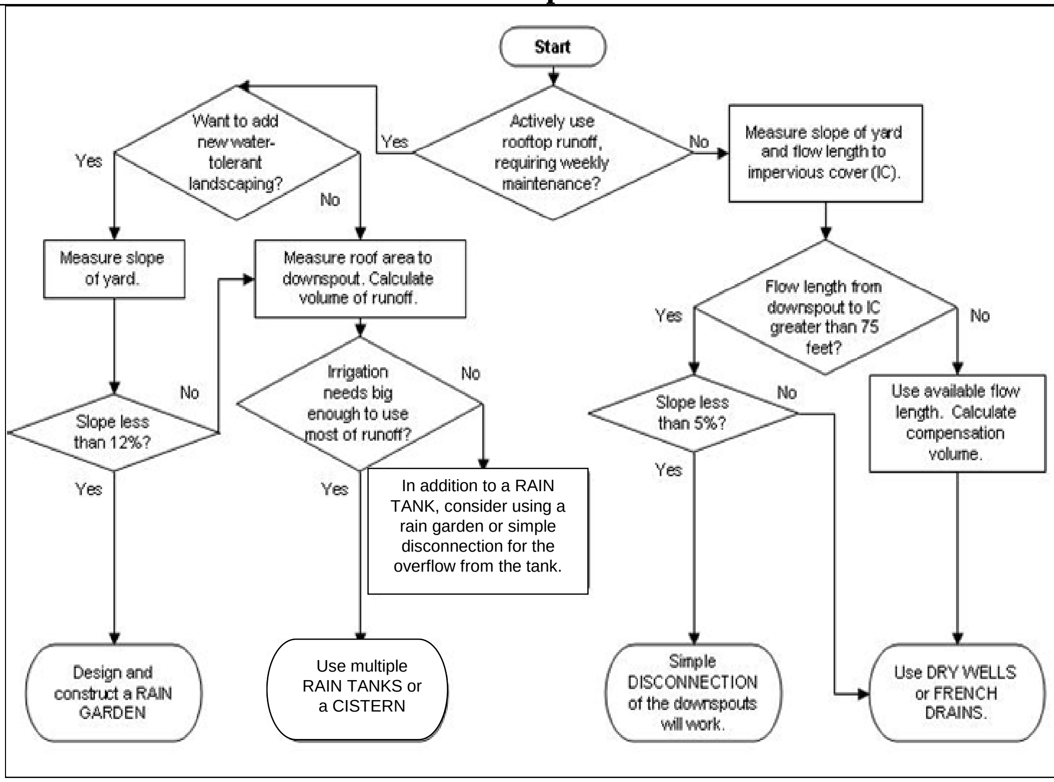

Figure E-1. Rooftop disconnection options.

Eligibility for Simple Downspout Disconnection (25 to 50% RR)

- Simple disconnection is only allowed for residential lots greater than 6000 sf. For lot sizes smaller than 6000 sf, disconnection with supplementary runoff treatment can be considered.
- The contributing flow path from impervious areas should not exceed 75 feet
- The disconnection length must exceed the contributing flow path
- If suitable soil amendments are provided (see Table E-2), the 50% runoff reduction rate for lawn runoff may be used for C/D soils
- A compensatory mechanism is needed if the disconnection length is less than 40 feet and/or the site has been mass-graded and has a Hydrologic Soil Group in the B, C or D category
- Pervious areas used for disconnection should be graded to have a slope in the 1 to 5% range
- The total impervious area contributing to any single discharge point shall not exceed 1000 square feet and shall drain through a pervious filter until reaching a property line or drainage swale
- The disconnection shall not cause basement seepage. Normally, this involves extending downspouts at least ten feet from the building if the ground does not slope away from the building

Disconnection with Soil Amendment (50% RR)

- See Table E-2
- If an amended lawn area does not receive any off-site runoff from impervious

Table E-4. Rooftop Disconnection
surfaces, a 75% runoff reduction can be used.[2]
Disconnection to Rain Garden or Dry Well (50% to 75% RR) • Depending on soil properties, roof runoff may be filtered in a shallow rain garden or infiltrated into a shallow dry well. • In general, these areas will require 10 to 15% of the area of the contributing roof area • An on-site soil test is needed to make the choice of what option to use. • The facility should be located in an expanded right of way or stormwater easement so that it can be accessed for maintenance. • For high density sites, front yard bioretention may be an attractive option
Disconnection to Rain Tanks or Cisterns (40% RR) • The practice for each of these devices depends on their storage capacity and ability to drawdown water in between storms for reuse as potable water, greywater or irrigation use. • Designers will need to estimate the water reuse volume, based on the method of distribution, frequency of use, and seasonally adjusted indoor and/or outdoor water demands for the building • Based on the prevailing climate for the region, a conservative runoff reduction estimate of 40% is recommended for initial design • Pretreatment measures may need to be employed to keep leaves, bird droppings and other pollutants from entering the tank or cistern • All devices should have a suitable overflow area to route extreme flows into the next treatment practice or stormwater conveyance system
[1] If the site is mass-graded, designers need to shift predevelopment HSG up one letter [2] The computation is not consistent with Version 1 of the BMP Planning spreadsheet (Appendix A); however future versions of the spreadsheet will resolve this discrepancy

Table E-5. Grass Channels
Description: The area draining to the grass channel (rooftop, driveway and sidewalk impervious cover and turf cover)
Computation: A 20% reduction in runoff volume is offered for combined turf and impervious cover draining to qualifying swales on A/B soils and 10% on C/D soils.
Eligibility: A qualifying grass channel meets the following criteria: • Primarily serves low to moderate residential development, with a maximum density of 4 dwelling units per acre • The bottom width of the channel should be between 4 to 8 feet wide. If suitable soil amendments are provided (see Table E-2), the 20% runoff reduction rate may be used for C/D soils • Swale side-slopes should be no steeper than 3H:1V

• The longitudinal slope of the channel should be no greater than 2%. (Checkdams or a terraced swale design may be used to break up slopes on steeper grades) • 5 acres maximum contributing drainage area to any individual grass channel • The dimensions of the channel should ensure that runoff velocity is non-erosive during the two-year design storm event and safely convey the locals design storm (e.g., ten year design event) • Designers should demonstrate that the channel will have a maximum flow velocity of one foot per second during a one-inch storm event
Note: Where feasible, the dry swale is always the preferable option due to its greater runoff reduction and pollutant reduction capability.

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APPENDIX G: DERIVATION OF EVENT MEAN CONCENTRATIONS FOR VIRGINIA

1. Introduction -- Adjusted Virginia Event-Mean-Concentrations

The Center for Watershed Protection (CWP) analyzed the National Stormwater Quality Database (NSQD) version 1.1 to compare Virginia and National Event Mean Concentrations (EMCs) derived for total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). Statistical trends were examined for the EMCs based on land use (residential/non-residential) and physiographic province (Piedmont/Coastal Plain). Table 1 provides the EMCs for Virginia, as well as the National EMCs for comparison. The following sections discuss the methods and implications of this analysis, as well as recommended EMCs for inclusion in Virginia's stormwater management program.

Table 1. National vs Virginia Event Mean Concentrations

Parameter	Median EMC (mg/L)
Total Nitrogen	
National	1.9
Virginia	1.86
Residential	2.67
Non-Residential	1.12
Virginia Coastal Plain	2.13
Residential	2.96
Non-Residential	1.08
Virginia Piedmont	1.70
Residential	1.87
Non-Residential	1.30
Total Phosphorus	
National	0.27
Virginia	0.26
Residential	0.28
Non-Residential	0.23
Virginia Coastal Plain	0.27
Virginia Piedmont	0.22
Total Suspended Solids	
National	62
Virginia	40

2. EMC Statistical Analysis

Virginia entries were separated from the NSQD and compared to the remaining entries in the database (NSQD – VA data). A significant percentage (approximately 22%) of the NSQD sites are located within Virginia, supporting the feasibility of the statistical comparison. The number of entries used in the statistical analysis is summarized in Table 2. A list of Virginia jurisdictions where NSQD data was available and utilized is included in Table 3. The following criteria were used to determine the entries included in the analysis:

- All sites that contained best treatment practices (BMPs) within their drainage areas were excluded from the analysis to obtain EMCs for untreated stormwater.

- Only observations above the detection limit for each pollutant were included.
- All sites located east of I-95 were considered coastal plain and sites located west of I-95 were considered Piedmont.

Table 2. Number of NSQD Entries

	Virginia	National (NSQD – VA entries)
# Total Individual Sites	78	282
# Sites with BMP Treatment	11	3
# Sites included in the Analysis	67	279
# Observations Included in the Analysis	753	2834
	Piedmont	**Coastal Plain**
# VA Sites Included in the Analysis	23	44
# VA Observations Included in the Analysis	150	603

Table 3. Virginia Jurisdictions within the NSQD

Jurisdiction	# Sites
Arlington	2
Chesapeake	7
Chesterfield County	9
Fairfax County	6
Hampton	7
Henrico County	6
Newport News	7
Norfolk	9
Portsmouth	5
Virginia Beach	9

Two statistical tests were used to determine if the Virginia EMCs were significantly different from National EMCs; Mann-Whitney (two-tailed) and one-way ANOVA statistical tests. The ANOVA was available from the Analysis Tools Add-In for Excel and the Mann-Whitney was set up as a spreadsheet in Excel. For both tests, p-values < 0.05 indicate that the samples are statistically different at the 95% or greater confidence level. P-values for the Mann-Whitney test are generally obtained from a critical values table for the test when the sample sizes are less than 20. However, sample sizes exceeded 20 for all of the EMC comparisons conducted as part of this analysis. For these large sample sizes, the Mann-Whitney was approximated by a normal distribution

(z) and the p-value was obtained from a standard normal curve area table. The results of the Mann-Whitney and ANOVA are provided in Tables 4, 5, and 6, and the calculations are provided in Appendix A. Land use included in this analysis included residential, non-residential (institutional, commercial, industrial, and freeway), and open space. Entries from mixed land use classifications were categorized according to the highest percentage land use in the drainage area.

Table 4. VA Comparison to National Data

Parameter	Mann-Whitney p-value	ANOVA p-value	Significant Difference Between VA and National Data	# VA Samples	# National Samples
TN	0.0366	0.000289	yes	664	2463
TP	0.2302	0.00262	ANOVA: yes Mann-Whitney: no	651	2368
TSS	<4E-04*	2.87E-17	yes	662	2603
Residential TN	<4E-04*	0.004514	yes	363	1002
Residential TP	0.002	0.000124	yes	399	967
Residential TSS	<4E-04*	2.88E-10	yes	400	1070
Non-Residential TN	<4E-04*	9.30E-22	yes	288	1277
Non-Residential TP	0.9204	0.464218	no	247	1221
Non-Residential TSS	<4E-04*	3.20E-07	yes	256	1347
Open Space TN	<4E-04*	0.454971	ANOVA: no Mann-Whitney: yes	13	184
Open Space TP	0.1616	0.62312	no	5	180
Open Space TSS	0.009	0.164779	ANOVA: no Mann-Whitney: yes	6	186

**Approximated from the highest value (z = 3.49) in a standard normal curve area table*

Table 5. VA Land Use Comparison

Parameter	Mann-Whitney p-value	ANOVA p-value	Significant Difference Between Land Use Data	# Residential Samples	# Commercial Samples
Residential/Non-Residential TN	4E-04*	3.73E-75	yes	363	288
Residential/Non-Residential TP	0.0238	0.295137	ANOVA: no Mann-Whitney: yes	399	247
Residential/Non-Residential TSS	0.61	0.733315	no	400	256
				# Residential Samples	**# Open Space Samples**
Residential/Open Space TN	4E-04*	9.59E-04	yes	363	13
Residential/Open Space TP	0.0702	0.175480	no	399	5
Residential/Open Space TSS	0.1096	0.338883	no	400	6
				# Commercial Samples	**# Open Space Samples**
Non-Residential/Open Space TN	4E-04*	2.15E-08	yes	288	13
Non-Residential/Open Space TP	0.1528	0.465171	no	247	5
Non-Residential/Open Space TSS	0.1528	0.246322	no	256	6

**Approximated from the highest value (z = 3.49) in a standard normal curve area table*

Table 6. VA Coastal Plain / Piedmont Comparison

Parameter	Mann Whitney p-value	ANOVA p-value	Significant Difference Between Coastal Plain and Piedmont Data	# VA Coastal Plain Samples	# VA Piedmont Samples
TN	<4E-04*	7.06E-09	yes	538	126
TP	0.0024	0.100758	ANOVA: no Mann Whitney: yes	522	129
TSS	0.0048	0.670342	ANOVA: no Mann Whitney: yes	531	131
Coastal Plain				**# Residential Samples**	**# Non-Residential Samples**
Residential/Non-Residential TN	<4E-04*	5.35E-73	yes	298	235
Residential/Non-Residential TP	0.0308	0.166395	ANOVA: no Mann Whitney: yes	324	198
Piedmont					
Residential/Non-Residential TN	<4E-04*	2.10E-22	yes	65	53
Residential/Non-Residential TP	0.6818	0.435501	no	75	49

**Approximated from the highest value (z = 3.49) in a standard normal curve area table*

The results show a significant difference between Virginia EMCs and National EMCs. Appendix B contains the median EMCs for all sample categories included in the statistical analysis. From the analysis, the following observations were made:

- VA has lower median EMCs for TN, TP, and TSS than the national data.
- Within VA, residential areas contain higher median TN, TP, and TSS EMCs than non-residential areas. Analysis of open space areas was disregarded due to limited data available in those locations.
- Within VA, the Coastal Plain contains higher median TN, TP, and TSS EMCs than the Piedmont physiographic region.
- TN- The following EMCs are significantly different within VA: residential/non-residential; Coastal Plain/Piedmont; Coastal Plain residential/non-residential; and Piedmont residential/non-residential.
- TP- The following EMCs are significantly different within VA: residential/non-residential; and Coastal Plain/Piedmont.
- TSS- While VA has lower median TN, TP, and TSS EMCs than the National median EMCs; no difference exists between residential/non-residential areas or Coastal Plain/Piedmont regions within the state. It is important to keep in mind that stream bank erosion is the main component of TSS within streams/rivers, as opposed to input from stormwater runoff.

3. Land Use loading Rates

The adjusted EMCs for Virginia were used to update previous land use loading rates (pounds/acre/year). Previous land use loading rates (Table 5-15 from the Virginia Stormwater Management Handbook) are presented in Appendix C, as well as updated rates based on the adjusted EMCs. The loading rates were computed using the Simple Method computation for Virginia by using residential and non-residential EMCs. Figures 1 and 2 show the original loading rates, as well as the adjusted loading rates for TN and TP.

Figure 1. Annual Total Nitrogen Load Calculated from the Simple Method

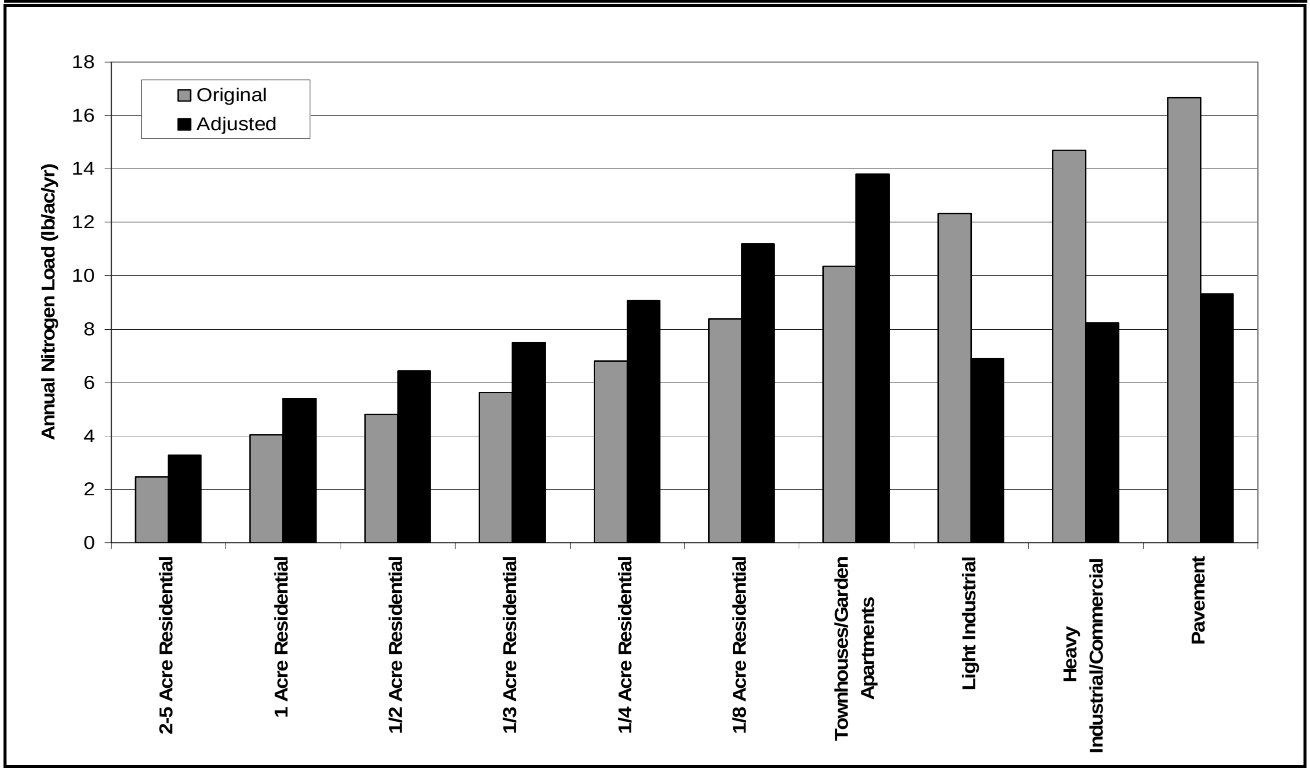
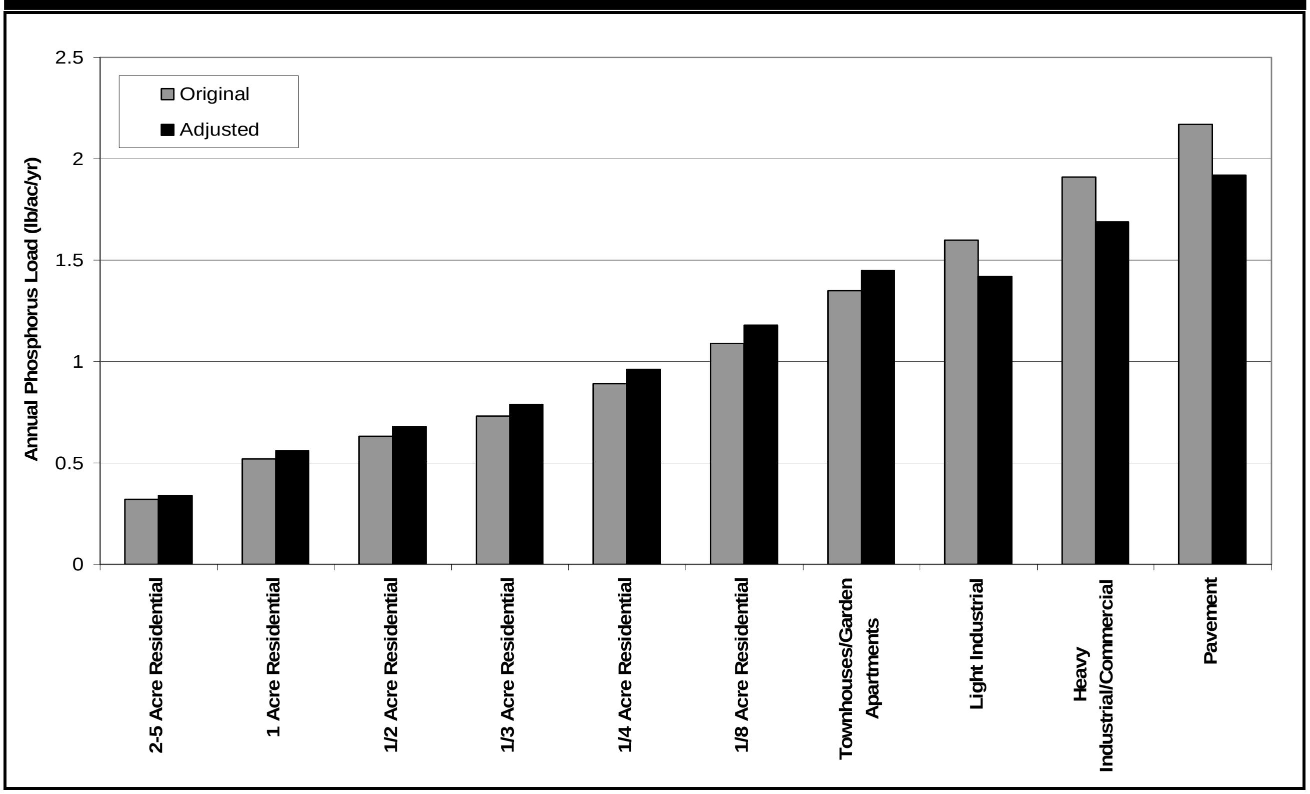


Figure 2. Annual Total Phosphorus Load Calculated from the Simple Method



4. Conclusions and Recommendation

Based on the statistical analysis, the options listed below for TN and TP are available for adjusting Virginia EMCs. As was previously mentioned, open space was not included in these recommendations due to the limited amount of data available for the statistical analysis. TSS was also disregarded because input from stormwater runoff is minimal in comparison to streambank erosion.

In Virginia, there is a statistically significant difference between residential and non-residential sites, particularly for TN. This provides justification for using different EMCs for the two categories of land use. Since the EMC for non-residential is lower, it also means that commercial sites have somewhat of a compliance "handicap," which is balanced by their generally higher levels of impervious cover.

Total Nitrogen
Option 1: Virginia Residential and Non-Residential EMCs – National EMCs were not considered an option based on the statistical analysis results that Virginia TN EMCs are significantly different than the National TN EMCs.
Option 2: Virginia Coastal Plain/Piedmont Residential and Non-Residential EMCs – While this option is statistically supported, it results in four EMC options and may be too complicated for utilization. The Piedmont also results in a lower standard and there may be equity problems with having Piedmont and Coastal Plain sites achieve different standards. Finally, since there is no data from the "mountain" physiographic provinces, there is no basis to recommend an EMC for those areas other than the State-wide numbers.

Total Phosphorus
Option 1: National EMC
Option 2: Virginia EMC
Option 3: Virginia Residential and Non-Residential – The national data provides justification that residential TP is greater than non-residential TP. This option would provide an incentive for compliance.

The recommended approach is to use Virginia residential and non-residential EMCs for both TN and TP due to the feasibility of implementation and the supporting data in the analysis.