I. Introduction

In 2015, HJR 587 requested that DEQ perform a two-year study of the application of the postdevelopment stormwater management technical criteria, as established in the Virginia Stormwater Management Program (VSMP) Regulations, in areas with a seasonal high groundwater table (SHGT). The Phase I report was submitted by DEQ to Governor McAuliffe and the General Assembly.[1] This current report highlights the conclusions reached following the completion of Phase II of the study.

The Phase I report presented a seasonal high groundwater table (SHGT) used in stormwater management in Virginia as "the shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (more than a few weeks)."[2] Background information was presented within the report concerning VSMP Regulations and the use of best management practices (BMPs) to meet the regulations. For example, the report explains that under the VSMP Regulations, the total phosphorus (TP) mass load from a post-constructed development site must be equal to or less than 0.41 pounds per acre per year (9VAC25-870-63). The report also described the relationship between the quality and quantity VSMP requirements, environmental constraints on BMP performance, made initial comparisons among state stormwater management approaches, and offered other compliance options. The Phase I report provided direction for the second-year of the study, citing that additional investigation would take place.

This report summarizes the work completed during the second year of the study. This effort included a continued search and study of the scientific literature as well as stormwater design manuals used in other states. The literature search helped DEQ to better understand issues associated with a SHGT and formed the basis for the agency's recommendations regarding the application of postdevelopment stormwater management technical criteria in areas with a SHGT.

The report describes the importance of understanding site characterizations, such as surface and subsurface hydrologic properties, and the use of that information for utilizing Environmental Site Design (ESD) and BMPs to meet stormwater management goals. The report includes a discussion of the possible uses of site-specific information in areas with a SHGT, including hydrologic information utilized in North Carolina to reduce the needed separation distance between a BMP and the SHGT. It also provides examples of BMPs used in other states, but not currently approved for use in Virginia, proposed design modifications for BMPs listed on the Virginia Stormwater BMP Clearinghouse, and suggested possible adjustments of BMP efficiencies. The report explains the logic needed to design effective treatment trains and highlights the possible development of a comprehensive stormwater management plan to meet the water quality and quantity objectives of the VSMP Regulations. The report concludes with recommendations by DEQ regarding future efforts to address stormwater management in areas with a SHGT.

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[1] *Application of the Postdevelopment Stormwater Management Technical Criteria, as Established in the Virginia Stormwater Management Program Regulations, in Areas with a Seasonal High Groundwater Table,* available at http://leg2.state.va.us/dls/h&sdocs.nsf/By+Year/HD22016/$file/HD2.pdf
[2] *Virginia DEQ Stormwater Design Specification No. 8: Infiltration Practices*

II. Site Considerations

Site Characteristics

It is important to know the environmental properties of the site. Understanding the local hydrogeology is essential in determining the benefits of ESD and which types of BMPs will function effectively. Both surface and subsurface hydrologic properties affect the type and placement of various BMPs used for compliance with the VSMP Regulations. For example, the function of infiltration BMPs is dependent on the movement of stormwater runoff through the BMP into the unsaturated zone underlying the practice. Pollutant removal and stormwater runoff volume reduction occur within the BMP and the underlying unsaturated zone. Treatment and runoff reduction processes will, however, be limited in infiltration BMPs if the unsaturated zone is shallow, as is often found in areas with a SHGT. Under such conditions, pollutants of concern can be transported to groundwater and nearby wells or stream channels. BMPs can also become saturated by groundwater, thereby limiting their treatment effectiveness. These factors make it imperative that site soils and subsoils are adequately identified and site hydrology is understood so that the function and treatment effectiveness of the selected BMP remains intact and the assigned removal credits continue to be achievable.

Site designs are developed for VSMP water quality compliance based on numerous site characteristics. These characteristics include, but are not limited to, topography, existing land cover, surface soils, and subsurface properties. Proper identification and analysis of surface soil properties provide a means to calculate soil and subsoil infiltration capacity. A thorough evaluation of the land surface and subsurface, in the form of a soil investigation, is required at the site of the proposed BMP to properly identify and determine soil properties, morphology, permeability, infiltration capacity, and depth to groundwater table or water impermeable layer (e.g., bedrock).

The unsaturated soils may also require field testing in order to determine the hydrologic soil group (HSG) for areas where the upper layer soils have been disturbed or are identified in the NRCS Soil Survey as “urban land,” meaning the site has been previously disturbed by construction activities. The HSG is used in stormwater calculations. The HSG designation is one of the parameters used in estimating the amount of stormwater runoff generated from a site and is used for calculating the TP loading. The HSG is partly determined by the soil layer with the lowest saturated hydraulic conductivity located between the surface and the groundwater table or impermeable bedrock layer. Site specific soil morphology data are identified at various depths to determine the HSG. If this parameter is estimated and not verified, the BMPs may be over or under designed for the site.

A geotechnical investigation typically includes the excavation of a soil pit, which enables depth determination of various soil layers, and extraction of samples for laboratory infiltration testing (Figure 1). Soil data are collected starting from the surface down to a designated distance. New Jersey, for example, requires test pits to be greater than 8 feet or twice the maximum water depth in the BMP (NJ BMP Manual). Soil data can then be collected and analyzed for each individual soil layer. Soil borings at various locations throughout the site are performed to check for soil profile consistency. This approach is used to identify the most restrictive soil layer and to determine the location of the SHGT or impermeable layer.

Environmental Site Design

In Virginia, TP is the regulated pollutant in stormwater and is to be managed so that no individual project site releases TP loads in excess of the regulatory threshold. The most effective method for removing TP and reducing runoff volume is to prevent stormwater runoff in the first place. This concept is the foundation for the design process known as ESD. In reviewing many stormwater programs throughout the United States, the minimization of impervious cover and disturbance, and the preservation of natural soils and vegetation within a given site is the first step in reducing the dependence on BMPs to manage stormwater quality and quantity. By understanding the natural environmental characteristics of a site and designing a project to work with pre-development hydrology, BMP design constraints and site restrictions become less of a concern. ESD should be considered for all projects, but it is most important in areas where infiltration BMPs will be of limited use because of high groundwater or soils with low infiltration capacity.

ESD and the preservation of natural features such as wetlands, forests, natural drainage features, undisturbed soils, and open space are all constructive steps for minimizing the impact of development. By applying ESD techniques, stormwater impacts will be minimized, thus reducing the type, size, and number of BMPs needed for VSMP compliance.

BMP Selection

BMPs that can be used to meet the VSMP Regulations are listed on the Virginia Stormwater BMP Clearinghouse[3] and include 15 non-proprietary practices and nearly 30 proprietary practices. The Virginia Stormwater BMP Clearinghouse also includes the standards and specifications for each of the listed non-proprietary BMPs for use in complying with the VSMP Regulations. As part of the specifications, each BMP is assigned TP pollutant removal (PR) efficiency and volume reduction (RR) credits. These two removal credits provide a mass load TP removal percentage for each BMP.

Not all BMPs are suitable for use at all sites (refer to the individual BMP standards and specifications for guidance on the feasibility of the practice and design adapts to specific regional situations). Environmental site constraints, such as a SHGT, limit the performance capability of some BMPs. In order to select an appropriate BMP for a site, it is necessary to understand both the functionality of the BMP and the characteristics of the site.

BMPs can be grouped by treatment mechanism: infiltration, filtration, and sedimentation practices.

- Infiltration practices are those BMPs that allow stormwater to percolate into native soils after filtering through a medium, such as sand or organic materials.

[3] http://www.vwrrc.vt.edu/swc/

- Filtration practices also treat stormwater runoff by passing it through a medium, such as sand or organic materials.
- Sedimentation practices, such as wet ponds and constructed wetlands, slow down the runoff flow and allow the particulates to settle out of suspension.

Infiltration practices may not function as intended in areas with a SHGT. With infiltration BMPs, stormwater exfiltrates from the BMP into the unsaturated soil zone below the practice. Additional physical, biological, and chemical processes occur within this unsaturated zone that can further treat stormwater. For example, pollutants can adsorb to soil particles, thereby preventing their migration to groundwater and surface waters. Bacterial action can alter some constituents, essentially removing these constituents from the system. Plant roots extending below infiltration BMPs can take up dissolved nutrients coming from runoff. Oxidation-reduction reactions can chemically alter pollutants which may change adsorption properties in soil or pollutant bacterial uptake, thus affecting pollutant mobility and consequent potential impacts. Without a buffer between the bottom of the BMP and the groundwater table, many pollutants will not have the opportunity for these processes to occur within the unsaturated zone, and thus the pollutants will be transported directly to the groundwater table.

III. Discussion

BMP Minimum Separation Distance from the SHGT

Maintaining a sufficient separation distance between the bottom of infiltration BMPs and the SHGT is necessary for the following reasons:

- Proper BMP functionality for treating pollutants in stormwater,
- Sufficient hydraulic gradient so stormwater can flow from the practice to the subsurface for volume reduction,
- Protection of groundwater quality, and
- Prevention of pollutant introduction to a downgradient stream system.

For most practices that require a separation distance between the bottom of the BMP and the water table, Virginia assigns a minimum distance of 2 feet. Other states (e.g., Minnesota, New Jersey), where groundwater protection and volume recharge are the key issues addressed through stormwater regulations, require 3 feet of separation.

Two perspectives critical in assessing the importance of this separation distance are as follows: (1) The function of the BMP in terms of pollutant removal and volume reduction; and (2) The protection of groundwater from stormwater pollutants. Both perspectives consider the interaction of the BMP with surrounding native soils.

SHGT and BMP Pollutant Reduction

The PR credit of the VRRM assumes that pollutants removed by the BMP are retained in the practice or converted to non-harmful by-products that leave the system. Runoff treated by infiltration BMPs flows through the practice into the underlying unsaturated zone, where additional treatment (e.g., adsorption, oxidation-reduction, decomposition) can occur. If the unsaturated zone is shallow (e.g., less than 2 feet), the opportunity for additional treatment processes is limited, and the likelihood of groundwater contamination increases.

The RR component of the VRRM mass load is mainly dependent on the volume of stormwater retained in the practice and the volume that is infiltrated to subsurface soils. Other volume losses occur through evaporation, transpiration, and interception. BMPs that mainly depend on infiltration for volume reduction (e.g., bioretention, permeable pavement, infiltration facilities) may not achieve the assigned volume reduction credit because the minimum separation distance is not maintained. The separation distance can vary throughout the year and during storm events. During rainfall events small amounts of water can quickly fill up naturally occurring void space in the unsaturated zone and lead to saturation. In these cases, flow to the BMP practice will stagnate and will become saturated. This saturation condition within the BMP can change the physical, chemical, and biological processes occurring within the practice and will also compromise the integrity of the BMP.

Also occurring during rainfall events is a process known as groundwater mounding. Mounding can occur where infiltrating water intersects the groundwater table at a rate faster than the groundwater flow can carry the water away. This mounding can occur below any given infiltration BMP. The height of the mound can vary depending on the hydraulic characteristics of the subsurface soils and the initial separation distance between the BMP and water table. It is possible for the mound to extend into the BMP, which would cause saturation of the BMP. Mounding also causes the vertical direction of flow to change to a horizontal flow. This alteration of the hydraulic gradient can dislodge trapped stormwater pollutants and transport them down gradient to receiving streams or wells.

BMP Minimum Separation Distance from SHGT and Groundwater Protection

With infiltration BMPs, migration of pollutants into the underlying aquifer is possible. The larger the separation distance between the BMP and the groundwater table, the greater the opportunity for additional treatment to occur. Conversely, if sufficient separation distance between the practice and the water table is not maintained, the likelihood of groundwater contamination rises. In reviewing many stormwater management manuals, the concern for groundwater contamination from stormwater runoff is highly emphasized and is discussed prior to any discussion of using infiltration type practices.

In Virginia, total phosphorus was selected as the pollutant of concern in stormwater runoff, in part, because it is often the limiting nutrient in surface waters and because it occurs substantially in particle-bound form. Controlling phosphorus levels can also directly limit excessive algal growth in receiving streams, account for concurrent nitrogen removal through terrestrial biological update, and control other particle-bound pollutants. By using phosphorus as the regulatory target pollutant, it is assumed that other pollutants such as metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and microbes will also be removed. TP may not be the stormwater pollutant of most concern in terms of groundwater contamination. For example, algal blooms are not a concern within the dark aquifer environment where sunlight does not reach. Because aquifers are often a source of drinking water, contaminants in groundwater with higher toxicity for human health (e.g., bacteria, lead, and nitrates) can be of much greater concern compared to TP. TP has no drinking water criteria. It should be noted that groundwater does contribute to surface waters so groundwater contaminated with dissolved phosphorus can be a source of phosphorus to surface waters.

Comparison of Groundwater Separation Distance Requirements: Virginia and North Carolina
Virginia's non-proprietary BMP requirements for minimum separation distance from the SHGT and the exceptions to the requirements were compared to those in North Carolina (Table 1; NCDEQ 2016, VDEQ 2011). Although each state sometimes recommends somewhat different designs or gives BMPs somewhat different names, we have attempted to compare functionally equivalent BMPs. This comparison of the requirements in Virginia with those in a neighboring state with similar climate and SHGT characteristics provides additional information for DEQ to consider as it makes recommendations on revisions to Virginia's minimum separation distance requirements.

There are five practices that do not have SHGT separation distance requirements in either Virginia or North Carolina: (1) vegetative filter strips, (2) green roofs, (3) rainwater harvesting, (4) constructed wetlands, and (5) wet ponds. All five practices are classified as "preferred" or "acceptable" for use in the Coastal Plain by the Chesapeake Stormwater Network[4] (Schueler 2009). In Virginia, however, designers must consider the depth to the SHGT for sheet flow to conserved open space and vegetative filter strips, but the design specifications for this practice (No. 2) do not mention a specific depth requirement.

Four practices require at least a 2-foot separation from the SHGT in both Virginia and North Carolina: (1) permeable pavement,[5] (2) infiltration, (3) bioretention, and (4) filtering practices. North Carolina makes a distinction between permeable pavement designed to infiltrate the design storm and permeable pavement not intended for infiltration; the practice without significant infiltration requires a minimum separation distance from the SHGT of only 1 foot. Similarly, North Carolina separates its sand filters based on their infiltration capabilities. Sand filters with closed bottoms, those not designed for infiltration, only require a 1 foot separation from the SHGT.

In general, Virginia places more restrictions on the minimum separation distance than does North Carolina. Virginia requires a minimum 2-foot separation distance from the SHGT for four BMPs that North Carolina requires less than 2 feet of separation: (1) rooftop disconnection, (2) grass channels, (3) soil amendments, and (4) extended detention ponds. North Carolina does not require any separation distance for disconnected impervious surfaces and soil amendments. For

[4] The Chesapeake Stormwater Network is a well-respected nonprofit corporation that seeks to improve implementation of more sustainable stormwater management and environmental site design practices in each of 1,300 communities and seven states in the Chesapeake Bay Watershed.
[5] North Carolina's permeable pavement design relies on an underdrain with an upturned elbow to promote detention of stormwater within the practice. Virginia's permeable pavement design requires an underdrain but does not include the creation of a detention area.

grass swales, North Carolina only requires that they not be excavated below the SHWT, and extended detention ponds in North Carolina need only a 6 inch separation from the SHWT.

Table 1- Required separation distance between the best management practice and the seasonal high groundwater table (SHGT) in Virginia and North Carolina.

Practice	Va. Minimum SHGT Separation Requirement (feet)	Va. SHGT Separation Exceptions (feet)	NC Minimum SHGT Separation Requirement (feet)	NC SHGT Separation Exceptions (feet)
Rooftop Disconnection (Va.) / Disconnected Impervious Surface (NC)	2	NA	NA	NA
Sheet Flow to COS/VFS[a] (Va.)/ Level Spreader & VFS (NC)	NA[b]	NA	NA	NA
Grass Channels (Va.) / Grass Swales (NC)	2	1[c]	>0	NA
Soil Amendments	2	NA	NA	NA
Green Roofs	NA	NA	NA	NA
Rainwater Harvesting	NA	NA	NA	NA
Permeable Pavement (PP) (Va.) / PP – Infiltration (NC) PP – Detention (NC)	2	NA	 2 1	 1[d] NA
Infiltration	2	NA	2	1[e]
Bioretention	2	1[f]	2	1[g]
Dry Swales	2	1[h]		
Wet Swales	0	NA		
Filtering Practices (Va.) / Sand Filter – Open Bottom (NC) Sand Filter – Closed Bottom (NC)	2	1[i]	 2 1	 NA <1[j]
Constructed Wetlands	NA	NA	NA	NA
Wet Ponds	NA	NA	NA	NA
Extended Detention Pond	2	NA	0.5	NA

NA = not applicable; empty cells indicate that the state does not have an equivalent BMP.
[a] COS = Conserved Open Space, VFS = Vegetative Filter Strip
[b] The designer must consider the depth to the water table. Shallow water tables may inhibit the function of vegetated filter strips.
[c] In the Coastal Plain, the minimum depth from the swale invert to the seasonally high water table should be 12 inches.
[d] If applicant provides a soils report prepared by a licensed professional that demonstrates that the modified soil profile allows for infiltration of the design volume within 72 hours.
[e] If the applicant provides a hydrogeologic evaluation prepared by a licensed professional that demonstrates that the water table will subside to its pre-storm elevation within five days or less.
[f] In coastal plain residential settings if the bioretention area is equipped with a large-diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the bed.
[g] If the applicant provides a hydrogeologic evaluation prepared by a licensed professional.
[h] If the dry swale is equipped with an underdrain.
[i] If the filter is equipped with a large diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the filter bed.
[j] If a licensed professional provides documentation that the design will neither float nor drain the water table.

Additionally, the separation exceptions granted in Virginia are more general, whereas the ones in North Carolina are site specific. The exceptions allowed in Virginia are either based on geographic location, i.e., the Coastal Plain, or the use of an underdrain (the exception may specify a large-diameter underdrain that is only partially efficient at dewatering the media bed). In North Carolina, a separation exception is allowed for a site when additional information prepared by a licensed professional supports the allowance.

Alternatives to Infiltration BMPs

The challenge of finding subsurface conditions in areas with a SHGT that are appropriate for infiltration practices means that stormwater practitioners need to consider alternatives that do not depend on infiltration. In addition to incorporating ESD to the maximum extent possible, site designers should consider the use of BMPs that do not rely on infiltration into the ground. There are five non-proprietary BMPs approved for use in Virginia that meet this goal: green roofs, rainwater harvesting, wet swales, constructed wetlands, and wet ponds. These BMPs generally offer substantial total mass load removals for TP, from 45% (for level-1 design green roofs and wet ponds) up to 90% for rainwater harvesting. Among these BMPs, only wet swales have a relatively low TP reduction credits, 20% for level-1 design and 40% for level-2 design. These five BMPs are also listed as "preferred" or "acceptable" practices for use in areas with a SHGT in *Technical Bulletin No. 2: Stormwater Design in the Coastal Plain of the Chesapeake Bay Watershed* by the Chesapeake Stormwater Network (CSN). In addition, certain manufactured treatment devices can be used, provided that any requirements for a separation distance from the water table can be achieved in areas with a SHGT.

In recent times, Virginia has allowed the use of bioretention, dry swales, and permeable pavement in areas with a SHGT. This exception has been allowed for Level 1 designs because the practice is providing the reduction and is not dependent on exfiltration into the native soils. This type of design requires an impermeable liner, uplift calculations, an underdrain, and a possible French drain system located below the liner.

<u>*Additional BMPs*</u>

The pollutant removal (PR) and volume reduction (RR) credits for the 15 non-proprietary BMPs are listed on the Virginia Stormwater BMP Clearinghouse. These credits were based on the research at the time of posting. For non-proprietary BMPs, the PR and RR efficiencies were based on research published in 2008 or earlier. The reviewed studies are cited in *Technical Memorandum: The Runoff Reduction Method* published by the Center for Watershed Protection (CWP 2008).

Since the 2008 technical memorandum was published by the CWP, the design and testing of non-proprietary BMPs not included in the memorandum has taken place, and other states are incorporating some of these BMPs into their respective handbooks. A deeper review of the technical information for these practices has been initiated and may provide new BMP options for use in Virginia.

Additionally, Virginia has established a temporary process for the approval of proprietary BMPs along with the assignment of a PR credit for each. Currently, Virginia has 16 hydrodynamic manufactured devices and 12 filtering manufactured devices approved for water quality compliance in Virginia. The review of proprietary BMP applications for inclusion on the Virginia Stormwater BMP Clearinghouse is ongoing, and adjustments to the PR credits already awarded are made as new information is reviewed and approved by DEQ.

The following sections will provide a list and description of some BMPs that could potentially be added to the clearinghouse.

Tree BMPs

The tree BMP is a bioretention practice that includes *tree trenches* and *tree pits*. A tree trench utilizes multiple trees growing in a soil medium that typically has pavement overlaying the root system of the trees. Runoff is delivered to the underlying media in which the trees are planted. A tree pit, also called a tree box, usually incorporates a single tree into a bioretention cell or within proprietary media. A tree BMP can be used as a stand-alone practice or as part of a treatment train.

Tree BMPs capture and treat stormwater runoff through various means. The tree canopy reduces the volume and velocity of precipitation as it moves through the branches (a process known as interception). When trees capture precipitation on their leaves and branches, the precipitation can either evaporate into the atmosphere or run down the tree to the ground, which lessens the impact of the storm. Leaf litter and tree roots promote the infiltration of precipitation into the soil. Tree roots also take up water and the constituents found in stormwater (e.g., nutrients). Trees utilize the absorbed water for photosynthesis and eventually transpire some of it back into the atmosphere, thereby removing it from the storm sewer system. Furthermore, by utilizing nutrients in stormwater, trees contribute to pollution reduction (EPA 2013).

In addition to providing stormwater treatment, tree BMPs provide other community benefits that make them attractive as a practice. The tree BMP also helps clean the air, reduce noise pollution, serve as windbreaks, and provide shade (EPA 2013).

Tree BMP Design

Minnesota has approved the use of tree BMPs for treating stormwater for regulatory compliance. The Minnesota Stormwater Manual (MPCA 2016; available at https://stormwater.pca.state.mn.us/index.php?title=Main_Page) provides most of the design and crediting information given here. As a bioretention practice, a tree BMP is classified as an "infiltration/filtration" practice in Minnesota. Pretreatment is required for all bioretention practices, including tree BMPs. Minnesota requires tree BMP media to have infiltration rates between 1 and 4 inches per hour, and the Minnesota construction general permit requires a drawdown within 48 hours for tree BMPs (drawdown time represents the period from which stormwater is captured by a BMP until it drains into the underlying soil) (MPCA 2016).

In Minnesota, tree BMPs can be used with or without an underdrain depending on the permeability of the underlying soil. An underdrain removes excess water from the bottom of the cell and returns it to the storm drainage system. The underdrain may be elevated within the tree BMP to create internal water storage, which encourages infiltration into the surrounding soils. At some sites, an impermeable liner may be needed around the bioretention cell to protect adjacent retaining walls, building foundations, or other structures. In Minnesota, a three foot separation is required between the bottom of the BMP and the SHGT (MPCA 2016), but EPA (2013) cautions that sites where the SHGT is less than four feet from the surface may not be suitable for tree BMPs.

The Minnesota Stormwater Manual provides information regarding many different tree species. The tables can help designers select the most suitable species for use with tree BMPs at a given site in Minnesota (MPCA 2016; available as an Excel spreadsheet at https://stormwater.pca.state.mn.us/index.php?title=Main_Page). The tables of information cover such characteristics as tree size, growth rate, moisture and sun requirements, tolerance to stress (inundation, salt, hardiness), pH requirements, etc.

Space limitations, above and/or below ground, are often the primary constraint on the use of tree BMPs. For example, the tree canopy may conflict with utilities, signs, lighting, or structures, or tree root growth may be limited by structures, pavement, or utilities.

Tree BMP Soil Media

Trees need adequate soil volume to grow to maturity and thrive. Lindsey and Bassuk (1991) estimated that trees need 2 cubic feet of soil for every square foot of tree canopy. Thus, trees in a 6 foot by 6 foot tree pit with a 2 foot depth have only 72 cubic feet of available rooting soil, which is only enough soil to support a small tree (e.g., a tree with a canopy radius of 5 feet) (MPCA 2016). Large trees, which provide more benefits than small trees, can easily require more than 1,000 cubic feet of soil (EPA 2013, MPCA 2016).

It is possible to protect soil under the pavement from compaction so that it is suitable to support tree growth. Soil protection can be accomplished through *structural cells* or *structural soil* (rock-based or sand-based).

- Suspended pavement relies on pillars, piles, or structural cells to support the pavement (suspend the pavement) while allowing the created void space to be filled with soil media. Because the pavement is supported by the installed structures, the soil under the pavement is not compacted and can therefore be utilized by tree roots. Structural cells are strong enough to support large vehicles with 3-4 axles. The Minnesota Pollution Control Agency (MPCA) recommends a soil depth of at least 34 inches and at least 1,536 cubic feet of soil within structural cells to support each mature tree with a 30 foot diameter canopy (MPCA 2016).
- Structural soils are typically rock-based and are engineered to be compacted enough to support foot traffic, parking lots, and low-use roads while maintaining adequate pore spaces to allow root growth. The rock base is coated with soil media, a necessary component for tree health. Day and Dickinson (2008) provide design specifications for structural soils. The Minnesota Stormwater Manual estimates that twice the volume of underground space (up to 2,826 cubic feet) may be needed to support a tree using structural soils compared to the same tree growing in sandy loam soil with no pavement above the rooting space (1,413 cubic feet) (MPCA 2016).

Sand-based structural soils have also been developed, although the Minnesota Stormwater Manual (MPCA 2016) cautions that the amount of settling reported to occur (0.75 inches in 3 years; Couenberg 1993) may not be acceptable for many localities.

Minimal Impact Design Standards (MIDS)

The MPCA developed the MIDS calculator to estimate credits for volume reductions and annual pollutant load reductions for TP and TSS. The credits can be used by local stormwater authorities in Minnesota to provide incentives for preserving open spaces, comply with antidegradation requirements, or comply with TMDL waste load allocations. The calculator was based on information obtained from available literature. The Minnesota Stormwater Manual acknowledges limited information in the literature for pollutant removal by tree BMPs, however, general trends were found. High load reductions were consistently reported for tree BMPs for the following constituents: TSS, metals, polycyclic aromatic hydrocarbons (PAHs), and other organic compounds. Nutrient removal results were more variable (MPCA 2016).

The Minnesota MIDS calculator can be used for either tree trenches or tree boxes. The MIDS calculator can estimate values for tree BMPs with or without an underdrain and with or without an internal water storage zone. The MIDS calculator uses an Excel spreadsheet to determine these values based on information given by the user for a specific site. The Minnesota Stormwater Manual provides and explains the equations used by the MIDS calculator to determine the results (MPCA 2016).

The volume credit awarded by the MIDS calculator for tree BMPs is based upon estimations of interception, ET, and infiltration. The amount of credit depends on whether or not an underdrain is used to transport treated runoff that did not infiltrate into the surrounding soils to the storm sewer system and/or a liner is used along the bottom and sides of the cell to protect adjacent structures (MPCA 2016).

TSS and TP reduction credits generated by the MIDS calculator are based on mass load reductions so depend on both the volume of runoff and event mean concentrations of the pollutants. The MIDS calculator uses 65% removal for TSS. Phosphorus credits are more complicated to estimate. The TP load is comprised of particulate phosphorus (PP, which represents 55% of the TP) and dissolved phosphorus (DP, which represents 45% of the TP; Erickson et al. 2012). The assigned removal rates for these two constituents depend on the answers provided by the user about the soil media, including the P content of the media and amendments added to the media. For example, phosphorus may leach out of the soil media and increase the amount of phosphorus leaving the system instead of reducing it. Media with a low P content (< 30 mg/kg) is less likely to leach P so is assigned a higher reduction credit (80% of the particulate fraction) than is media with high P content (0%). In contrast, media treated with phosphorus sorbing amendments can receive additional DP credits (40% for the dissolved fraction). Iron filings (if >5% by volume) and water treatment residuals (if >5% by weight to a depth of 3.9 inches) are two types of amendments that can be used to increase the DP credit used in the MIDS calculator (MPCA 2016).

Regenerative Stormwater Conveyance (RSC) BMP
An innovative BMP that can be used to comply with stormwater permits in Maryland is referred to in this report as “regenerative stormwater conveyance” (RSC) (Maryland DEQ 2014). This practice also goes by several other names, such as “regenerative step pool storm conveyance,” “biofiltration conveyance,” and “coastal plain outfalls” (Cizek 2014, Flores et al. 2012).

RSC is an open channel conveyance system with a series of constructed pools and/or riffles that attempt to mimic stream flow found in undeveloped areas. Low in-stream weirs can be used to slow the flow of water, help it spread into the floodplain, and encourage sedimentation. A mixture of sand and wood chips underlay the system to promote filtration, and vegetation growing within the system provides additional treatment. The system is designed to follow the natural flowpath. Stormwater runoff that enters the RSC is conveyed as both surface flow and shallow groundwater flow (Flores et al. 2012, West Virginia DEP 2012).

The Anne Arundel County, Maryland design guidelines, used in Maryland and proposed for use in West Virginia, describe three design configurations: coastal plain outfall, wetland seepage system, and constructed instream riffle. The RSC works well as a retrofit and can be used to halt excessive erosion in association with outfalls, ditches, and gullies. RSC is not recommended for treating runoff from areas identified as “hotspots,” sites expected to generate pollutants at higher concentrations than typically found in urban runoff (Flores et al. 2012, West Virginia DEP 2012).

Depending on the site and treatment needs, the RSC can be used alone or as part of a treatment train. The RSC is designed to convey the peak flow from a 100-year storm without causing erosion. If the RSC system alone cannot meet this requirement, an upstream practice is needed so the goal can be met. Also, pretreatment is advised for systems handling runoff from roads treated with deicing salts and sands, which can clog the sandwood chip bed of the RSC (Flores et al. 2012, West Virginia DEP 2012).

The RSC is best suited for areas with slopes of 10% or less, and typically treats drainage areas of 10 to 30 acres. It is often used within the Coastal Plain because it requires a shallower depth than constructed wetlands and stormwater ponds. When designing the RSC for use in areas with a SHGT, the pool areas should be able to drain within 72 hours of a storm. Setback requirements and other design specifications are provided within *Design Guidelines for Step Pool Storm Conveyance* by Anne Arundel County, Maryland (Flores et al. 2012).

Two studies in North Carolina as part of a dissertation project indicate promising performance for RSCs. One site for this study was located in the Coastal Plain and the other was in the Piedmont. High groundwater levels at the Coastal Plain site reduced infiltration into the surrounding soils and prevented drawdown for extended periods within the pools. Despite the SHGT, the hydraulic performance of the RSC was significant. The RSCs at both sites reduced surface flows by 80% to 95%. Most of the water left the systems through seepage into the media, which mimics natural shallow interflow. A water quality analysis was also performed as part of the second study involving a RSC located in the Piedmont. This RSC reduced TSS by 72%, TP by 28%, and TN by 30% (n = 20 events; Cizek 2014).

In Maryland, the RSC is classified as a runoff reduction practice and is therefore assigned removal rates established for such practices. Thus, RSCs meeting the design criteria of removing 100% volume reduction for the first 1 inch of rainfall are assigned the following removal rates in Maryland: 70% for TSS, 66% for TP, and 57% for TN (Maryland DEQ 2014). In West Virginia, pollutant removal rates are considered provisional until additional monitoring data are obtained. The provisional values are based on Level 2 water quality swales and incorporate both runoff reduction and stormwater treatment efficiencies, providing an overall reduction of 90% for TSS, 76% for TP, and 74% for TN (West Virginia DEP 2012).

Dune Infiltration System BMP
Two field studies of a new infiltration treatment system developed in North Carolina show promise for reducing runoff and removing bacteria from stormwater (Bright et al. 2011, Price et al. 2013). The design of this new treatment system, referred to as a dune infiltration system (DIS), is provided by Bright et al. (2011). The system utilizes open-bottom polyethylene infiltration chambers installed within a sand dune. Stormwater is piped to the infiltration chambers where it infiltrates into the dune system and flows towards the ocean. As the stormwater flows through the sand, bacteria and other pollutants are trapped within the subsurface.

At the demonstration site, the dune height was 13-16 feet, and dune width was 130-150 feet. The beach area provided an additional 80 feet of treatment, for a total distance to the ocean in excess of 200 feet. The separation distance from of the bottom of the DIS to the mean water table exceeded six feet.

The demonstration systems did not receive the expected amount of stormwater, which was attributed to infiltration by lawns and a lack of curb-and-gutter streets within the drainage area. During a one-year study, the overall runoff reduction was 95% for the DIS at the demonstration site (Bright et al. 2011), and for a three-year study, the overall volume reduction was 97% (Price et al. 2013). Groundwater fecal bacteria concentrations were similar prior to installation of the DIS and after installation of the system. Thus, the DIS may be useful for beach communities faced with bacterial TMDLs. Price et al. (2013) mention the possible application of the system to non-beach areas with sandy soils, sufficient separation from the SHGT, and separation from buildings and other structures that could be impacted by mounding near the practice. Because of the high runoff reduction rates, the DIS may also be useful for controlling stormwater. Removal of nutrients and other pollutants in stormwater, however, were not analyzed as part of either study so additional research is needed.

<u>*Modifications to BMPs*</u>

Sand Filter BMP
As a part of the literature review conducted for this project, we compared Virginia's design specifications for sand filters (referred to as "filtering practices" in Design Specification No. 12) to those of North Carolina, Maine, and Minnesota. A summary of our findings is provided below and includes a modified practice being considered in Minnesota, the iron-enhanced sand filter.

Virginia's Sand Filter Design Specifications

Stormwater flowing through a filtering practice is pretreated, often with a settling chamber, to capture coarse sediment particles before they reach the filter bed and to slow the velocity of the flow to prevent erosion within the filter bed. The runoff is further treated as it passes through a filter bed consisting of at least 12 to 18 inches of an engineered filter medium. The filtered water flows to an underdrain, which is connected to the storm drainage system. Virginia allows the use of filters with a sand medium (Level 1 designs) and organic medium (such as a peat/sand mixture or a leaf compost; Level 2 designs). Filtering practices typically treat stormwater runoff from small drainage sites (generally less than 2 acres), although multiple filters can be used to increase the amount of stormwater treated (see Design Specification No. 12, Filtering Practices).

There are currently six filtration design variants used in Virginia:

- Non-Structural Sand Filter – As the name implies, this filter utilizes sand as the treatment medium. The medium is covered with sand, turf, or pea gravel, and the bottom of the practice is lined with an impermeable filter fabric.
- Surface Sand Filter – With these filters, both the pretreatment chamber and sand filter bed are located at ground level. In most cases, the chambers are made of concrete. Treatment of drainage areas up to 5 acres are allowed with surface sand filters.
- Organic Media Filter – This filter is essentially the same as the surface sand filter, except the sand medium is replaced with an organic medium (e.g., leaf compost or a peat/sand mixture). Organic media filters can achieve higher pollutant removal for metals and hydrocarbons, but they can add nutrients from the organic medium to the runoff, making it a poor choice for waters where nutrients are of concern.
- Underground Sand Filter – This filter is installed underground and therefore takes up little space so is well suited for use in ultra-urban areas.
- Perimeter Sand Filter – This design is generally installed along the edge of a parking lot.
- Proprietary Filters – Proprietary filters use various types of media and configurations to achieve filtration within a packaged structure. Devices approved by DEQ and listed on the Virginia Stormwater BMP Clearinghouse (http://www.vwrrc.vt.edu/swc/) can be used in Virginia to meet the water quality design requirements (Part IIB) of the Virginia Stormwater Management Program (VSMP) Regulation (9VAC25-870).

Because filters rely on gravity to transport stormwater through the system, they tend to need a hydraulic head (the vertical distance between the top of the filter and the bottom of the storm drain) of 2 feet to 10 feet, depending on the design variant. The non-structural sand filter and perimeter sand filter have a comparatively low head requirements so are good choices for use in the Coastal Plain (provided specific design requirements can be met; see Design Specification No. 12, Filtering Practices).

A SHGT can limit the use of filtering practices in the Coastal Plain. In general, a two foot separation is required between the bottom of the practice and the SHGT. The minimum depth to the SHGT can be relaxed to 1 foot for a non-structural sand filter and perimeter sand filter if equipped with a large diameter underdrain (e.g., 6 inches) that is only partially efficient at dewatering the filter bed.

In Virginia, filtering practices are not typically assigned any runoff volume reduction unless a second cell is incorporated into a Level 2 system that utilizes infiltration treatment. The TP mass load removal is 60% for the Level 1 design and 65% for the Level 2 design. The TN mass load reduction is 30% for Level 1 and 45% for Level 2.

North Carolina's Sand Filter Design Specifications

The sand filter design specifications and regulatory credits used in North Carolina are similar to those used in Virginia. When designed, constructed, and operated as specified in the North Carolina Stormwater Design Manual, sand filters are assigned 85% removal for TSS, 45% reduction for TP (lower than Virginia's assignment), and 35% removal for TN. North Carolina's manual warns that if anoxic conditions exist within the filter (when there is a lack of oxygen in the filter bed), phosphorus levels can increase as the runoff flows through the filter. For this reason, sand filters must be able to completely drain within 40 hours (same as in Virginia).

North Carolina differs from Virginia in the required use of an underdrain. In Virginia, most filtering practices are to use an underdrain and are not assigned any runoff volume reduction. Only if a second cell is incorporated into a Level 2 system that is designed according to the infiltration or bioretention specifications can volume reduction be granted in Virginia. In contrast, sand filters in North Carolina may have an open bottom and therefore rely on infiltration if soil conditions allow (e.g., in coastal areas). Underdrains are required in areas with low permeable soils (e.g., Piedmont, mountains).

In North Carolina, the SHGT must be at least 2 feet below the bottom of the filter for open-bottom designs and 1 foot below the bottom of closed designs (e.g., those with filter beds with a concrete bottom). Exceptions to the 1 foot requirement for closed filters are granted if the practice will not float and will not drain groundwater. To protect nearby water resources, additional separation distances are required for sand filters in North Carolina: a separation of at least 30 feet from surface waters, 50 feet from tidal salt waters used for commercial shellfishing, and 100 feet from water supply wells (except for closed systems utilizing underdrains).

Maine's Sand Filter Design Specifications

Maine is similar to Virginia in that it has stormwater criteria for phosphorus, except in Maine, phosphorus is only limited for new development draining to a lake. Because a different crediting system is used in Maine, the Maine Stormwater Manual does not provide a list of phosphorus removal efficiencies for various practices.

The harsh winters of Maine restrict the use of sand filters (e.g., ice over and within the filter bed negatively impacts the functionality of the surface and perimeter filters). The use of sand filters in Maine is therefore limited to *grassed underdrained soil filters* (Virginia comparable is a non-structural sand filter) and *subsurface sand filters* (Virginia comparable is an underground sand filter). Only grassed underdrained soil filters are recommended by the Maine Department of Environmental Protection (MDEP) for meeting phosphorus standards.

As in Virginia, Maine requires a subsurface investigation prior to the construction of sand filters to determine the depth to the SHGT and bedrock. Also, sand filters in both Virginia and Maine need pretreatment and an underdrain. The required drawdown time for filters in Maine is between 24 and 48 hours, which exceeds the 40 hours required in Virginia.

- Grassed Underdrained Soil Filters – Grass soil filters used in both Maine and Virginia must have media at least 18 inches deep. Whereas Virginia requires a sand medium for Level 1 filters and sand with an organic layer for Level 2 filters, the medium in Maine can consist of the following: (1) a mix of silty sand and mulch, or (2) a 12-inch layer of sand and 6-inch layer of loamy topsoil.

  The required separation from the SHGT is 18 inches in Maine, but in certain situations, an impermeable liner can be used if the required separation distance cannot be met. This specification is in contrast with that in Virginia, which requires a 2-foot separation that can be reduced to 1 foot with the use of a large-diameter underdrain.

- Subsurface Sand Filters – The design specifications for Virginia provide little specific information pertaining to underground sand filters. In contrast, an entire section of the Maine Stormwater Manual (Volume III, 7.3) is dedicated to these filters.

  The schematic from the Virginia design specifications for an underground sand filter shows an enclosed filter bed chamber, likely representing concrete, with various inlets and outlets. The schematic from the Maine manual shows a different type of subsurface sand filter (one that does not rely upon a concrete encasement). In Maine, subsurface sand filters consist of layers of different sized material, e.g., 12 inches of backfill, 6 inches of stone above and below pre-treatment chambers, 18 inches of compacted sand, 6 inches of coarse gravel as a transition layer, and 12 inches of underdrain bedding (crushed stone) in which the underdrain pipes are embedded. The depth needed for subsurface sand filters in Maine exceeds 5 feet, and the required separation distance between the bottom of the BMP and the SHGT is 1 foot. Thus, the SHGT needs to be more than 6 feet below the surface to utilize this filtering system in Maine.

Minnesota's Sand Filter Design Specifications

The state of Minnesota currently utilizes three classes of media filters: surface sand filters, underground sand filters, and perimeter sand filters. Design specifications for these practices are comparable to the similarly named filtering practices in Virginia, e.g., pretreatment is required, a medium depth of at least 12-18 inches is needed for the filter bed, underdrains are a necessary component of the design. There are also differences between the state programs. For example, the minimum separation from the SHGT is three feet in Minnesota but is only two feet in Virginia, and the drawdown time in Minnesota is 48 hours whereas it is reduced to 40 hours in Virginia. Furthermore, Minnesota does not allow the use of filters that utilize an organic medium.

- Surface sand filters: These filters contain two chambers at the ground surface: the first is for pretreatment, and the second is for filtration through a bed of sand 18 inches in depth. The filter bed may be covered with grass or sand. The bottom may be open or closed, depending on the permeability of the underlying soils and the likelihood of groundwater contamination.

- Underground sand filters: These filters have three underground chambers: the first is for pretreatment; the second is for filtering the stormwater through the sand bed; and the third collects the filtered water.
- Perimeter sand filter: These filters have two trench-like chambers that run parallel to each other and are often installed along the perimeter of parking lots. The first chamber provides pretreatment, and the second chamber has a sand bed through which stormwater is filtered.

In Minnesota, the following pollutant removal efficiencies are recommended for sand filters: 85% for TSS, 50% for TP, 35% for TN, 50% for metals, 80% for bacteria, and 80% for hydrocarbons. The TP reduction credit assumes that 55% of the phosphorus removed is of the particulate form (PP) and 45% is of the dissolved form (DP). Removal efficiencies of 91% for PP and 0% for DP are recommended for sand filters. Volume reduction credits are not provided in Minnesota for sand filters.

Pollutants are removed by sand filters primarily by gravitational settling and filtration. Because of poor phosphorus removal performance, some variants of media filters are not recommended in Minnesota, where the storm sewer system drains to a lake or nutrient impaired waters. In an effort to improve phosphorus removal, Minnesota is considering the use of iron-enhanced sand filters, which in addition to settling and filtration utilizes chemical processes to remove pollutants.

Enhanced Sand Filters

Minnesota is considering the use of enhanced sand filters, which use sand that is mixed with iron to facilitate the removal of dissolved constituents such as phosphates. Iron-enhanced sand filters can be established as a filtration basin or as a filtration bench for wet ponds. Because these filters are a new technology, however, there is not much performance data available. The Minnesota Stormwater Manual (MPCA 2016) summarizes the pollutant removal results for three studies, one that considered TSS, TP, and phosphate removal from an iron-enhanced sand filter basin and two that compared phosphate removal from iron-enhanced sand filter benches in a wet pond. Additional research is ongoing, and the removal efficiencies proposed for enhanced sand filters are not currently accepted for regulatory compliance in Minnesota. The proposed pollutant removal efficiencies for iron-enhanced sand filters are the same as for other media filters in Minnesota for TSS, PP, TN, metals, bacteria, and hydrocarbons. Dissolved phosphorus removal is substantially higher, estimated at 60% for this practice (compared to 0% for other sand filters), which increases the expected TP removal of 77% (assuming 55% exists as particulate phosphorus and 45% exists as dissolved phosphorus).

Iron-enhanced sand filters could be a viable practice for use in areas with a SHGT, and therefore Virginia should keep apprised of the ongoing research associated with this practice.

Soil Restoration/Reforestation BMP
Specification Number 4 (Soil Compost Amendments) of the 15 BMPs specifications currently listed on the Clearinghouse website is actually not a BMP. This specification is a practice that is applied after construction is completed. When soil is compacted soil porosity decreases and bulk density increases. As a result air and water movement within the soils is decreased, water holding capacity is reduced, and plant root growth is impeded. This leads to increase runoff and a higher potential for soil erosion to occur. The purpose of the specification is to restore compacted soils back to pre-existing conditions. Specifically, the purpose is to restore the pre-developed infiltration capacity of the unsaturated zone. Thus, the quantity of runoff is minimized, and nutrient loadings are limited.

Returning soils back to its original structure and hydraulic characteristics is a difficult process and takes a period of time for the soil structure to return to its pre-existing function. This process can be accomplished by applying two methods: soil ripping and the addition of organic matter. Both of these methods are discussed in specification 4, but not to the same level of detail as found in several other states such as Minnesota, Washington, and Pennsylvania. These states provide additional guidelines and more recent research for applying soil restoration techniques. The end results are restoration areas that provide nutrient and volume reduction on project sites.

Specification 4 also contains a section on reforestation. This practice will enhance volume reduction by increasing soil infiltration rates, promote evapotranspiration, and provide for the interception of rainfall. The Virginia Runoff Reduction method accounts for forested land cover by assigning a low runoff coefficient for that land type, thus generating a small nutrient load. Additionally, soil restoration and reforestation generate less stormwater runoff, which is accounted for within hydrologic models.

Adjustments to BMP Efficiencies

The PR and RR credits listed for each BMP on the Virginia Stormwater BMP Clearinghouse were based on the research at the time of posting. For non-proprietary BMPs, the PR and RR efficiencies were based on research published in 2008 or earlier. The reviewed studies are cited in *Technical Memorandum: The Runoff Reduction Method* published by the Center for Watershed Protection (CWP 2008). With BMP research evolving, and the number of available BMP research studies continuously increasing since 2008, the PR and RR efficiencies could be re-evaluated and adjusted at some future date.

The authors of the runoff reduction method technical memorandum explained that data were not always as abundant as desired. For example, the CWP (2008) publication notes that only a limited number of studies were available for determining volume reduction performance for some BMPs. Thus the authors recommended provisional rates based on conservative assumptions and best professional judgment. The ongoing review of published BMP literature should initially focus on these practices.

Opportunities may also exist for increasing existing BMP PR and RR values based on current understanding of BMP performance. Given the amount of data and professional engineering judgement used to establish the PR values for each of the non-proprietary BMPs, we do not expect significant changes to occur at this time. However, design changes to BMPs have been suggested in recent years that could improve the functionality of some BMPs and allow more PR credit (and/or RR credit). There is also a possibility that RR credits could be assigned to non-proprietary BMPs without current assigned volume reduction credits. Presently, BMPs such as constructed wetlands, wet swales, and wet ponds receive no RR credit. Further investigation of volume losses within these BMPs from transpiration, evaporation, and interception storage may allow for some runoff volume reduction credit to these practices.

Volume reduction credits in the VRRM are based on the results of many studies performed over the years. These studies determined volume loss using different mathematical methods with the data collected at these study sites. Volume loss was sometimes measured directly or determined based on an annual water budget. Volume reduction credit can also be estimated using equations for infiltration, evapotranspiration, and interception of rainfall by tree canopy. These equations can be found in many groundwater text books. The Minnesota Stormwater Handbook also provides equations for computing the volume losses based on equations. The results of the equations are used to show compliance with their program.

Reduction credits can also be determined by the use of models. Models are available that can be used to show reductions in TSS, TP, and volume. A modeling approach is being developed by the City of Virginia Beach, working with the Department. Once finalized other localities may have other tools to demonstrate VSMP compliance.

Treatment Trains

Site designs can either rely on stand-alone BMPs or BMPs in a series to serve a given site drainage area. When multiple BMPs are used in a series – known as a treatment train – the downstream BMP receives stormwater that has been treated by the upstream BMP. The advantage of this approach is that different removal mechanisms can be applied to lower nutrient concentrations. An example, based on removal processes, could include infiltration, filtration and then sedimentation. The application of the treatment train is best used within large drainage areas or within a watershed master plan. It can also be applied to smaller development site.

The selection of BMPs to use in a treatment train is dependent on the project goals and site conditions. If the infiltration of stormwater runoff is limited because of underlying soils or SHGT then the BMPs chosen as part of the treatment train can be selected to meet VSMP requirements given the physical constraints. In this case, manufactured treatment devices, swales, and constructed wetlands may be the BMPs of choice because of the environmental constraints.

Comprehensive Stormwater Management Plan (9VAC25-870-92)

The Virginia Stormwater Management Program provides a section on the creation of a comprehensive stormwater management plan that meets the water quality and quantity objectives of the Regulations. The Regulations also provide the use of other methodologies to meet the quality and quantity requirements (9VAC25-870-65 and 9VAC25-870-66). By combining these sections of the Regulations, a watershed approach can be taken that uses different modeling techniques to demonstrate water quality and quantity compliance. Actual field data can also be collected and used to verify modeling results.

This approach is useful because it will identify areas within any defined watershed that may require aggressive stormwater management treatment as opposed to other areas needing less. The watershed approach will assign nutrient loading rates to land coves and take into account removal processes within a watershed that the Runoff Reduction method does not address. One example would be interception losses that a forest cover would provide. This process, if accounted for, could help with volume reduction calculations which in turn would help with meeting channel protection and flooding requirements.

Several agencies and municipalities have submitted regional plans for consideration. This includes universities and local governments. One plan currently in development is from the City of Virginia Beach. DEQ is working with the City to not only approve their plan, but to use this plan as a template for other entries.

IV. Recommendations

Based on work conducted during a two-year study in fulfillment of HJR 587, DEQ proposes the following recommendations:

1 – Site-Specific Flexibility in the Required Separation Distance from SHGT

DEQ recognizes the need to develop criteria that utilize site-specific hydrologic information to justify reducing the standard separation distance between the bottom of a BMP and the SHGT. The agency recommends developing a process that allows the evaluation of site-specific information, providing flexibility in the required separation distance established in the approved BMP design specifications. DEQ recommends additional review and evaluation of the use of an intensive hydrologic study as allowed in North Carolina, a neighboring state with similar climate and SHGT characteristics.

2 -- Additional BMPs

DEQ recommends continued review and evaluation of BMPs not currently listed on the Virginia Stormwater BMP Clearinghouse but utilized in other states. Specifically, DEQ recommends development of BMP design specifications for tree BMPs, regenerative stormwater conveyance, and stream restoration. In addition, DEQ recommends further investigation to evaluate dune infiltration systems and if appropriate after staff review, develop design specifications for this BMP.

3 -- Modifications to BMPs

Scientific research can yield design modifications to BMPs that improve their performance. DEQ recommends continued evaluation of research results suggesting design modifications to BMPs listed on the Virginia Stormwater BMP Clearinghouse. Further evaluation is recommended for the sand filters (filtering practices) and soil restoration non-proprietary BMPs to include the design modifications discussed in this report. Revision of these designs will allow more use of these BMP in areas with SHGT.

4 – Adjustments to BMP Efficiencies

a) DEQ recommends updating Chapter 11, "Hydrologic Methods and Computations" of the *Virginia Stormwater Management Handbook* (second edition), to allow more tools in calculating water quantity requirements to meet channel protection and flooding requirements of the VSMP regulation.
b) DEQ recommends reassessing the runoff reduction credit given to BMPs and if appropriate, develop additional tools for volume reduction credit beyond those currently listed in the BMP design specifications. This recommendation will require extensive investigation, development of revised calculations, and stakeholder technical input and is a long-term recommendation for the program.

5 – Treatment Trains

Because the present BMP design specifications do not specify requirements on the use of BMPs in treatment trains, their use within treatment trains is often less effective than desired. DEQ recommends guidance to clarify the sequence of treatment trains associated with BMPs in series and to develop site cases for examples in selecting treatment trains for effective pollutant removal. This information could be particularly helpful in areas with site constraints, such as a SHGT.

6 – Comprehensive Stormwater Management Plans

DEQ recommends working with the City of Virginia Beach to develop a program whereby DEQ will be able to approve a comprehensive plan that meets the objectives of the water quantity and quality components of the VSMP. Such a program, if developed successfully with Virginia Beach, would provide more flexibility in meeting the water quality and water quantity requirements and could provide a roadmap for other localities with a SHGT.

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