REPORT OF THE
DEPARTMENT OF ENVIRONMENTAL QUALITY

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 [HJR 587, 2015]

TO THE GOVERNOR AND
THE GENERAL ASSEMBLY OF VIRGINIA

HOUSE DOCUMENT NO. 15

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To: The Honorable Terence R. McAuliffe

Members of the General Assembly

From: David K. Paylor

Date: December 21, 2016

Subject: Report on the 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

I am pleased to provide you with a copy of the Department of Environmental Quality's Report on the 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. This report was prepared pursuant to House Joint Resolution 587 (2015).

This report is being made available on Virginia's Legislative Information System webpage at: http://lis.virginia.gov.

If you have any questions concerning this report or would like a hard copy of this report, please contact Brandon Bull, Water Policy Manager, at (804) 698-4092.

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

A Report to
The Honorable Terence R. McAuliffe, Governor,
And
The General Assembly of Virginia

Department of Environmental Quality

December 2016

Executive Summary

The 2015 Virginia General Assembly passed House Joint Resolution Number 587 (HJ 587). The resolution as passed states in part:

> That the Department of Environmental Quality be requested to study the 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.

The resolution specifies that the Department of Environmental Quality (DEQ) evaluate the existing design specifications for best management practices (BMPs) listed on the Virginia Stormwater BMP Clearinghouse and recommend design specification revisions to allow the effective use of these BMPs in areas with a seasonal high groundwater table (SHGT), if applicable. The purpose of this effort is to achieve greater flexibility in meeting the stormwater management requirements in areas with a SHGT.

This report summarizes the work completed for the study. DEQ reviewed 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. Based on work conducted in fulfillment of HJ 587, DEQ is proposing recommendations regarding regional methodology for compliance with the VSMP, additional BMPs, modifications to BMPs, adjustments to BMP efficiencies, and treatment train guidance.

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I. Introduction

Background

In 2015, House Joint Resolution (HJ) 587 requested that the Virginia Department of Environmental Quality (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 in January 2016.[1] This current report highlights the conclusions reached following the completion of Phase II of the study.

The Phase I report defined a SHGT as 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 explained 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 interrelationship between meeting the water quality VSMP technical criteria and the water quantity VSMP requirements. It also discussed environmental constraints on BMP performance, made initial comparisons among selected state stormwater management approaches, and offered other compliance options. The Phase I report concluded by providing a direction for the second-year study, citing that additional investigation would take place.

Purpose

This report summarizes the work completed during the second year of study. This effort included a continued search and review of 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.

This report describes the importance of understanding site characterizations, such as surface hydrology and subsurface hydrogeological 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 development of a comprehensive stormwater management plan to meet the water quality and quantity objectives of the VSMP Regulations

[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] Taken from *Virginia DEQ Stormwater Design Specification No. 8: Infiltration Practices* (2013 draft version), which can be found on DEQ's website at http://www.deq.virginia.gov/Programs/Water/StormwaterManagement/Publications.aspx.

and the uses of site-specific information in areas with a SHGT. It provides examples of BMPs used in other states but not currently approved for use in Virginia, proposes design modifications for BMPs listed on the Virginia Stormwater BMP Clearinghouse,[3] and suggests possible adjustments of BMP efficiencies. The report also explains the logic needed to design effective treatment trains. The report concludes with recommendations by DEQ regarding future efforts to address stormwater management in areas with a SHGT.

Public Participation

Two public meetings were held in 2016 in association with this study. Approximately 20-25 stakeholders participated in each meeting. The first meeting was held in the summer to receive input from stakeholders on the following topics, as outlined in last year's report: (1) the Phase I report; (2) issues and/or concerns not previously considered by DEQ; and (3) examples of experiences working in areas with a SHGT. The second public meeting was held in December to receive input on the final report for the study. A draft of the report was provided to stakeholders several days prior to the meeting. In association with both meetings, written comments were received and considered by DEQ following the meetings.

II. Site Considerations

Site Characteristics

It is important to know the surface and subsurface environmental characteristics of the site to be developed. Understanding the site's hydrogeology is essential in applying the principles of ESD and in the selection of BMPs that will function most 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 soils. Pollutant removal and runoff reduction processes will be limited in infiltration BMPs if the unsaturated soils are shallow. Under such conditions, pollutants can be transported to groundwater and nearby wells or stream channels. BMPs will also become saturated by groundwater, thereby limiting their treatment effectiveness and increasing the maintenance needs of the practice. These factors make it imperative that site soils and subsoils are adequately identified and site hydrogeology is understood.

Site designs and the selection of BMPs for VSMP water quality and quantity compliance are partly based on the characteristics of the surface and subsurface soils and groundwater hydrology. Soil characteristics include, but are not limited to, soil type, soil texture, soil composition, bulk density, infiltration capacity, and permeability. These characteristics describe the soil properties of the unsaturated and saturated zones. Additional subsurface information is required for BMP selection. This includes the depth to groundwater table, estimation of SHGT, and groundwater flow in the vertical and horizontal directions. To obtain this information, a thorough investigation of the surface and subsurface soils is required within the site's boundaries

[3] Also known as the "BMP Clearinghouse;" available at http://www.vwrrc.vt.edu/swc/.

and below the bottom of the proposed BMP. Monitoring wells may need to be installed within the site at different elevations to determine flow characteristics.

The unsaturated soils may 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 Natural Resources Conservation Service (NRCS) Soil Survey as "urban land," meaning the site has been previously disturbed by construction activities. The HSG designation is used in estimating the quantity of stormwater runoff generated from a site and is also needed for calculating the TP loading. The HSG designation is partly determined by the identification of the most hydraulically restrictive soil layer located within the soil profile. When this parameter is estimated and not verified, the designer may end up designing unnecessary BMPs to obtain VSMP compliance. For sites with limited BMP selection options, such as sites with a SHGT, the collection of additional field and laboratory research may be a reasonable tradeoff to save design costs, long-term BMP maintenance costs, and land for future development that would otherwise be utilized by BMPs.

A hydrogeological investigation typically includes the excavation of a soil pit, which enables identification of various soil layers and extraction of samples for laboratory infiltration testing. Soil data are collected starting from the surface and going down to a designated distance. For testing below BMPs, New Jersey, for example, requires borings to be greater than eight feet or twice the maximum water depth in the BMP.[4] Soil data can then be collected and analyzed for each individual soil layer. Borings at various locations throughout the site are performed to check for soil profile consistency. This approach will identify the most restrictive soil layer and to determine the location of the SHGT.

Environmental Site Design

In Virginia, TP is the regulated pollutant in stormwater to be managed. The VSMP Regulations require that no individual project site release TP loads in excess of the regulatory threshold of 0.41 pounds per acre per year. The first method to apply to site design for meeting this threshold and reducing runoff volume is to limit the amount of land-cover changes and site disturbance that would generate additional stormwater runoff. This approach to site design is the foundation for the process known as ESD. ESD includes, but is not limited to, the preservation of natural features such as wetlands, forests, and natural drainage features. ESD also includes not disturbing soils, maintaining open space, and minimizing impervious cover. These steps are constructive for reducing post development stormwater runoff.

In reviewing many stormwater programs throughout the United States, ESD is highly encouraged as the first method to reduce the dependence on BMPs to manage stormwater quality and quantity. Minnesota, for example, considers ESD as a non-structural practice that is included as the first BMP in a treatment train.[5] ESD helps the designer understand the pre-existing hydrology of a site so the development project can be designed to optimize the site's natural predevelopment hydrology. By applying ESD techniques, stormwater impacts such as

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[4] *New Jersey Stormwater Best Management Practices Manual*; available at http://www.njstormwater.org/bmp_manual2.htm.

[5] A treatment train consists of multiple BMPs used in series.

downstream channel erosion and flooding will be minimized. This reduction of runoff will determine the type and reduce the size and number of BMPs needed for VSMP compliance. ESD should be considered as a first approach for all projects, but it is most applicable in areas where infiltration BMPs will be of limited use because of a SHGT.

BMP Selection

BMPs that can be used to meet the VSMP Regulations are listed on the Virginia Stormwater BMP Clearinghouse[6] and include 15 non-proprietary practices and nearly 30 proprietary practices. The 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 together provide a mass load TP removal quantity for each BMP.

Not all BMPs are suitable for use at all sites.[7] 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 environmental characteristics of the site.

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

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

Infiltration practices may not function as intended in areas with a SHGT. Infiltration BMPs depend on the stormwater exfiltrating from the BMP into the unsaturated soil surrounding the practice. Additional physical, biological, and chemical processes occur within the unsaturated soils that 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 located within the BMP and extending below infiltration BMPs will also 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, and thus affect pollutant mobility and potential down gradient impacts. Without adequate 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 soils, and thus the pollutants will be transported directly to the groundwater. These pollutants may resurface in nearby wells or in receiving streams located down gradient of the practice.

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

[7] Refer to individual BMP standards and specifications for guidance on the feasibility of a practice and design adaptations for specific regional situations.

III. Discussion

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

The VSMP provides a section on the creation of a comprehensive stormwater management plan that meets the water quality and quantity objectives of the Regulations. The VSMP Regulations also provide for 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 VSMP Regulations, a watershed scale approach can be implemented that uses various modeling techniques to demonstrate water quality and quantity compliance. In addition, field data can be collected to verify modeling results.

This approach will identify areas within any watershed that may require aggressive stormwater management treatment as opposed to other areas needing less. The watershed approach should include a watershed inventory of natural resources, existing land covers, and proposed land use planning considerations. Nutrient loading rates should be assigned to existing and proposed land covers. Pollutant and stormwater volume credits can be assigned to BMPs located within the watershed. Other removal processes within a watershed can be accounted for such as volume reduction due to stream routing. One specific example would be interception losses that a forest cover would provide. This process, if accounted for, could help with volume reduction calculations which would help with meeting channel protection and flooding requirements.

DEQ is working with several agencies and municipalities to determine what a comprehensive watershed master plan should include and how to apply the plan as individual sites are developed. These watershed plans need to balance meeting VSMP compliance at the watershed level against individual site VSMP compliance. Also streams must be protected from channel erosion and flooding within the watershed as well as at the watershed point of discharge.

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 BMPs located in Virginia for water quality compliance, a required separation distance between the bottom of the BMP and the water table is two feet. Other states (e.g., Minnesota, New Jersey), where groundwater protection and stormwater volume recharge are the key issues addressed through stormwater regulations, require three feet of separation. There are three perspectives critical in assessing the importance of this separation distance: (1) The function of the BMP in terms of pollutant removal and volume reduction; (2) The protection of groundwater from stormwater pollutants; and (3) The protection of the practice itself. These perspectives consider the interaction of the BMP with surrounding native soils and the long-term performance of the BMP with a reasonable amount of maintenance

SHGT and BMP Pollutant Reduction
The PR credit assigned within the Virginia Runoff Reduction Method (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 two feet), the opportunity for additional treatment processes is limited, and the likelihood of groundwater contamination increases.

The volume reduction or RR credit assigned within the VRRM is partly dependent on the volume of stormwater retained in the practice and the volume that is infiltrated to surrounding subsurface soils. Other volume losses occur through interception,[8], evaporation and transpiration.[9] BMPs that mainly depend on infiltration for volume reduction (e.g., bioretention, permeable pavement, infiltration facilities) may not achieve the assigned RR credit because the minimum separation distance is not maintained. The separation distance will vary throughout the year and during storm events. The groundwater table elevation naturally varies throughout the year due to rainfall patterns and seasonal vegetation changes. Also during rainfall events, small amounts of water can quickly fill up naturally occurring void space in the unsaturated soils and lead to the temporary saturation of these soils. In these cases, flow through the BMP practice will not occur, causing the water to stagnate within the practice, and thus saturating a portion of the practice and preventing water to flow outward. This saturation condition within the BMP can change the physical, chemical, and biological processes occurring within the practice. As mentioned previously, this saturation condition will compromise the integrity of the BMP and lead to increased maintenance costs.

Also occurring during rainfall events is a phenomenon 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.

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[8] Interception is a where trees and plants capture precipitation on their leaves and branches.
[9] Transpiration involves water exiting a plant through small openings on leaves; the water changes to vapor and is released to the atmosphere.

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, TP 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 TP 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 TP 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. However, 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 also be noted that groundwater contributes 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).[10] Although each state sometimes recommends somewhat different designs or gives BMPs somewhat different names, DEQ has 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.[11] In Virginia,

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[10] NCDEP (North Carolina Department of Environmental Quality). 2009. Sand filter. In: *North Carolina Stormwater Design Manual*. https://deq.nc.gov/sw-bmp-manual (accessed December 2, 2016).
VDEQ (Virginia Department of Environmental Quality). 2011. *Virginia DEQ Stormwater Design Specification, No. 12: Filtering Practices*. Version 1.8, March 1, 2011. http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html (accessed December 2, 2016).
[11] Schueler, T. 2009. *CSN Technical Bulletin No. 2: Stormwater Design in the Coastal Plain of the Chesapeake Bay Watershed*. Version 1.0. May 1, 2009. Chesapeake Stormwater Network. Ellicott City, Md. http://chesapeakestormwater.net/training-library/design-adaptations/stormwater-in-coastal-plain/ (accessed December 19, 2016).

however, designers must consider the depth to the SHGT for 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 two foot separation from the SHGT in both Virginia and North Carolina: (1) permeable pavement,[12] (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 one 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 one foot separation from the SHGT.

In general, Virginia places more restrictions on the minimum separation distance than does North Carolina. Virginia requires a minimum two foot separation distance from the SHGT for four BMPs that North Carolina requires less than two 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 grass swales, North Carolina only requires that they not be excavated below the SHGT, and extended detention ponds in North Carolina need only a six-inch separation from the SHGT.

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.[13] In North Carolina, a separation exception is allowed for a site when additional information prepared by a licensed professional supports the allowance.

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.

[12] 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.

[13] The underdrain exception may specify a large-diameter underdrain that is only partially efficient at dewatering the media bed.

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., six 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., six 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.

Additional Hydrogeological Analysis of the Site
As mentioned above, North Carolina allows exceptions to the separation distance, if supported, with additional hydrogeological analyses. The analyses would require detailed subsurface investigation. Additional field data would be collected from soil pits, soil borings, and piezometers located throughout the site or watershed. From the data collected, soil profile maps and groundwater flows maps can be constructed which will aid in the determination of an acceptable separation distance. Groundwater mounding calculations can be computed to estimate if the BMP will be compromised. To initiate a similar approach in Virginia, DEQ would need to develop a criteria and method to determine an alternative separation distance that would be supported by the findings of the analysis.

Additional BMPs

Alternatives to Infiltration BMPs
The challenge of finding subsurface conditions in areas with a SHGT that are appropriate for infiltration practices means that designers 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 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.

Examples of Additional BMPs under Consideration

The 15 non-proprietary BMPs listed on the Virginia Stormwater BMP Clearinghouse were selected based on reviewed studies cited in *Technical Memorandum: The Runoff Reduction Method* published by the Center for Watershed Protection.[14] Since the publication of the 2008

[14] Hirschman, D., K. Collins, and T. Schueler. 2008. *Technical Memorandum: The Runoff Reduction Method*. April 18, 2008. Center for Watershed Protection, Ellicott City, Md. http://www.vwrrc.vt.edu/swc/documents/CWP_TechMemo_VRRM_20080418 (accessed December 19, 2016).

technical memorandum, 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 provides new BMP options for possible use in Virginia.

The following sections describe BMPs that could potentially be added to the BMP Clearinghouse: tree BMPs, urban stream restoration (includes regenerative stormwater conveyance), and dune infiltration systems. As research continues, other BMPs not listed here will also be considered to expand the number of BMPs potentially allowed for use in Virginia.

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. 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. 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). Furthermore, by utilizing nutrients in stormwater, trees contribute to pollution reduction (EPA 2013).

In Minnesota, tree BMPs can be used with or without an underdrain depending on the permeability of the underlying soil. At some sites, an impermeable liner may be needed around the bioretention cell to protect adjacent retaining walls, building foundations, or other structures. A liner can also be used in situations where a SHGT exist. In Minnesota, a three foot separation is required between the bottom of the BMP and the SHGT,[15] but EPA cautions that sites where the SHGT is less than four feet from the surface may not be suitable for tree BMPs.[16]

The Minnesota Stormwater Management Manual (Manual) could be used as a starting place for Virginia to establish PR and RR credits in Virginia. The Manual provides calculation methods to compute the quantity of stormwater volume permanently removed by the BMP. The Manual provides equations to compute infiltration into the underlying soils, evapotranspiration[17] from tress, and interception of rainfall from the canopy. In addition, MSMH provides equations for

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[15] MPCA (Minnesota Pollution Control Agency). 2016. *Minnesota Stormwater Manual*. https://stormwater.pca.state.mn.us/index.php?title=Main_Page (accessed November 30, 2016).

[16] EPA (United States Environmental Protection Agency). 2013. *Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management*. EPA 841 B 13001. 31 pp.

[17] Evapotranspiration is the process in which water is transferred from the land to the atmosphere by evaporation from surfaces and by transpiration from plants.

calculating credits for TP and total suspended solids (TSS). The equations can account for different design configurations such as the presence or absence of an underdrain and whether the soil mix is propriety or not.[18]

Urban Stream Restoration
The Chesapeake Bay Program[19] has established a process whereby BMP research is reviewed by expert panels that establish recommendations. Their recommendations can then be applied to develop removal rates for proposed BMPs. Following a rigorous review, approved BMPs can be used to help meet load reduction targets of the Chesapeake Bay TMDL. Urban stream restoration was approved for such use in August 2014.[20]

Urban Stream Restoration stops further stream channel erosion from occurring in already degraded stream channels. The practice also provides wetland vegetation, volume reduction, and nutrient removal process.

There are three approaches that can be used to restore streams:

- Natural Channel Design – used to maintain a channel that is in equilibrium with water, sediment, and vegetation
- Legacy Sediment Removal – used to remove legacy sediments from the stream and associated floodplain thereby restoring stream aquatic resources
- Regenerative Stream Channel – used in-stream weirs in perennial streams to increase the interaction between the stream channel and the floodplain. This approach is further discussed in the following section as an individual practice.

Many stream restoration projects utilize a combination of these three approaches. Each approach receives different types of pollutant reduction credits for the following:

- Credit for the prevention of bank erosion that would otherwise be delivered downstream
- Credit for in-stream nitrogen reduction
- Credit for reconnecting the stream channel with the floodplain.

The third credit listed can be designed for small storm events (e.g., 0.50 or 1 inch). When these flows interact with floodplain, stormwater volumes are permanently removed along with nutrients (TP, TSS) from the wetland plants located within the floodplain. Additional research will be required to determine how to assign credits for VSMP compliance for water quality and quantity. This practice may be applied to site specific projects, but it is better suited as part of a comprehensive watershed approach.

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[18] Additional information concerning the specifics of the design and credit methodology can be found in the *Minnesota Stormwater Manual* at https://stormwater.pca.state.mn.us.
[19] The Chesapeake Bay Program is a regional partnership that includes federal and state agencies, local governments, academic institutions, and non-governmental organizations working to restore the Chesapeake Bay and its tributaries.
[20] More information is available at http://chesapeakestormwater.net/bay-stormwater/urban-stormwater-workgroup/urban-stream-restoration/.

Regenerative Stormwater Conveyance (RSC) BMP
A particular type of urban stream restoration is known as regenerative stormwater conveyance (RSC). RSC systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation and underlying sand channel to treat and safely detain and convey storm flow. RSC systems convert stormwater to groundwater via infiltration at coastal plain outfalls and other areas where grades make traditional practices difficult to implement. RSC systems combine features and treatment benefits of swales, infiltration, filtering and wetland practices. In addition, they are designed to convey flows associated with extreme floods (i.e., 100 year return frequency event) in a non-erosive manner, which results in a reduction of channel erosion impacts commonly encountered at conventional stormwater outfalls and headwater stream channels.

RSC structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles. RSC systems have the added benefit of creating dynamic and diverse ecosystems for a range of plants, animals, amphibians and insects. These ecosystems enhance pollutant uptake and assimilation and provide a natural and native aesthetic at sites. RSC systems are unique in that they can be located on the front or tail end of a treatment system and still provide water quality improvements and groundwater recharge benefits. Where located on the front end of a treatment train, they provide water quality, groundwater recharge, and channel protection, while also providing non-erosive flow conveyance that delivers flow to the stormwater quantity practice - a constructed wetland, wet pond, extended detention pond, or a combination of these BMPs.

Presently the RSC is included in Virginia's constructed wetland design specification (Number 13) and receives a PR credit only. Because this feature may be able to recharge groundwater and support wetland plants additional removal credits can likely be assigned. DEQ believes that this practice should be a standalone specification with credits assigned that the research supports.[21]

Dune Infiltration System
Two field studies of a new infiltration treatment system developed in North Carolina show promise for reducing runoff and removing bacteria from stormwater. The design of this new treatment system, referred to as a dune infiltration system (DIS), is provided by Bright et al.[22] 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.

[21] Additional information concerning the design of RSC can be found at http://www.aacounty.org/departments/public-works/wprp/watershed-assessment-and-planning/step-pool-conveyance-systems/.

[22] Bright, T.M., M.R. Burchell, W.F. Hunt, and W. Price. 2011. Feasibility of a dune infiltration system to protect North Carolina beaches from fecal bacteria contaminated storm water. *J. Environ. Eng*. 137(10): 968-979.

The demonstration system utilized in the studies did not receive the expected amount of stormwater so the system was considered to be oversized. The lower amounts of runoff were 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,[23] and for a three-year study, the overall volume reduction was 97%.[24] 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. 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.

Modifications to BMPs

The BMPs listed on the Virginia Stormwater BMP Clearinghouse were based on the research at the time of posting. For non-proprietary BMPs, the developed design specifications were based on research published in 2008 or earlier. Since then, numerous design modifications have been developed and tested. This section focuses on several published design amendments developed since 2008 that are being considered for use by Virginia.

Soil Restoration/Reforestation BMP

One modification to BMPs is already included on the BMP Clearinghouse: Specification Number 4 (Soil Compost Amendments). This specification is applied after construction is completed to restore compacted soils back to pre-existing hydraulic function. When soil is compacted (as occurs during construction), soil porosity decreases and bulk density increases. As a result, air and water movement within the soil decreases, water holding capacity is reduced, and plant root growth is impeded. In essence, soil compaction leads to increased stormwater runoff resulting in a higher potential for soil erosion. The purpose of the specification is to restore the pre-developed soil structure, thus returning the infiltration capacity back to the soils original capacity. By doing so, the quantity of runoff is minimized, and nutrient loadings are limited.

Soil restoration can be accomplished by applying two methods: soil ripping and the addition of organic matter. Both of these methods are discussed within Virginia's design specification 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. Applying these techniques in Virginia may provide additional nutrient and volume reduction credits that can be applied to meeting the VSMP regulatory thresholds.

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[23] Bright, T.M., M.R. Burchell, W.F. Hunt, and W. Price. 2011. Feasibility of a dune infiltration system to protect North Carolina beaches from fecal bacteria contaminated storm water. *J. Environ. Eng*. 137(10): 968-979.

[24] Price, W.D., M.R. Burchell II, W.F. Hunt, and G.M. Chescheira. 2013. Long-term study of dune infiltration systems to treat coastal stormwater runoff for fecal bacteria. *Ecological Engineering* 52:1-11.

Specifications 4 and 2 contain sections on reforestation. Incorporating the information on urban forest restoration available from the USDA Forest Service would improve both specifications. This practice will enhance volume reduction by increasing soil infiltration rates, promote evapotranspiration, and provide for the interception of rainfall. The VRRM accounts for forested land cover by assigning a small runoff coefficient for that land type, thus generating a small nutrient load. Together, soil restoration and reforestation generate less stormwater runoff, which can be accounted by using hydrologic models.

Sand Filter BMP

Sand filters have numerous different design variants, which depend on the site-specific subsurface conditions. Some states utilize variants not currently used in Virginia. For example, North Carolina allows open bottom filters if the underlying soil characteristics allow. Incorporating these designs into Virginia's program, as appropriate, would allow for more flexibility. Furthermore, in comparing Virginia's design requirements to those in other states, DEQ sees that Virginia is less restrictive with regard to the separation distance required between the bottom of the practice and the SHGT compared to some states (e.g., Minnesota).

As a part of the literature review conducted for this project, DEQ 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. Similarities and differences were apparent among the specifications. DEQ paid particular attention to the required separation distance to the SHGT. A summary of the findings is provided below and includes a modified practice being considered in Minnesota, the iron-enhanced sand filter.

Virginia's Sand Filter Design Specifications

Because filters rely on gravity to transport stormwater through the system, they tend to need a hydraulic head[25] of two feet to ten feet, depending on the design variant. Non-structural sand filters and perimeter sand filters have a comparatively low head requirements so are good choices for use in the Coastal Plain.[26]

A SHGT can limit the use of certain types of filtering practices listed in the specifications for use within the Coastal Plain. In general, a two foot separation is required between the bottom of the practice and the SHGT in Virginia. The minimum depth to the SHGT can be relaxed to one foot for a non-structural sand filter and perimeter sand filter if equipped with a larger size diameter underdrain (e.g., six inches). If the filtering practice is contained within an enclosed structure then further relaxation of the separation distance is possible.

North Carolina's Sand Filter Design Specifications

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. As

[25] Hydraulic head refers to the vertical distance between the top of the filter and the bottom of the storm drain.
[26] Provided specific design requirements can be met; see Design Specification No. 12, Filtering Practices, available at http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html.

described in the *North Carolina Stormwater Design Manual*,[27] sand filters 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 two feet below the bottom of the filter for open-bottom designs and one foot below the bottom of closed designs (e.g., those with filter beds with a concrete bottom). Exceptions to the one foot requirement for closed filters are granted if the practice will not float and will not drain groundwater.

Maine's Sand Filter Design Specifications

As in Virginia, Maine requires a subsurface investigation prior to the construction of sand filters to determine the depth to the SHGT. Also, sand filters in both Virginia and Maine require pretreatment and an underdrain.

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 Stormwater Best Management Practices Manual*[28] 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. The depth needed for subsurface sand filters in Maine exceeds five feet, and the required separation distance between the bottom of the BMP and the SHGT is one foot. Based on the design of the filter and the characteristics of the hydrogeology, the separation distance may be relaxed in Maine.

Minnesota's Sand Filter Design Specifications

The *Minnesota Stormwater Manual*[29] currently includes 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. Differences between the state programs include the minimum separation from the SHGT, i.e., three feet in Minnesota and two feet in Virginia. Furthermore, Minnesota does not allow the use of filters that utilize an organic medium whereas Virginia does.

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

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[27] Available at https://deq.nc.gov/sw-bmp-manual (accessed December 20, 2016).
[28] Available at http://www.maine.gov/dep/land/stormwater/stormwaterbmps/ (accessed December 20, 2016).
[29] Available at https://stormwater.pca.state.mn.us/index.php?title=Main_Page (accessed December 20, 2016).

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, there is not much performance data available. The *Minnesota Stormwater Manual* 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, TP, 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.

Floating Treatment Wetlands

Floating treatment wetlands (FTWs) are comprised of rafts that float in a wet pond and contain wetland plants that enhance pollutant removal. A panel of stormwater management experts reviewed research on FTWs and were approved by the Chesapeake Bay Program to help meet load reduction targets of the Chesapeake Bay TMDL.

The expert panel classified FTWs as a BMP enhancement. The panel endorsed the practice for use with wet ponds when the drainage area does not exceed 400 acres. Other specifications recommended by the expert panel included the amount of pond coverage by rafts, minimal vegetation coverage of the raft, and types of plants to use.

The roots of the vegetation within FTWs improve the hydraulics of the wet pond by reducing flow velocities, which encourages particulate settling. The biofilm growing within the network of roots removes nutrients from the water column, however, the plant roots themselves are not thought to contribute significantly to nutrient removal. The expert panel recommended modest removal rates for TN (<5%), TP (≤8%), and TSS (<12%) that vary depending on the amount of pond coverage. For example, a pond with 10% coverage by FTWs would receive 1.6% removal for TP, and one with 50% coverage by FTWs would receive 8.0% TP credit. The credits assigned for FTWs are in addition to those provided by the pond.

Because FTWs are expected to have relatively short lifespans, the expert panel recommended credit for only a three-year cycle (one year if there is not an operation and maintenance plan). Additionally, most reviewed studies took place in warmer climates so information on performance in cold weather (for both rafts and vegetation) is sparse. Given that the amount of research thus far conducted on FTWs is not as plentiful as desired, the panel further recommended that it reconvene within five years to evaluate the results of ongoing and future studies.[30]

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.[31] With BMP research evolving, and the number of available BMP research studies continuously increasing since 2008, the PR and RR efficiencies should be re-evaluated and adjusted at some future date.

The authors of the runoff reduction method technical memorandum explained that data were not as abundant as desired. For example, the authors noted that 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. Because of this fact, the ongoing review of published BMP literature should initially focus on these practices.

Opportunities also exist for increasing existing PR and RR values based on the 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, DEQ does 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 currently without 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 interception, evaporation, and transpiration may allow for some runoff volume reduction credit to these practices. Other practices that currently have RR could also be adjusted.

Volume reduction credits in the VRRM are based on the results of many studies that determined volume loss using different mathematical methods with the data collected at 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 volume losses based on equations, with the results being used to show compliance.

[30] Schueler, T., C. Lane, and D. Wood. 2016. Recommendations of the Expert Panel to Define Removal Rates for Floating Treatment Wetlands in Existing Wet Ponds. Approved Final Report WQGIT, September 12, 2016. Chesapeake Stormwater Network, Ellicott City, Md.

[31] Hirschman, D., K. Collins, and T. Schueler. 2008. Technical Memorandum: The Runoff Reduction Method. April 18, 2008. Center for Watershed Protection, Ellicott City, Md.

Reduction credits can be determined by the use of hydrological and hydraulic watershed models. Models are available that show reductions in TSS, TP, and runoff volume. A modeling approach is being developed by the City of Virginia Beach, which is working with the Department. Once finalized other localities may have a template to follow which can be applied to their specific environmental character.

Another possible approach is the design and installation of a monitoring program. Surface water sampling sites, groundwater wells, and monitoring down gradient streams may be a viable approach to demonstrate VSMP compliance. This approach is discussed in other states stormwater management manuals.

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. This approach offers the advantage of allowing different removal mechanisms to lower nutrient concentrations. An example of a treatment train that uses different removal processes could include infiltration, followed by filtration, and then sedimentation. The application of the treatment train is best used within large drainage areas or within a comprehensive stormwater master plan, but treatment trains can be applied to smaller development site.

The selection of BMPs to use in a treatment train is dependent on project goals and site conditions. If the infiltration of stormwater runoff is limited because of the underlying soils or the SHGT, then the choice of BMPs to be part of the treatment train can be limited to non-infiltrating practices. In this case, manufactured treatment devices, swales, and constructed wetlands may be the BMPs of choice because of the environmental constraints.

IV. Recommendations

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

Regional Methodology for Compliance with the VSMP

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 stormwater management plan that meets the objectives of the water quantity and quality technical criteria of the VSMP. Such a program, if developed successfully with Virginia Beach, would provide more flexibility in meeting water quality and water quantity requirements and would provide a roadmap for other localities with a SHGT.

Site-Specific Flexibility in the Required Separation Distance from SHGT
DEQ recognizes the need to develop criteria that utilize site-specific hydrologic information to potentially justify reducing the standard separation distance between the bottom of a BMP and the SHGT. The agency recommends developing a process to provide flexibility in the required separation distance established in the approved BMP design specifications whereby evaluation of site-specific information can be used to decrease the separation distance as appropriate. 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.

Regional Approaches for Water Quantity Compliance
DEQ will investigate using different hydraulic models to demonstrate compliance with the channel protection criteria contained with the VSMP Regulations. Presently, the model reference in the Regulations; "Energy Balance Equation" is the method referenced and applied statewide. DEQ recognizes that this method may not be appropriate for general statewide application.

Additional BMPs

DEQ recommends continued review and evaluation of BMPs not currently listed on the Virginia Stormwater BMP Clearinghouse but utilized in other states. In addition, DEQ will also review BMPs approved by the Chesapeake Bay Program that are not currently listed as a VSMP compliance tool. Specifically, DEQ recommends development of BMP design specifications for tree BMPs and stream restoration (including regenerative stormwater conveyance). In addition, DEQ recommends further investigation to evaluate dune infiltration systems and if appropriate after staff review, develop design specifications for this BMP.

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 and technology improvements which optimize BMP removal efficiencies to BMPs listed on the Virginia Stormwater BMP Clearinghouse. Further evaluation is recommended for soil restoration, sand filters (filtering practices), and floating treatment wetlands, as well as the use of electronic sensors and other devices to improve BMP hydraulic performance. Revision of these designs will improve pollution load reductions and thereby encourage more use of these BMPs in areas with a SHGT. In addition

Adjustments to BMP Efficiencies

Increase Tools for Calculating Water Quantity
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.

Reassess Runoff Reduction Credits
DEQ recommends reassessing the runoff reduction credit given to BMPs, and if appropriate, developing 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. This is a long-term recommendation for the program.

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 in selecting treatment trains for effective pollutant removal. This information could be particularly helpful in areas with site constraints, such as a SHGT.

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