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	75th 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.

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.

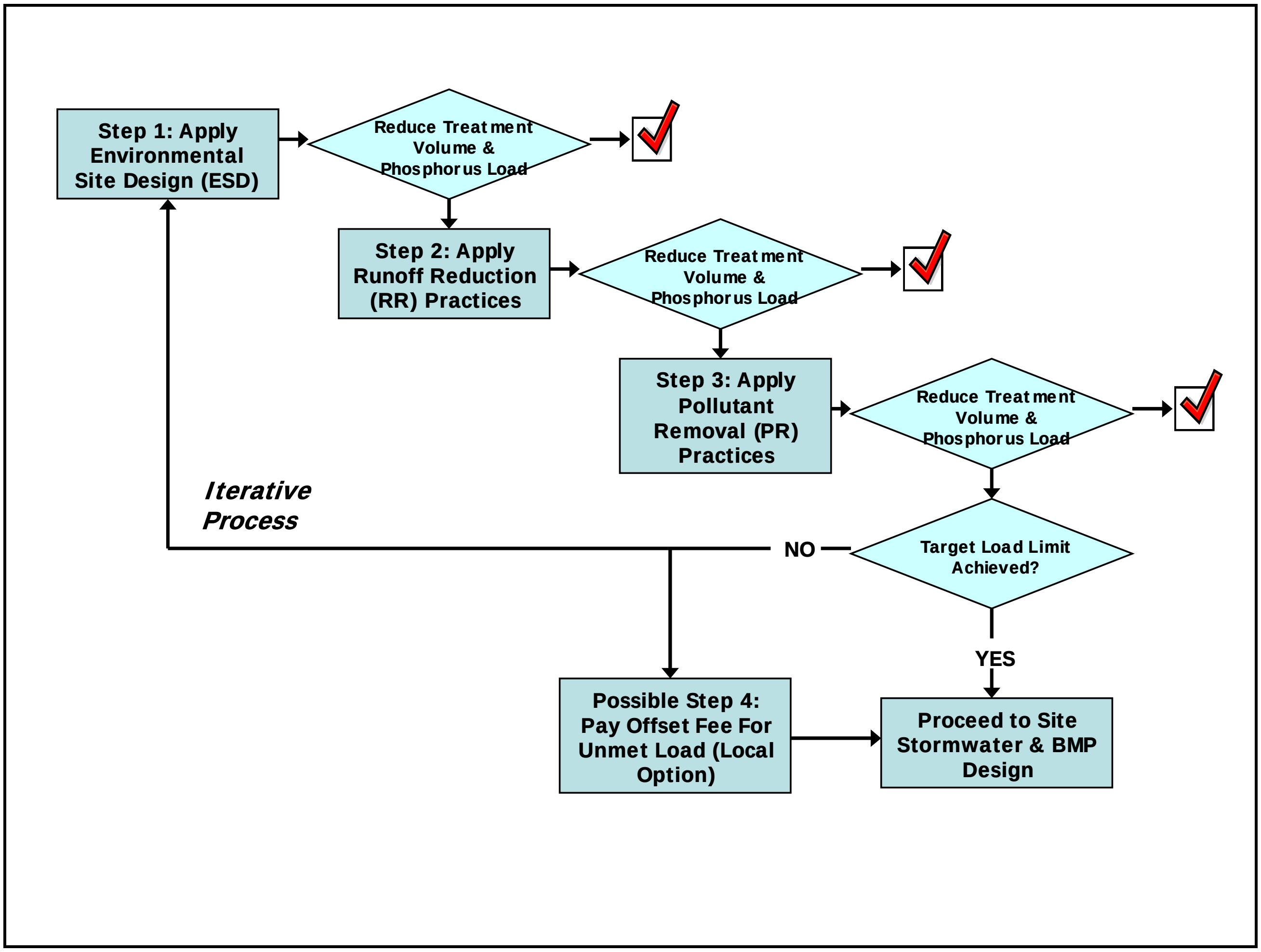

Figure 1. Step-Wise Process for Site Compliance

<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.

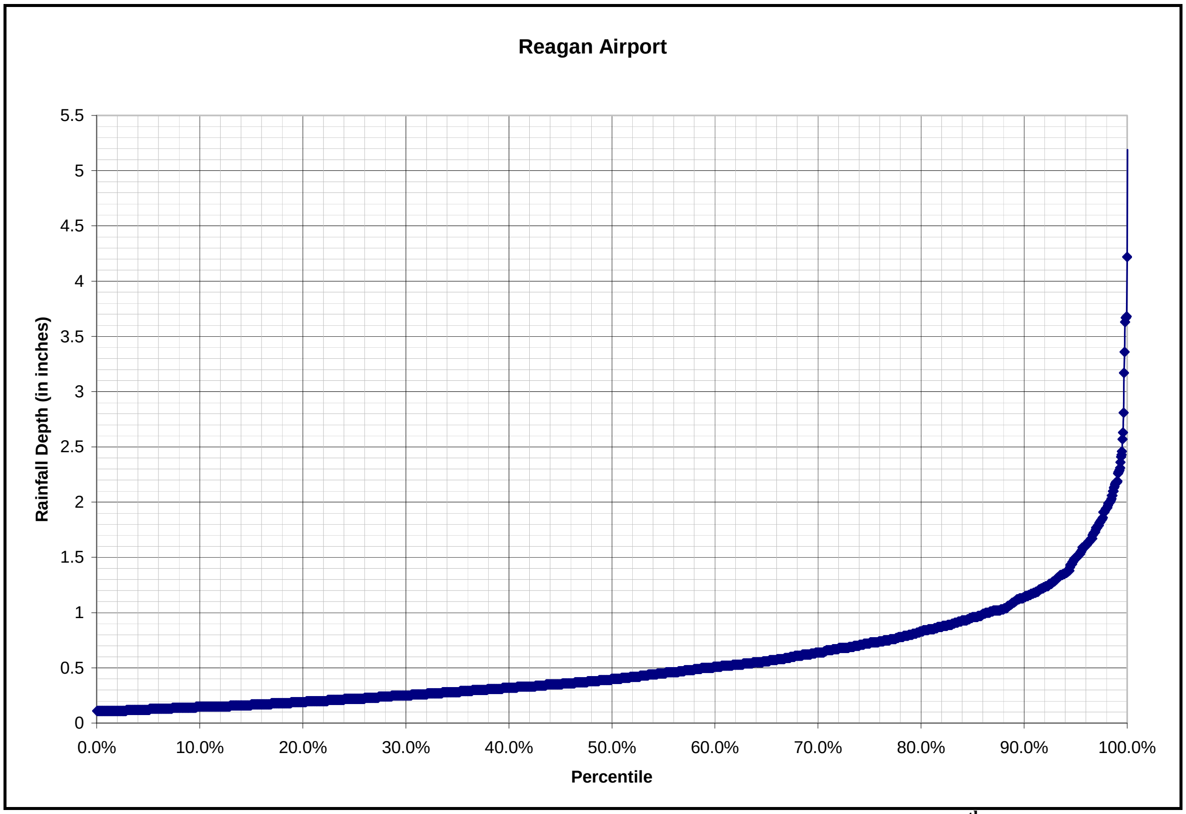

Figure 2. Rainfall Frequency Curve for Reagan Airport in Washington, D.C. The 90th percentile storm event is slightly more than 1" (DeBlander, et al., 2008).

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 75th 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