ANNE ARUNDEL COUNTY

MARYLAND

DEPARTMENT OF PUBLIC WORKS DESIGN MANUAL CHAPTER VI

STORMWATER MANAGEMENT

CHAPTER VI
STORMWATER MANAGEMENT

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List of Acronyms

AASCD Guidelines	Anne Arundel Soil Conservation District Small Pond Guidelines
BMP	Best Management Practice
BSM	Bioretention Soil Mix
CIPs	Capital Improvement Projects
COMAR	Code of Maryland
CPv	Channel Protection Volume
CWP's	Center for Watershed Protection's
DCR	(Virginia) Department of Conservation and Recreation
DPW	Department of Public Works
EPA	Environmental Protection Agency
ESD	Environmental Site Design
ESDv	Environmental Site Design Volume
MDE	Maryland Department of the Environment
MDE Manual	*Maryland Stormwater Design Manual*
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OPZ	Office of Planning and Zoning
P&P Manual	*Anne Arundel County Stormwater Management Practices and Procedures Manual*
SHA	State Highway Administration
SPSC	Step Pool Storm Conveyance
TMDL	Total Maximum Daily Load
WIPs	Watershed Implementation Plans
WLA	Waste Load Allocation
WQ	Water Quality
WQv	Water Quality Volume

ANNE ARUNDEL COUNTY DESIGN MANUAL

CHAPTER VI

STORMWATER MANAGEMENT

I. INTRODUCTION

A. Purpose and Goal

This chapter of the *Anne Arundel County Design Manual* is provided as a supplement to the *Anne Arundel County Stormwater Management Practices and Procedures Manual* (P&P Manual). The P&P Manual outlines criteria for preparing stormwater management feasibility reports, stormwater management reports, and construction plans and specifications for public stormwater management systems. Historically, the Department of Public Works (DPW) has provided additional stormwater guidance in Chapter VI of the *Anne Arundel County Design Manual* specific to Capital Improvement Projects (CIPs). However, the P&P Manual has been changed to more clearly require private development to meet the same requirements as CIPs, bringing the stormwater requirements represented in the two documents into closer alignment. Therefore, Chapter VI now includes:

- Information that supplements the P&P Manual;
- References and supplemental information needed to prepare and submit an acceptable stormwater management plan for Anne Arundel County;
- Guidance for the selection and design of stormwater retrofit projects; and
- Supplemental standard specifications and details for management measures that have been approved by the County.

The primary users of Chapter VI are expected to be DPW project managers, design consultants, other County agencies and employees, and developers.

B. Ordinance and Authority

Environmental Article Section 4-203 of the Annotated Code of Maryland (COMAR) mandates that counties and municipalities adopt ordinances requiring communities to implement stormwater management programs. Through COMAR 26.17.02 Stormwater Management, the Maryland Department of the Environment (MDE) instituted guidelines for implementing these programs.

Anne Arundel County Council Bill 58-10 (Stormwater Management Ordinance), amended September 7, 2012, addresses the mandate as stated above and has been incorporated into the County Code as Article 16, Title 4, Sections 101–403 Stormwater Management. The Office of Planning and Zoning (OPZ) has the responsibility of implementing the Stormwater Management Ordinance, which includes preparing and regularly updating a technical manual (the P&P Manual) for stormwater management design, construction, and maintenance. Chapter VI of the *Anne Arundel County Design Manual* was prepared by DPW and provides information that supplements the P&P Manual.

Anne Arundel County Council Bill 2-13 (Stormwater Management – Watershed Protection and Restoration Special Revenue Fund and Program) establishes the Watershed Protection and Restoration Special Review Fund as a special, non-lapsing fund through Anne Arundel County Code Article 13, Title 7. The revenue paid to the Watershed Protection and Restoration Special Revenue Fund is dedicated to and appropriated only for the purposes set forth in Environment Article, § 4-202.1(h)(4), of the State Code. DPW is responsible for the day-to-day operation and administration of the County's Watershed Protection and Restoration Program.

II. How to Use This Document (Chapter VI)

Chapter VI of the *Anne Arundel County Design Manual* is provided in a single volume and is to be used in conjunction with the P&P Manual and the *Maryland Stormwater Design Manual* (MDE Manual). Information in the P&P Manual is not repeated here. When beginning a new and/or redevelopment project, **refer to the P&P Manual first** to find information on:

- Submittal requirements
- Exemptions
- Design guidance and criteria
- Review processes
- Ownership of facilities
- Security, fees, and maintenance agreements
- Construction and maintenance inspection
- Grandfathering and waivers
- Modified road standards to support environmental site design (ESD)
- Easement sizing
- Sample standard notes and tables
- Maintenance and inspection notes for private stormwater management practices
- Runoff curve numbers by zoning/land use
- Residential single lot development
- Stream order determination

This document, Chapter VI of the *Anne Arundel County Design Manual,* can then be referred to for supplemental information, such as:

- Detailed planning and design guidance for retrofit projects
- Data sources approved by the County
- Standard details and specifications for specific practices to simplify the review process

III. Reference Documents

Documents incorporated by reference are listed in **Appendix A**. Web links that were current at the time of this printing are also included in the Appendix.

A. Document Hierarchy

In case of a conflict between documents, precedence is as follows:

1. *Anne Arundel County Stormwater Management Practices and Procedures Manual*
2. *Anne Arundel County Design Manual and Standard Specifications and Details for Construction,* Chapter VI – Stormwater Management
3. *Maryland Stormwater Design Manual*
4. Other MDE guidance
5. Other Anne Arundel County guidance, including:
   Regenerative Step Pool Storm Conveyance (SPSC) guidance

B. Comprehensive Watershed Studies

DPW's Bureau of Watershed Protection and Restoration is responsible for developing Comprehensive Watershed Management Studies and Plans as part of its National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) permit. These plans were prepared for the 12 County watersheds. (Refer to Figure 1 for watershed designations.) Summary reports for each study can be found at the Watershed Studies link provided in Appendix A.

Source: Anne Arundel County, DPW

Figure 1: Anne Arundel County Major Watersheds and Non-Tidal Stream Reaches

Watershed management studies and plans enhance the County's ability to integrate and link existing watershed management business processes with watershed models to discover how changes in land use, development regulations, best management practices, and other watershed conditions affect water quality and waterway habitat.

The County's Comprehensive Watershed Management Studies and Plans provide a comprehensive and systematic watershed perspective on land use planning and development review activities. Each study includes a prioritized list of projects and should be referred to for preliminary guidance. In addition, they provide the tools necessary to:

- Facilitate daily land use and infrastructure management decisions,
- Protect watershed resources by providing an informed basis for prioritizing watershed restoration and preservation initiatives, such as Total Maximum Daily Load (TMDL) implementation plans, and
- Characterize watershed baseline conditions and resources.

They also identify existing and potential concerns such as stream stability, adequacy of buffers, physical health of habitat for aquatic organisms, etc., along with short- and long-term opportunities to improve water quality.

Developers are required to comply with additional or revised stormwater management goals as determined by the needs of each watershed. Field verification is required to verify the applicability of the proposed retrofits and the priority level of a given project. As part of these studies, the design standards for stormwater management in any watershed may be modified to help mitigate known problems with water quality, sedimentation, or flooding. Recommendations in the Comprehensive Watershed Management Studies and Plans are incorporated by reference, which can be found in Appendix A.

IV. Best Management Practice Preferences for Capital Improvement Projects

Anne Arundel County implements CIPs for improvements in a variety of program areas including "the construction or reconstruction in whole or in part of any road, bridge, street, building, or water, sewer, or stormwater facility, or any similar physical structure or facility necessary for carrying out the activities of the County government" (Anne Arundel County Code, 8-1-101 (1)). Any CIP that requires stormwater management controls is required to meet the stormwater design criteria and computational methodology referenced in this document and the P&P Manual. For these CIPs, the County requires the designer to adhere to following Best Management Practice (BMP) preferences:

1. New Development Projects (as determined by MDE classification)
    a. ESD to the Maximum Extent Practicable (MEP).

   b. The use of specified structural practices:
      i. Infiltration/filtration practices
      ii. Open channel practices
      iii. Ponds and wetland practices
      iv. Extended detention (e.g., channel protection)

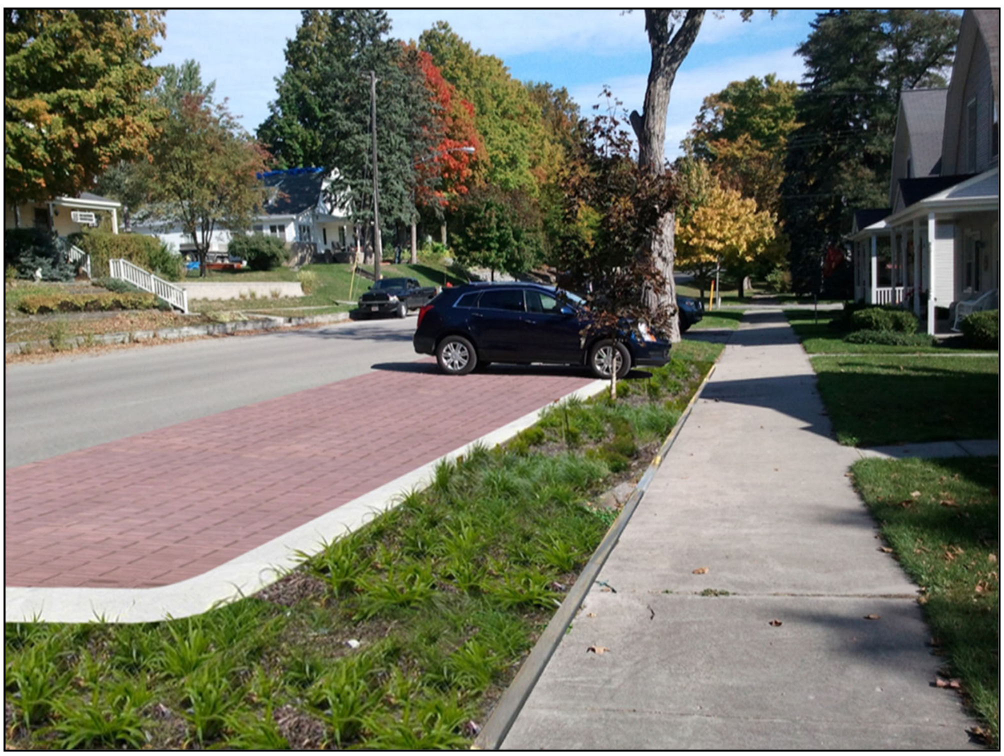
2. Redevelopment Projects (as determined by MDE classification)
   a. Reduction of impervious surfaces
   b. ESD to the MEP treating up to 50% of existing impervious surfaces and 100% of new impervious surfaces.
   c. The use of the following structural practices for treating up to 50% of existing impervious surfaces and 100% of new impervious surfaces:
      i. Infiltration/filtration practices
      ii. Open channel practices
      iii. Ponds and wetland practices
      iv. Extended detention (e.g., channel protection)
   d. Retrofitting existing practices (e.g., on or off site); or
   e. Combination of all or some of the above practices.

3. Stormwater Retrofit Projects
   a. For proposed stormwater management improvements in existing developed areas, refer to Section VI, Stormwater Retrofit Procedures

For all proposed stormwater improvements, whether new development, redevelopment, or retrofit projects, the County prefers multi-functional systems such as adding sidewalks and bike lanes using porous pavement or porous concrete, bioretention bump-outs as traffic control devices, roundabouts with a depressed bioretention area, permeable pavers that support fire trucks, and meandering streets with bioretention facilities as traffic control devices. Figure 2 through Figure 7 show examples of some of these types of multi-functional systems.

Source: New York City Design Manual, DPR

Figure 2: Multi-Functional Example: Forebay and Planting Area Integrated with Traffic Calming Strategies



Source: URS

Figure 3: Multi-Functional Example: Innovative Off-Street Parking Incorporating Permeable Pavers and Rain Garden

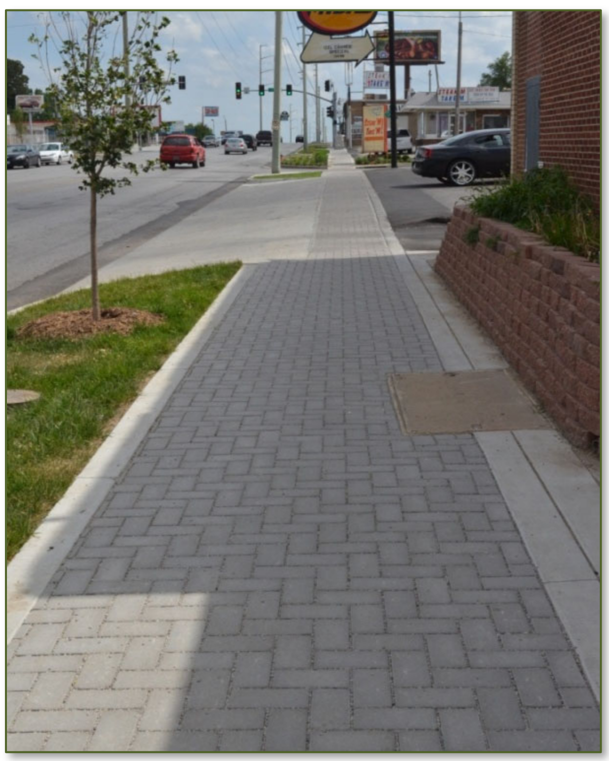
Above: Storage Under Bump-Out

Above: Final Bump-Out

Source: URS

Figure 4: Multi-Functional Example: Stormwater Collection Focal Point with Traffic Calming Devices

Storage Under Porous Pavers



Porous Pavers – Finished Product

Source: URS

Figure 5: Multi-Functional Example: Below-Grade Storage for Pervious Sidewalks

Before – Traditional Sidewalk draining to inlet

After – Pervious Sidewalks/Improved Vegetation

Source: URS

Figure 6: Multi-Functional Example: Pervious Sidewalks with Improved Vegetation and Pedestrian Access on a Commercial Street

Source: sfbetterstreets.org

Figure 7: Multi-Functional Example: Depressed Roundabout with Bioretention

V. NPDES Municipal Separate Storm Sewer System Program Requirements

A. Program Overview

In 2010, the U.S. Environmental Protection Agency (EPA) established the Chesapeake Bay TMDL for nitrogen, phosphorus, and sediment, which required all states whose stormwater drains to the Chesapeake Bay to work together to reduce the amount of pollutants in their waters. The EPA had set a goal for Maryland, Delaware, Virginia, Pennsylvania, West Virginia, and Washington, D.C. to meet their pollutant reduction goals by2025. MDE developed Phase I and II Watershed Implementation Plans (WIPs) that describe the strategies adopted by the State to meet its TMDL goals and how the goals would be further subdivided among all the counties and jurisdictions.

MDE is responsible for ensuring that all counties implement the WIP through the NPDES MS4 stormwater program. Anne Arundel County has maintained its NPDES MS4 permit since 1990. The current NPDES permit for Anne Arundel County was issued on February 14, 2014. In February 2019, that permit was administratively continued until the next permit is issued. The current NPDES permit is available on the MDE website, which is linked in Appendix A.

B. Projects to Address TMDL/Waste Load Allocation (WLA) Requirements

1. Recommendations in the Comprehensive Watershed Management Studies

The Comprehensive Watershed Management Studies include a prioritized list of projects for each watershed and should be referred to for preliminary guidance. The studies can be accessed at the link provided in Appendix A. Field verification of the applicability of the proposed retrofits and the priority level of a given project is required.

2. Bay Class Projects

Bay Class (B-Class) Projects are County stormwater retrofit projects that are being implemented to meet the Chesapeake Bay TMDL requirements. The following procedure should be followed when prioritizing a series of B-Class Projects.

a. Attend a field visit with County personnel and the regulatory agencies that would have jurisdiction over the potential work site.
b. Prepare documentation of existing conditions to update or verify the information in the Comprehensive Watershed Management Studies.
c. Based on revised data, determine which B-Class site should take priority.

C. Pollutant Removal Efficiency Reporting

To demonstrate that it is meeting the Chesapeake Bay TMDL goals and the NPDES MS4 requirements (and receive restoration credit), the County is required to document the progress toward implementing stormwater management practices that treat the unmanaged impervious area. Once a project has been constructed, designers must submit the data required for the NPDES permit compliance to the County. The data sheet is provided in the P&P Manual Section 11.6.

The August 2014 MDE guidance document, *Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated* (Wasteload Allocation document) lists the MDE-approved ESD techniques and alternative urban BMPs along with their pollutant removal efficiencies and impervious acre equivalent credits. This document should be used to complete the data sheet referenced in the paragraph above.

If the BMP is not listed in the MDE Wasteload Allocation document, the user should consult the recommended pollutant removal efficiencies presented in Section 4 of *Recommendations of the Expert Panel to Define Removal Rates for New State Stormwater Performance Standards*, which received approval from the Water Quality Goal Implementation Team in October 2012

VI. Stormwater Retrofit Procedures

"Stormwater retrofit" is the implementation of a device or practice in an existing developed watershed to improve the quality of stormwater runoff, thereby benefitting the receiving waterbody. Retrofit practices include upgrading existing stormwater facilities, improving existing degraded outfalls and stream systems, providing new nonstructural and structural facilities, altering land cover (removing existing impervious surfaces, planting trees to create new forested areas or urban tree canopy, etc.), and implementing pollutant-reducing maintenance practices. Guidelines in this section can be applied to all retrofit projects in Anne Arundel County.

A. Primary Goals for Stormwater Retrofit Projects

The primary goal for stormwater retrofit projects is to improve the water quality of the Chesapeake Bay and its tributaries, which is a requirement of the County's NPDES MS4 permit. In addition to removing pollutants, the retrofit design should also (1) function long term at the given site, (2) be cost effective to install and maintain, (3) be acceptable to the local community and landowners, and (4) meet the most recent County and MDE design requirements and specifications for stormwater BMP designs.

In addition to meeting the NPDES permit requirements for reducing nonpoint source pollutant discharge, retrofit projects can also provide other benefits to the site and communities in the receiving watershed. The following project types have been established as budgeted priorities through the Watershed Protection and Restoration Program to help improve the County's watershed and existing infrastructure:

- Updating stormwater management practices (e.g., private and public pond conversions of dry ponds to wet ponds or wetland systems)
- Improving outfalls and installing additional stormwater treatment systems
- Stabilizing or restoring degraded stream segments

B. Additional Goals for Stormwater Retrofit Projects

In addition to improving water quality, watershed retrofitting goals include:

- Improve Failing or Outdated Infrastructure: The designer should assess the condition and functionality of existing public infrastructure in and adjacent to the site and upgrade or improve outdated infrastructure. The County encourages combining stormwater management retrofit projects with improvements to existing infrastructure (refer to Section IV-multi-functioning systems).
- Address Downstream Erosion: When retrofitting a structural facility or location where concentrated flow is discharged to a stream channel, assess the downstream channel to determine if the receiving waterbody would benefit from outfall protection or from channel protection volume control. Additional information is provided in section VI.D.3.a.
- Avoid Aggravating Sensitive Streams/Thermal Loading: As applicable, design techniques should be incorporated that do not contribute to erosion, negative impacts to habitat and wildlife, or thermal loading. Additional information is provided in Section VI.D.3.b.
- Floodplain Uplift and Flooding Mitigation: Riverine flooding is not a widespread issue, as the County is characterized by tidally influenced estuaries. However, retrofit design should incorporate flood control storage, as feasible, to alleviate known

downstream flooding problems as well as ensure floodplain uplift (reconnecting the eroded stream to its natural floodplain). The designer should consult available County Comprehensive Watershed Management Studies and also the County to determine the need for providing flood control storage.

C. Permitting Strategies

Stormwater retrofit projects have to obtain approval from Anne Arundel County per the P&P Manual. Further, retrofit projects often affect waters of the U.S. and/or wetlands, and would therefore require approval from state and federal agencies. However, there are several options for streamlining the permitting process for retrofit projects, including the following:

- Stay within the footprint of an existing pond or BMP when designing modifications.
- Eliminate impacts to the floodplain.
- Minimize fill in the existing floodplain if impacts cannot be avoided.
- In the event of a situation where the County needs to provide an immediate (e.g., emergency) repair or restoration, coordination with the County, State and federal agencies should occur so that emergency authorization can be obtained from the State.

D. Site Selection

The County's stormwater strategy is to upgrade and improve water quality to meet the goals of the WIP. The County has assessed its watersheds and identified specific areas as priorities to be retrofitted. These areas are identified in the Comprehensive Watershed Management Studies and Plans and include public and private ponds, storm drain outfalls, and stream segments. The Plans should be referenced for specific requirements within each watershed. Refer to Section III of this document for additional information on the County's Watershed Management Studies and Plans. The designer should note that the proposed systems were identified using broad-brush planning techniques. Prior to detailed design, the designer should verify that the recommendations are appropriate for the proposed site.

1. Site Selection Guidance

a. Additional BMP siting and selection guidance is provided in the Center for Watershed Protection's (CWP's) Urban Subwatershed Restoration Manual No. 3: Urban Stormwater Retrofit Practices Manual (CWP Manual), refer to link in Appendix A.). The CWP manual provides guidance on the selection of a suitable location, and BMPs to implement depending on the site conditions. Otherwise, BMP siting and selection should follow the County's Comprehensive Watershed Management Studies and/or specific instructions from the County's project managers for a certain subwatershed.

b. BMP site selection assistance for practices in residential areas may be obtained through the Watershed Stewards Academy The County is working with the Anne Arundel County Watershed Stewards Academy to educate citizens and enhance stormwater management treatment as well as other environmental activities in residential communities. Master Watershed Stewards are trained to work in their neighborhoods to address the problem of stormwater pollution coming from private property. Designers (through coordination with the County PM's) may work with the Master Watershed Stewards to determine if there is a project on private property that may help meet retrofit goals.

c. When finalizing the project location, the designer should take into account site conditions, public acceptance, environmental impacts, and permitting to determine the optimum placement of a retrofit and appropriate BMPs. These elements are the basis for the retrofit location preferences provided in the following section.

2. Suggested Locations for Retrofit Projects

a. Existing Structural Facilities: For existing facilities with wet or other forms of water quality treatment, consult MDE's *Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated* to determine whether retrofitting the existing facility would provide nutrient reduction benefits.

b. Conveyance System: Vegetated conveyance systems (see Appendix C.2) and/or step pool storm conveyance measures are preferred. For design guidance, please refer to Chapters 3 and 5 of the MDE Manual (e.g., swales, open channel practices, and filtration and infiltration systems) or the County's Regenerative Step Pool Storm Conveyance Guidance Document. Other and/or additional guidance is available through Center for Watershed Protection Manuals regarding certain conveyance systems design options (e.g. grass swale, bioswale, infiltration trench).

c. Cross Culvert Inlets/Outlets: Opportunities for water quality features are often present upstream and downstream of roadway cross culverts. This is typically only feasible for non-perennial streams (i.e.: zero- and first-order streams) due to environmental impacts and subsequent permitting. Wet pools, extended detention facilities can be provided upstream of new and existing roadway culverts using the roadway embankment. Determine the area that is available for storage below or above the culvert.

d. County Road Rights-of-Way: Space is often available within the County road right-of-way (ROW) for the installation of a retrofit project. The County will consider how the project would affect driver safety and the level of maintenance required when evaluating the potential project in the ROW. The designer should consider safety and maintenance issues prior to selecting a ROW for a retrofit project. A separate review process is necessary for private projects proposing facilities in the County ROW.

3. Design Considerations for Downstream Issues

a. Downstream Erosion: When retrofitting an existing structural facility or location where concentrated flow is discharged to a stream channel, assess the downstream channel to determine if the receiving waterbody would benefit from outfall protection or from channel protection volume control.

The stream should be assessed using the County's Stream Assessment Protocol, which can be accessed at the following location:.

If there is scour at the discharge point to the stream, stabilize the outfall using energy dissipators designed per Anne Arundel County's *Regenerative Step Pool Storm Conveyance System Guidance Document*.

Refer to Section VII.B for additional guidance on stable conveyance.

b. Sensitive Streams/Thermal Loading: If the BMP discharges to a sensitive stream, the designer should verify that the BMP will not contribute to thermal loading. A stream's sensitivity to thermal loading is based on the stream classifications in Maryland, which can be found in Appendix D.9 of the MDE Manual.. The County's Comprehensive Watershed Studies should also be reviewed for specific requirements related to thermal loading. (NOTE: Jabez Branch is the only Use III Stream in Anne Arundel County.)

The designer should refer to Chapter 4 of the MDE Manual for guidelines on selecting the appropriate BMPs for sensitive streams: Minimum Water Quality (WQ) Treatment Volume Requirements for Retrofits

By definition, retrofit projects are located in or adjacent to developed areas with limited space available. So although a retrofit design would ideally treat the same volume as Chapter 5 of the MDE Manual describes for computing stormwater management volume for new development projects, it is not typically possible to obtain the same design volumes. However, providing a portion of the water quality volume is an acceptable approach, as noted in this section.

The County has adopted the minimum target WQ volume percentage that should be treated by a retrofit facility as presented in the CWP Manual. The manual recommends the following minimum volumes for a retrofit project to be considered:

BMP	Minimum Target WQv Percentage
Wet Ponds	35%*
Stormwater Wetlands	
Bioretention	50%
Sand / Organic Media Filter	
Infiltration	
Dry/Wet Swales	

* The percentage for wet ponds and stormwater wetlands refers to the minimum wet storage. Extended detention volumes for water quality may be provided in addition to the 35% water quality volume (WQv).

Facilities that treat less than the percentages above are not recommended for consideration as CIPs. However, if a facility that treats less than the target percentages is to be considered, documentation of all the County's retrofit options in that specific subwatershed area will need to be presented. In highly urban areas options may be very limited due to volume and/or area constraints in order to provide water quality improvements.

Designers should follow all other BMP guidelines pertaining to facility geometry, design velocities, and pretreatment requirements as outlined by the MDE Manual and the P&P Manual. For facilities that do not treat 100 percent of the required volume, the designer should consider an off line practice or using a flow splitter to divert a portion of the flow to the BMP. (Flow splitter design guidance is provided in **Appendix C.8**.) For BMPs that do not provide 100 percent of the water quality volume, pollutant removal should be calculated using the method described in Section V.C. of this document.

E. Retrofit of Stormwater Management Ponds

When designing a retrofit of a quantity control pond, the overall goal is to maximize the amount of treatment in the existing pond (up to 1 inch of rainfall and the 1-year storm for total ESD volume) as well as ensure safe conveyance for 10- and 100-year storms through either the principal or emergency spillway. During a pond retrofit, the 10-yr and 100-yr discharge rates and water surface elevations must be maintained or reduced. The water surface elevations may be increased if the 10-year freeboard is greater than or equal to 2 feet in a pond without an emergency spillway, or 1 foot in a pond with an emergency spillway. The peak rate may be increased if it can be proven that the downstream reach can accommodate the increase in peak discharges. This requires and extensive downstream channel analysis which is outlined in the Detailed Design Criteria – Overbank Flood Protection (Chapter 7.2) of the P&P Manual. If the peak rate increase can be accommodated, the quantity control volume can be converted for water quality treatment.

The facility must meet Natural Resources Conservation Service (NRCS) Pond Code 378 (MD-378) and be approved by the Anne Arundel Soil Conservation District (AASCD) unless the design results in the decommissioning of the pond and only provides water quality treatment. If possible, peak flow control should be over managed. The decision matrix for pond retrofits is shown in Figure 8.

1. Design Options for Pond Retrofits

Numerous design options exist for retrofitting stormwater management ponds, including the examples below.

- Convert a dry pond to a wet pond or a stormwater wetland system.
- Convert a dry pond to a bioretention or sand filter system.
- Enhanced sand filtering using available storage (Figure 9).
- Convert a dry or partially wet pond to a decommissioned pond with a Step Pool Storm Conveyance (SPSC) outfall system. The SPSC outfall system is equivalent to a filter system for pollutant removal requirements (Figure 10).
- Convert a failed pond to a new constructed BMP.

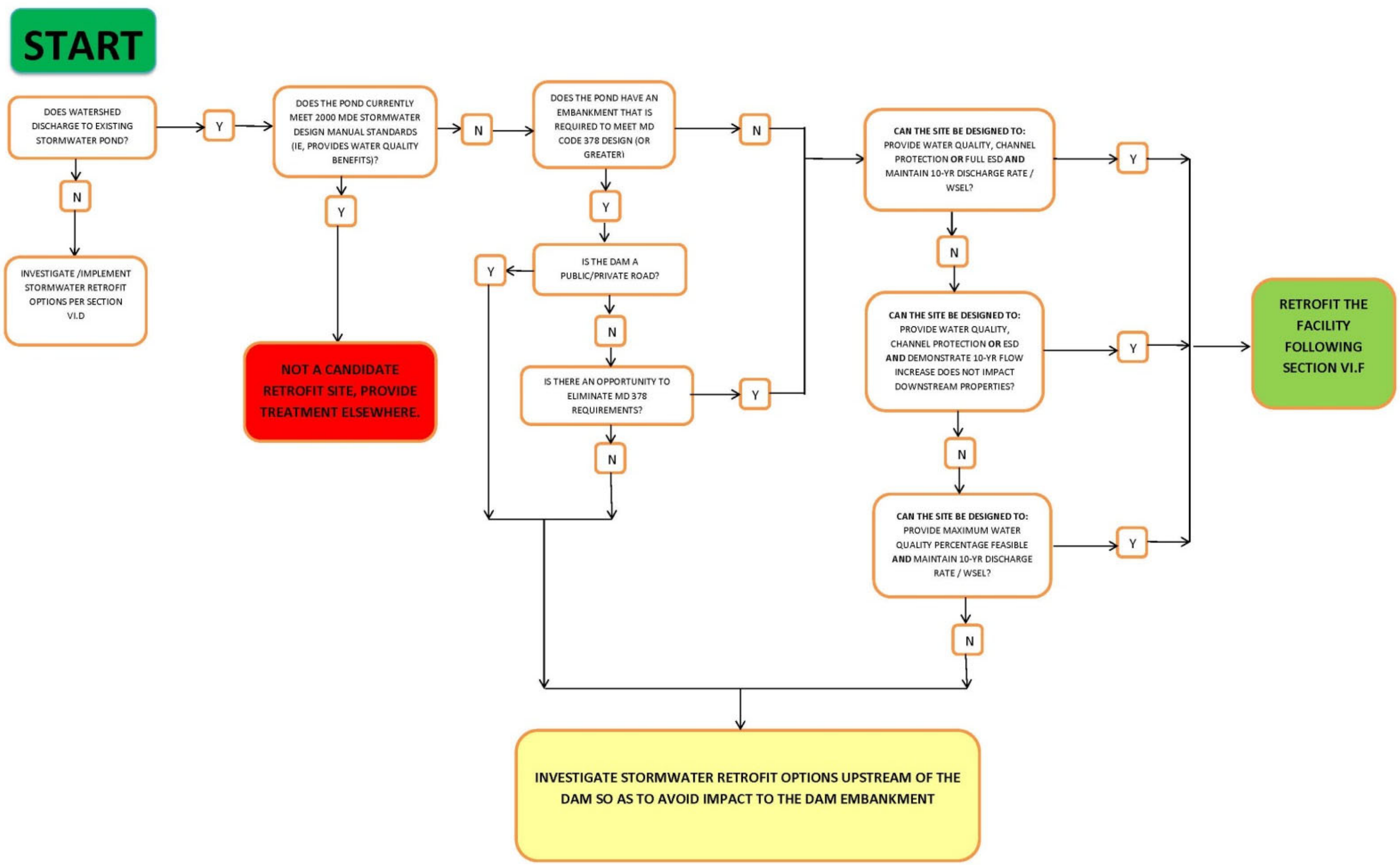
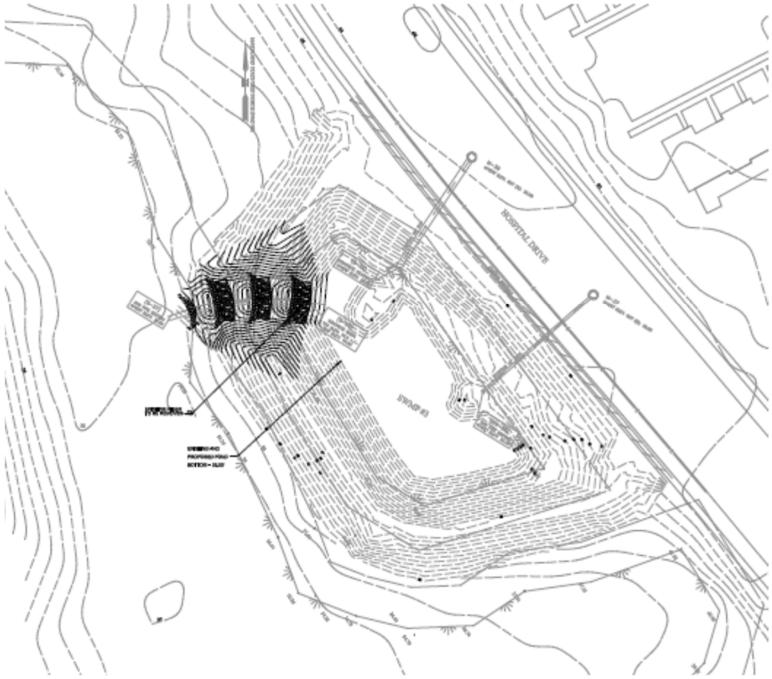


Figure 8: Decision Matrix for Pond Retrofits

- Remove the existing corrugated metal pipe riser and barrel system and replace it with a weir wall (concrete, stone, or wood) or earth berm.
- Modify the outlet structure to improve water quality by using an orifice plate, perforated PVC pipe with an internal orifice, new upstream riser, or other method (Figure 11).
- Convert an existing stormwater detention facility to an infiltration basin. (Figure 12).
- Convert an existing stormwater detention facility to a filter facility Figure 13).
- Provide a berm upstream of the dam (note that cut and fill needs to be balanced to maintain storage volume).

Source: Anne Arundel County, DPW

Figure 9: Design Option Example: Enhanced Sand Filtering Using Available Storage, Cypress Creek Stormwater Management Practice in Severna Park (SPSC Inside of Existing Pond)



Source: Anne Arundel County, DPW

Figure 10: Design Option Example: Decommissioned Pond with SPSC Outfall System

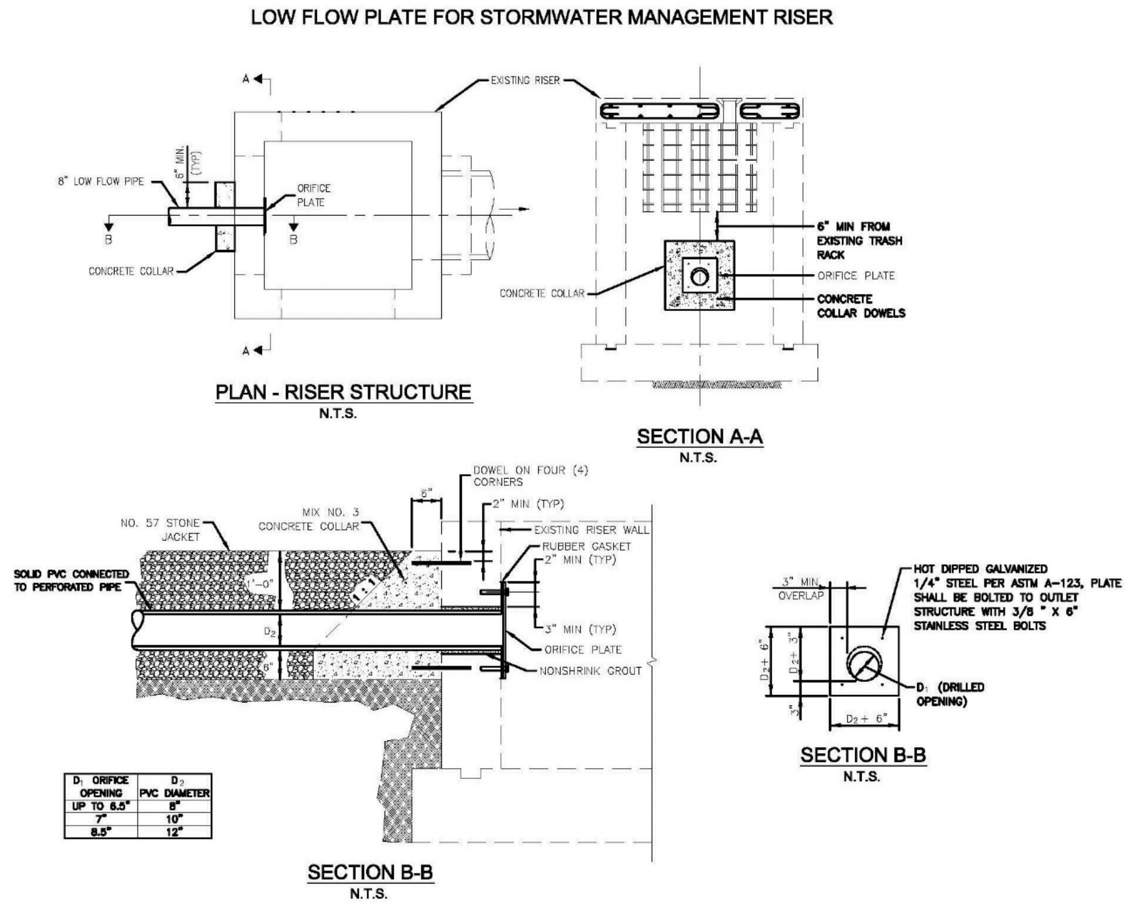
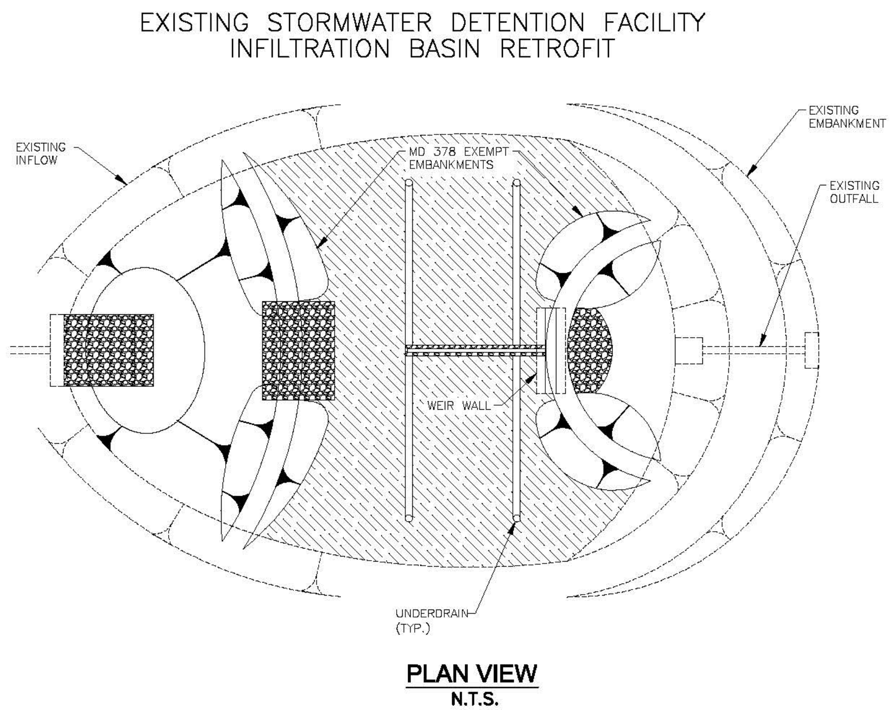


Figure 11: Design Option Example: Modify Existing Outlet Structure: Low Flow Plate on Stormwater Management Riser



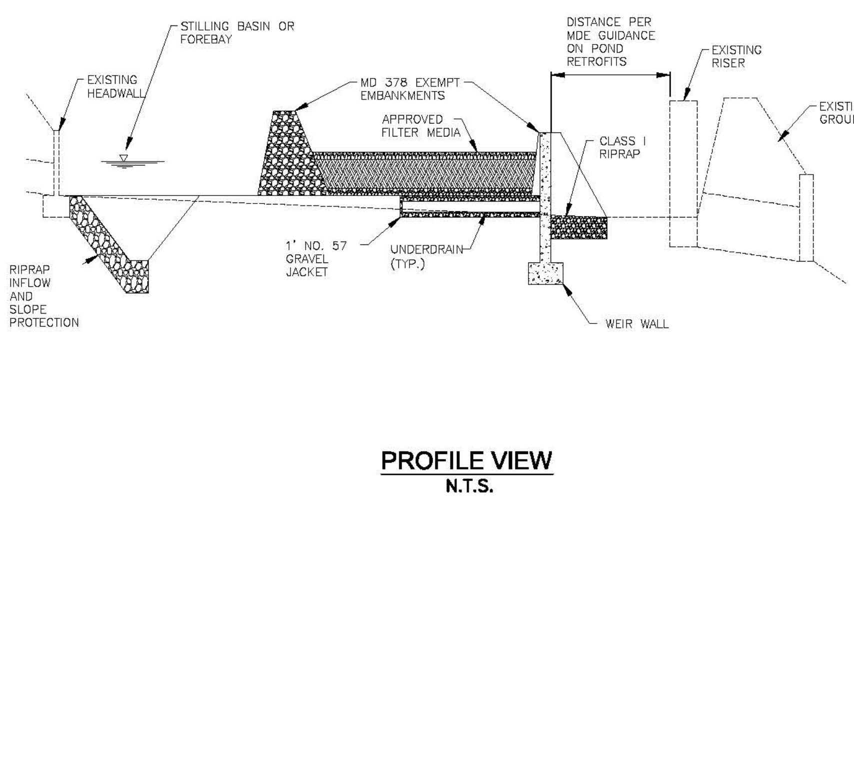


Figure 12: Design Option Example: Convert an Existing Stormwater Management Detention Facility to Filter Facility

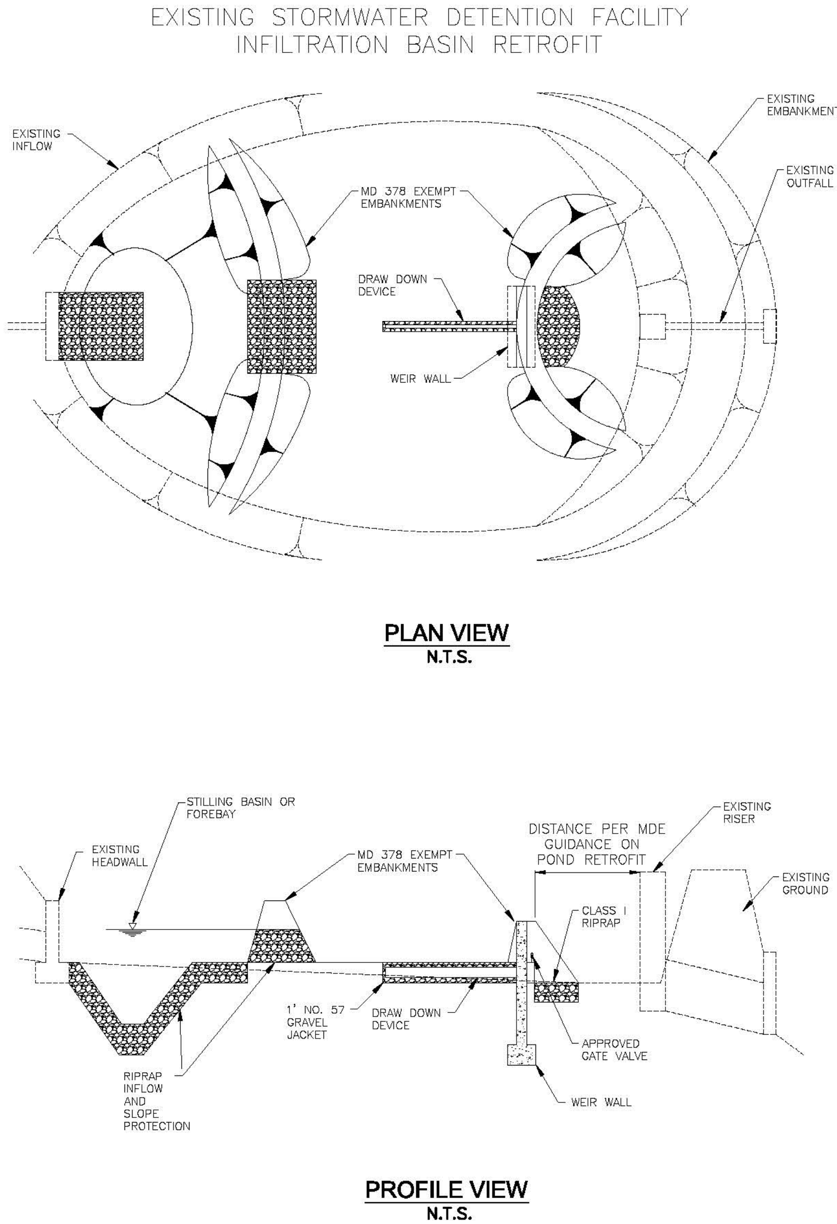


Figure 13: Design Option Example: Convert an Existing Stormwater Management Detention Facility to an Infiltration Basin

2. Classification of Stormwater Management Ponds

Stormwater management ponds may be either embankment ponds or excavated ponds. Depending on various criteria, ponds may or may not be subject to the requirements of MD-378. Refer to Appendix B1 of the MDE Manual: Retrofit procedures vary based on whether the existing pond requires MD-378 approval.

Following is an overview of the MD-378 exemption criteria. Note that non-roadway embankments have stricter criteria for exemptions than roadway embankments.

- Non-Roadway Embankment Requirements for MD-378 Exemption must meet one of the following criteria:

  Embankment height < 4 feet, OR

  100-year storage volume < 40,000 cubic feet AND
  embankment < 6 feet, OR

  Depth of 100-year storage < 3 feet

- Roadway Embankment Requirements for MD-378 Exemption must meet one of the following criteria:

  Any of the requirements above, OR

  Satisfying all of the following:
  HW-TW < 10 AND HW/D < 2,
  OR
  Permanent pool < 3 feet
  OR
  No riser structure

  Where: HW = Headwater
  TW = Tailwater
  D = Depth

3. Decommissioning a Pond from the MD-378 Code Requirements

When considering a pond upgrade, the County preference is to avoid embankment reconstruction and instead “decommission” existing MD-378 embankments by altering the embankment. In addition to County review, at this point, MDE has the responsibility to review and approve plans for facilities with embankments over 8 feet in height.

The designer should consider removing an existing MD-378 embankment in the following scenarios:

- Removal of embankment requirements does not increase design storm discharge.
- MD-378 exemption requirements would increase design storm (i.e., 10-year return period) discharge where increases in flow are permissible given adequate downstream capacity in accordance with the P&P Manual.

The P&P Manual requirements pertaining to 10-year downstream flood control govern and must be met. The following is the order of preference.

- **Removal of the Embankment.** Removing the embankment entirely and providing a non-embankment BMP (e.g., step-pool conveyance). The designer should attempt to remove the pond entirely and provide water quality BMPs to meet all MDE Manual and P&P Manual requirements.
- **Bypassing the 100-Year Storm.** Installing a flow splitter upstream of the facility and lowering the emergency spillway to allow for a water quality or channel protection volume facility without requiring a MD-378 embankment. (Flow splitter design guidance is provided in **Appendix C.8**.) The design must comply with the MDE and P&P downstream flooding requirements, which will often be a design constraint. By keeping extreme flood events from entering the facility and lowering the emergency spillway to reduce the 100-year water surface elevation, the designer may be able to reduce the 100-year storage below 40,000 cubic feet or reduce the depth of the 100-year storage to less than 3 feet. These criteria keep the pond MD-378 exempt.
- **Roadway Embankment – Removal of Riser.** A typical roadway embankment with a riser can exhibit the hydraulic characteristics of a pond. Conveying the 100-year storm around the roadway embankment is not likely to be feasible. However, it may be feasible to retrofit the pond outlet so it functions as a cross culvert rather than a stormwater management facility. Water quality measures, such as a check dam and other devices, could be installed upstream of the roadway embankment.

  As long as the permanent pool is less than 3 feet, this method would make the embankment exempt from MD-378 criteria. This method assumes that the downstream conveyance is adequate or can be enhanced to accommodate the design storm.

  If the roadway embankment does not meet all of the requirements for MD-378 exemption, a geotechnical engineer must inspect the roadway embankment to determine if it is possible to remove the requirements for a cut-off trench and impervious core. Other Pond Code 378 criteria must be met.

4. Retrofitting Ponds Exempt from MD-378 Criteria

Existing stormwater management ponds that are MD-378 exempt may be upgraded to accommodate volumes for ESD or WQ, and channel protection can be improved by altering the outfall structure and interior pond grading. Provided the Overbank Flood Protection requirements in the P&P Manual are met, the environmental site design volume (ESDv), or water quality volume (WQv) and channel protection volume (CPv), can be used in exchange for the pond volume previously used to attenuate the 2-year and 10-year runoff.

Designers need to prioritize MD-378 exempt pond reconstruction in this order:

a. Provide full WQv and CPv and maintain existing 10-year discharge.

b. Provide full WQv and CPv. Determine downstream impacts from increase in 10-year discharge per the P&P Manual.

c. If the resulting increase in 10-year discharge is not acceptable, investigate the receiving reach per the P&P Manual to determine if it is feasible to increase downstream flow capacity. If not, reduce CPv and WQv storage to maintain the 10-year discharge. Prioritize WQv over CPv. Follow minimum water quality volume percentages (discussed in Section VI.E.).

Under all circumstances, the existing embankment should be inspected using MD-378 inspection checklists or another method preferred by the County. The MD-378 inspection checklist can be found in Appendix A of the NRCS Code 378 which is incorporated into Appendix B-1 of the MDE Manual or as a stand-alone document in the MDE Dam Safety web page.

5. Retrofitting MD-378 Ponds

a. Goals

- Maximize treatment volume in the existing pond:
  - Up to 1 inch of rainfall to meet WQv
  - To the 1-year storm for total ESD volume

- Ensure stable conveyance for the 10- and 100-year storm events through either the principal spillway or emergency spillway.

- Maintain or lower the 10- and 100-year peak flows to the predevelopment rate and meet MD-378 in areas where downstream flooding or erosion problems exist.

b. Guidelines

- The existing embankment must be inspected per the MD-378 inspection checklist or other County-accepted method. Geotechnical investigation and certification may be required. A permit from MDE Dam Safety Division may be required for any borings drilled into the embankment for the geotechnical investigation.

- Maintain the existing embankment and provide WQv and/or CPv for the future redesign.

- If the existing embankment will require MD-378 upgrades, follow the procedure identified in the Anne Arundel Soil Conservation District Small Pond Guidelines (AASCD Guidelines) to provide a water quality facility within the existing facility without disturbing the existing embankment. (This must be coordinated with AASCD Guidelines, Item No. 6.)

- If an existing pond will require MD-378 upgrades to provide the minimum water quality and meet the P&P Manual requirements, consider the costs and benefits of constructing the retrofit at this location versus finding a different location where MD-378 requirements are not necessary.

F. Examples of Outfall Retrofit Designs

Outfall retrofit designs can take many forms. While it is not possible to provide guidance that would meet the needs of all existing conditions, several stream retrofit options have been designed and/or constructed that can serve as examples for future designs.

The following lists presents a list of retrofit design options for eroded outfalls, stream stabilization and restoration, and existing wetland retrofits. Additionally, examples of a small watershed approach, common to all ESD projects, are also provided. Refer to

Figure 14 through Figure 23, located at the end of this section, for examples.

1. Restoration of Eroded Outfalls

- Refer to the SPSC Guidelines
- Stabilize conveyance with riprap or boulder channel improvements.
- Construct a boulder plunge pool with strategically placed boulder riffles downstream.
- Provide a BMP downstream of the outfall.

2. Stream Stabilization/Restoration

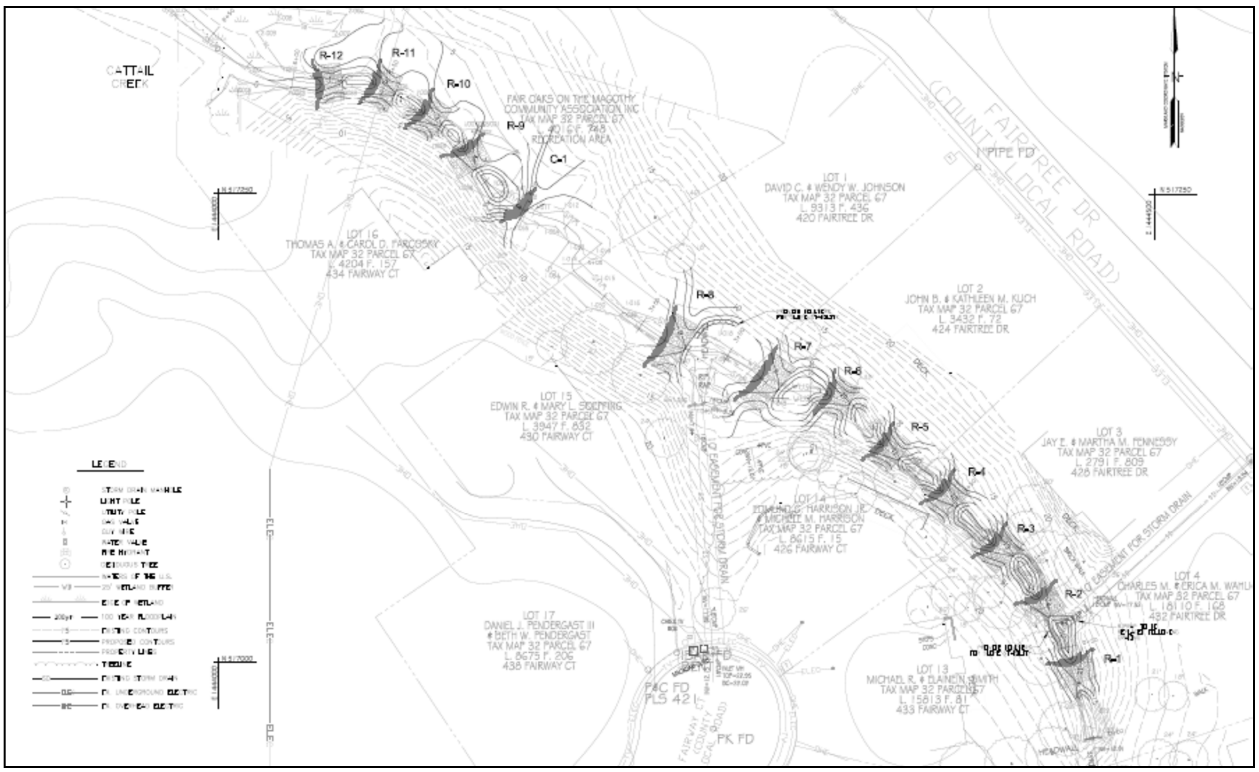
- Refer to SPSC Guidance.
- Provide riffle sections.
- Remove trash and debris.
- Reestablish native vegetation in the riparian zone and eliminate or control invasive species.
- Install streambank bio-stabilization to reduce erosion and sedimentation.
- Remove barriers to aquatic organism passage including failing culverts.
- Reestablish connectivity of the stream with its floodplain and associated wetlands.
- Restore in-stream aquatic habitat.
- Regrade to ensure uplift to qualify for a Nationwide 27 Permit from the U.S. Army Corps of Engineers with minimal impact to the existing forest system and buffer.

3. Small Watershed Approach – Environmental Site Design

To meet the requirements of ESD, designers should apply a 'small watershed' approach by dividing a project area into smaller contributing areas. Using nonstructural practices higher in the watershed is encouraged. Assistance from the Watershed Stewards Academy is recommended where appropriate. Potential BMPs include:

- Promote responsible stormwater behavior on residential properties and in neighborhoods through public outreach
- Installing rain barrels

- Using permeable pavements for driveways and patios
- Incorporating rain gardens
- Planting tree or meadows
- Converting closed drainage systems to open systems
- Adding bioswales
- Correcting eroded outfalls using cobble or boulder conveyance systems
- Applying SPSC
- Upgrading incised channels with riffle sections, SPSC, etc.



Source: Anne Arundel County, DPW

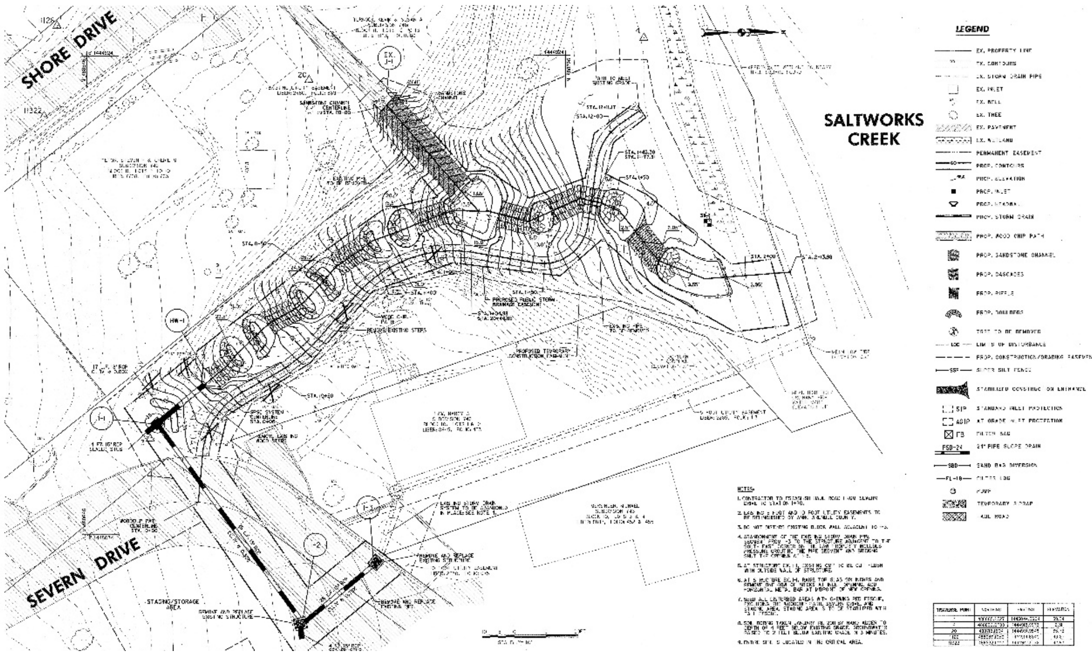
Figure 14: Example Retrofit of Eroded Outfall – BMP at Pipe Outfall (Fair Oaks Retrofit Project)

Source: Anne Arundel County, DPW

Figure 15: Example Retrofit of Eroded Outfall – Pre-Restoration Condition (May 2011)

Source: Anne Arundel County, DPW

Figure 16: Example Retrofit of Eroded Outfall – Post-Restoration Condition (Nov. 2013)

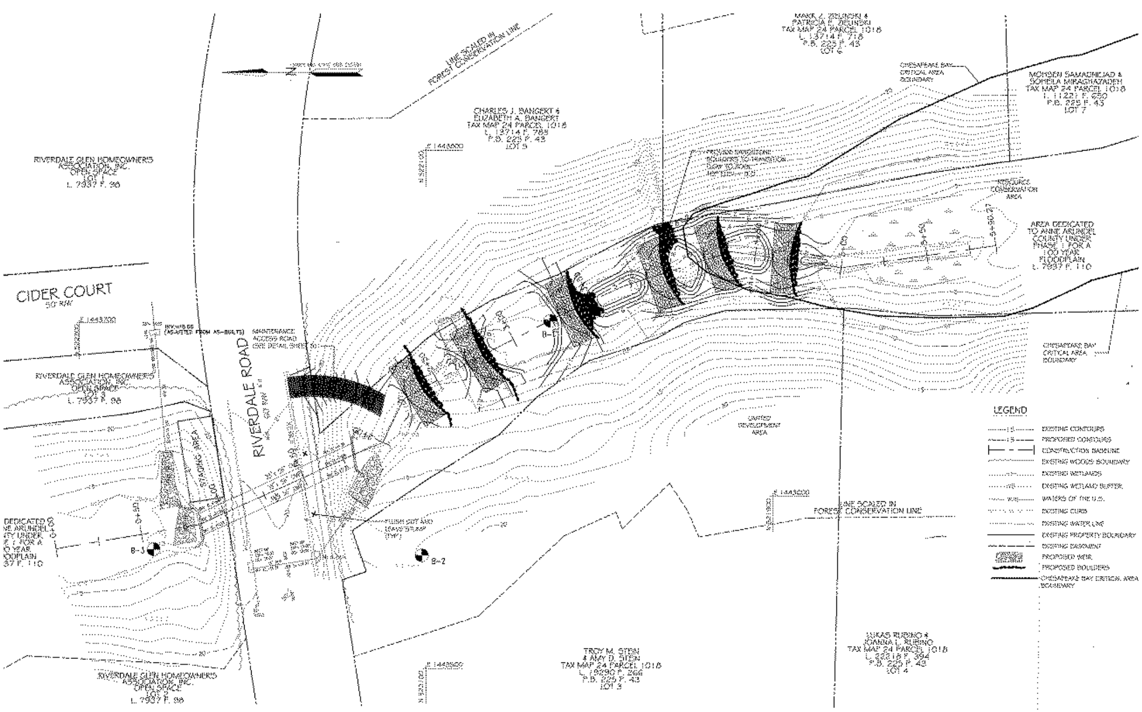


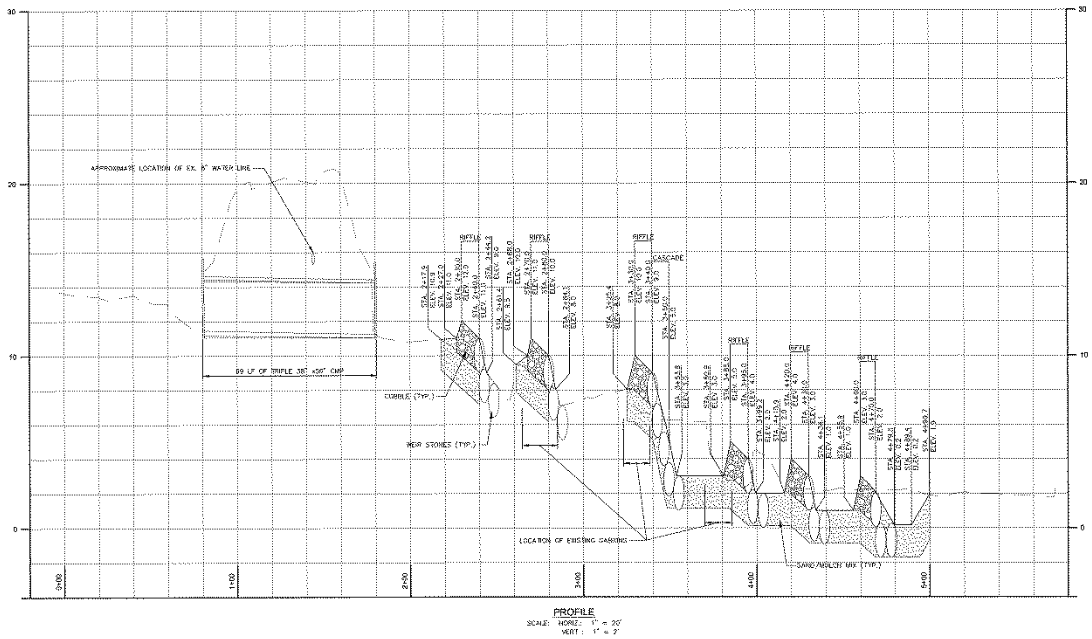
Source: Anne Arundel County, DPW

Figure 17: Example Retrofit of Eroded Outfall – Severn Drive Outfall Repair

Source: Anne Arundel County, DPW

Figure 18: Example Retrofit of Eroded Outfall – Post-Reconstruction Severn Run Outfall Repair





Source: Anne Arundel County, DPW

Figure 19: Example Retrofit of Eroded Outfall – Riverdale Road Outfall Project

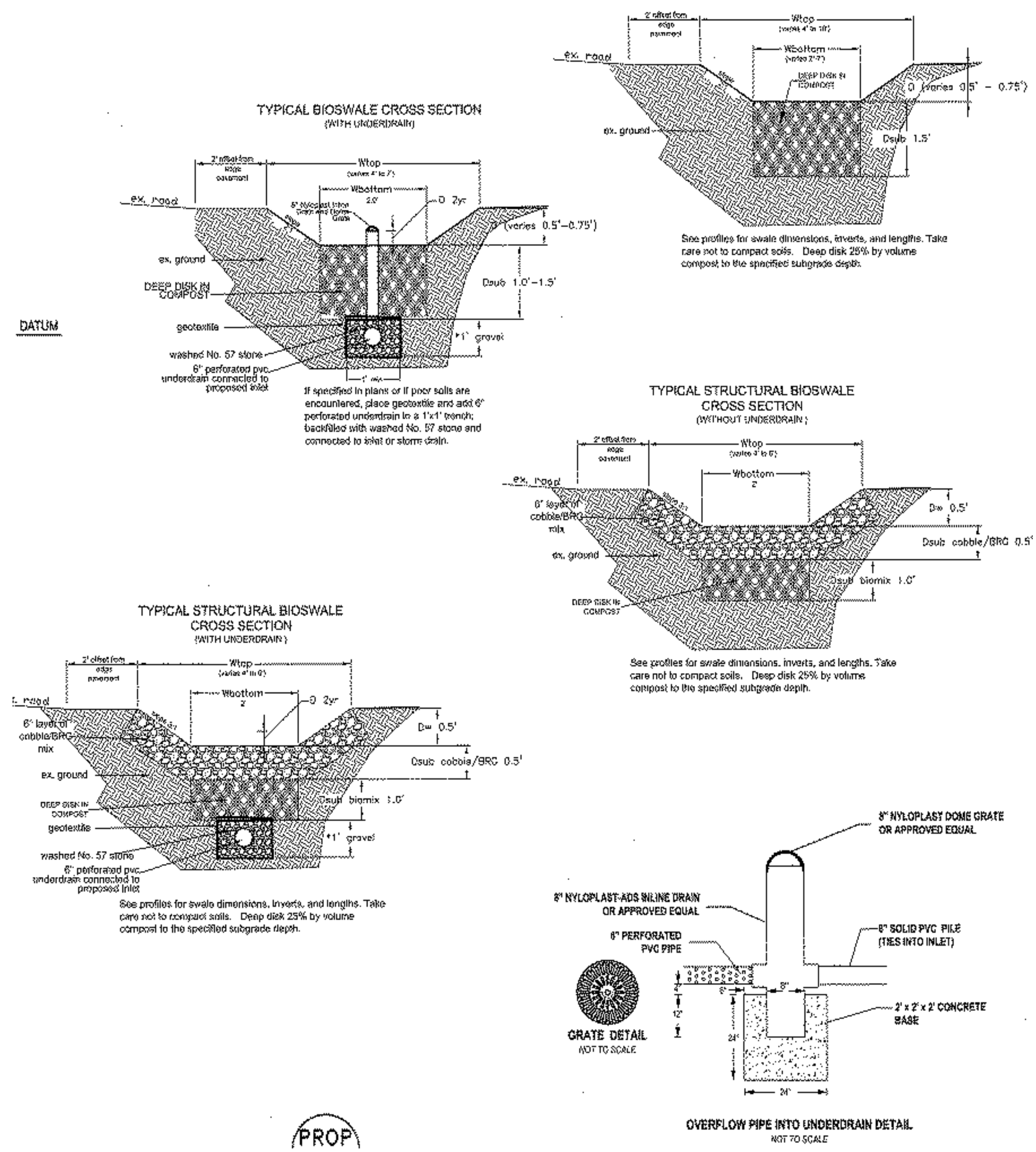
Source: Anne Arundel County, DPW

Figure 20: Example Retrofit of Eroded Outfall – Post-Reconstruction Riverdale Road Outfall Project

Pre-Restoration Post-Restoration

Source: Anne Arundel County, DPW

Figure 21: Example Stream Stabilization/Restoration



Source: Anne Arundel County, DPW

Figure 22: Example Small Watershed Approach – Bioswale

Source: Anne Arundel County, DPW

Figure 23: Example Small Watershed Approach – Post-Restoration Bioswale

Grid Pavers with Gravel Porous Pavers

Source: URS

Figure 24: Example Small Watershed Approach – Alternative Pavements

Source: URS

Figure 25: Example Small Watershed Approach – Rain Barrel

Source: URS

Figure 26: Example Small Watershed Approach – Rain Garden

VII. Stormwater Management Design Details and Specifications

Numerous data sources for standards and specifications for stormwater devices such as the Anne Arundel County Standards and Specifications, MDE Stormwater Design Manual, and the P&P Manual are available to the designer. Additional details and specifications generally applicable for retrofit projects have been developed to supplement these sources. The details and specifications are provided in **Appendix C,** and an overview of each detail/specification and their applicability is summarized below.

A. Bioretention Soil Mix

The recommended Bioretention Soil Mix (BSM) is based on the Maryland State Highway Administration (SHA) standard 920.01.05. The proposed soil mix has less clay than the mix currently recommended by MDE and works better in the County. Therefore, this soil mix should be used for all bioretention facilities, bioswales, rain gardens, and landscape infiltration with one exception. While parking on bioswales is not allowable, if a bioswale is being placed in an area where it may have vehicular loading, an alternate soil mix containing a higher percentage of sand should be considered. Specifications for the BSM are provided in **Appendix C.1.**

B. Stable Conveyance from Outfalls

1. Step Pool Storm Conveyance

For runoff leaving the project site in concentrated flow, refer to the County design guidance provided in the Regenerative Step Pool Storm Conveyance (SPSC)—also known as Coastal Plain Outfalls

2. Level Spreaders

Level spreaders have a tendency to re-concentrate flow and are not the preferred method for stable conveyance. Though not preferred, if there is no other feasible alternative, the designer may refer to MDE Manual Appendix D.8 for a level spreader detail. Other guidance on level spreaders can be found in the Virginia Department of Conservation and Recreation (DCR) *Stormwater Design Specification No. 2, Sheet Flow to a Vegetated Filter Strip or Conserved Open Space*.

3. Vegetated Filter Strip

For runoff leaving the project site as sheet flow, provide a vegetated filter strip. The Virginia DCR *Stormwater Design Specification No. 2* provides guidance for the design of both Conserved Open Space and Vegetated Filter Strips and can be referred to for guidance. Anne Arundel County has prepared a vegetated filter strip detail based on these guidelines. This detail can be found in **Appendix C.2.**

C. Planting Matrices for Stormwater Management Facilities

Plant selection tables for various types of stormwater management facilities are provided in **Appendix C.3**. The plant lists include native plants and plants indigenous to Maryland. Tables are provided for bioretention (no flowing water), bioswales (flowing water), dry ponds, and gravel wetlands. Once the appropriate table is selected for the intended stormwater management facility, specific plants may be selected based on mature size, visibility, and maintenance requirements.

D. Monitoring Gauge

Monitoring Gauges are used in the outfalls or downstream channel of a developed site where flow is concentrated to verify that sedimentation and erosion at the outfall is controlled. These are typically used only during construction and should meet the requirements of the AASCD Sediment Control Monitoring Device Detail.

However, all outfall repairs and stream restoration activities require a permanent monitoring gauge to verify the practice is successful and working properly. While the AASCD detail works effectively over the course of a construction project, a permanent gauge will require additional stability. Refer to **Appendix C.4** for details.

E. Curb Extensions/Curb Bump Outs

Curb extensions or curb bump outs are extensions of the curb line into the street, allocating a portion of street space to ancillary uses. The County promotes the use of multi-function facilities. While these are effective traffic calming tools, they also can provide safety measures for pedestrians, locations for landscaping, public art, seating, etc., and stormwater management facilities. Standard details for curb extensions are provided in **Appendix C.5**.

F. Micro-Bioretention Retrofit

Micro-Bioretention is a stormwater filtration system that is typically planted with native plants and has three layers: mulch; a layer of soil, sand, and organic material mixture; and a stone layer. A perforated pipe in the stone layer collects and directs the filtered rainwater from large storms to a storm drain system. The facilities should be well landscaped to enhance their function and appearance. Standard details for micro-bioretention retrofits for both open sections and closed sections are provided in **Appendix C.6**.

G. Bioswales

A bioswale is similar to a micro-bioretention area in that it is designed with layers of vegetation, soil, and a perforated pipe in the bottom stone layer. Bioswales are typically located along a roadway. A standard detail is provided in **Appendix C.7**.

H. Flow Splitter

Flow splitters are used to "split" the stormwater runoff, thereby restricting the volume or flow rate that enters a storm drain or stormwater management facility. Typically, flow splitters are used to allow the ESDv, WQv, or another desired, frequent storm event to enter a stormwater BMP, but the larger flows bypass the BMP so that the facility is not overwhelmed. This split allows for more effective pollutant capture and treatment by minimizing the amount of flow that suspends sediments and pollutants. Additional guidance and examples are provided in **Appendix C.8**.

I. Alternative Pavements

The County encourages the use of alternative pavement design, permeable and porous pavements, for use in sidewalks, bike lanes, overflow parking, and limited-use access roads. While the design guidance for alternative pavements from MDE in Chapter 5 of the Design Manual takes precedence, the County also recommends the New York City Street Design Manual for additional guidance and examples. Excerpts from this document are provided in **Appendix C.9** and can be accessed at:

Appendix A: Documents Incorporated by Reference

Anne Arundel County Guidance

Anne Arundel County, Department of Public Works, Watershed Protection and Restoration Program, Comprehensive Watershed Studies
http://www.aacounty.org/DPW/Watershed/WatershedStudies.cfm

Anne Arundel County Design Manual and Standard Specifications and Details for Construction
http://www.aacounty.org/DPW/engineering/designmanual.cfm

Anne Arundel County Government Chesapeake Bay TMDL Phase II Watershed Implementation Plan Final (July 2012)
http://www.mde.state.md.us/programs/Water/TMDL/TMDLImplementation/Documents/FINAL_PhaseII_Report_Docs/Final_County_WIP_Narratives/Anne_Arundel_WIPII_2012.pdf

Anne Arundel County Landscape Manual
http://www.aacounty.org/PlanZone/Resources/Landscape_Manual_Final.pdf

Anne Arundel County Stormwater Management Practices and Procedures Manual
http://www.aacounty.org/planzone/resources/practices_procedures_manual.pdf

Anne Arundel Soil Conservation District Small Pond Guidelines
http://www.aascd.org/urban_forms

Integrated Mapping Application
http://www.aacounty.org/OIT/GIS/MyAnneArundel.cfm

National Pollutant Discharge Elimination System Municipal Separate Storm Sewer System (NPDES MS4) Permit
http://www.mde.maryland.gov/programs/water/stormwatermanagementprogram/pages/programs/waterprograms/sedimentandstormwater/storm_gen_permit.aspx

Step Pool Storm Conveyance (SPSC) Systems
http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm

Regenerative Step Pool Storm Conveyance (SPSC) Design Guidelines
(http://www.aacounty.org/DPW/Watershed/SPSCdesignguidelinesDec2012rev5.pdf)

Stream Assessment Protocol
http://www.aacounty.org/DPW/Watershed/DownstreamAdequacyProtocols.cfm

Watershed Stewards Academy
http://www.aawsa.org/

State of Maryland Guidance

Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated – Guidance for National Pollutant Discharge Elimination System Stormwater Permits

http://www.mde.maryland.gov/programs/Permits/WaterManagementPermits/WaterDischargePermitApplications/Documents/GDP%20Stormwater/Chesapeake%20Bay%20Restoration%20Guidance/Accounting%20Guidance.pdf

Book of Standards for Highway and Incidental Structures, Maryland State Highway Administration (SHA)
http://apps.roads.maryland.gov/BusinessWithSHA/bizStdsSpecs/desManualStdPub/publicationsonline/ohd/bookstd/index.asp

Chesapeake Bay Critical Area 10% Rule Guidance Manual
http://www.dnr.state.md.us/criticalarea/guidance/10percent_rule.asp

Environmental Site Design Process and Computations
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/Documents/www.mde.state.md.us/assets/document/ESD%20Process%20Computations%20Review.pdf

Environmental Site Design Redevelopment Examples
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/Documents/ESD%20Redevelopment%20Example.pdf

Highway Drainage Manual, Maryland Department of Transportation, SHA
http://www.sha.maryland.gov/Index.aspx?PageId=38

Maryland Dam Safety Manual
(http://www.mde.state.md.us/assets/document/damsafety/MD%20Dam%20Safety%20Manual%201996.pdf)

Maryland Department of Natural Resources Rare, Threatened and Endangered Species of Maryland Plants & Animals Listed by County
http://www.dnr.state.md.us/wildlife/Plants_Wildlife/rte/rteanimals.asp

Maryland Department of the Environment Stormwater Design Manual
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Pages/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.aspx

Maryland Standards and Specifications for Soil Erosion and Sediment Control
http://www.mde.maryland.gov/programs/Water/StormwaterManagementProgram/SoilErosionandSedimentControl/Documents/2011%20MD%20Standard%20and%20Specifications%20for%20Soil%20Erosion%20and%20Sediment%20Control.pdf

Maryland Stormwater Management Guidelines for State and Federal Projects
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/Documents/www.mde.state.md.us/assets/document/State%20and%20Federal%20SWM%20Guidelines%20final.pdf

Maryland's Phase II Watershed Implementation Plan for the Chesapeake Bay TMDL , October, 2012
http://mde.maryland.gov/programs/Water/TMDL/TMDLImplementation/Documents/FINAL_PhaseII_Report_Docs/Final_Documents_PhaseII/Final_Phase_II_WIP_MAIN_REPORT_102612.pdf

NRCS-Maryland Code No. 378 Pond Standards/Specifications
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Documents/www.mde.state.md.us/assets/document/sedimentstormwater/Appnd_B1.pdf

Recommendations of the Expert Panel to Define Removal Rates for New State Stormwater Performance Standards
http://www.mde.maryland.gov/programs/water/tmdl/tmdlimplementation/documents/baltimore/final_cbp_approved_expert_panelreport_on_stormwater_%20retrofits.pdf

Stormwater Criteria for Maryland Critical Area IDA Zone
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/MarylandStormwaterDesignManual/Documents/www.mde.state.md.us/assets/document/sedimentstormwater/Appnd_D4.pdf

Additional MDE Guidance can be found on their website:
http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SedimentandStormwaterHome/Pages/Programs/WaterPrograms/SedimentandStormwater/home/index.aspx

Other Reference Document Sources

Center for Watershed Protection, Urban Subwatershed Restoration Manual No. 3: Urban Stormwater Retrofit Practices
http://www.cwp.org/online-watershed-library/cat_view/64-manuals-and-plans/80-urban-subwatershed-restoration-manual-series

http://www.cwp.org/online-watershed-library/doc_download/60-urban-subwatershed-restoration-manual-series-manual-3-urban-stormwater-retrofit-practices

Federal Highway Administration Hydraulic Engineering Circular 14 (FHWA HEC-14), Hydraulic Design of Energy Dissipators for Culverts and Channels
www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14.pdf

National Engineering Handbook Natural Resources Conservation Service, (NRCS) U.S. Department of Agriculture
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043063

NYC Street Design Manual
http://www.nyc.gov/html/dot/html/pedestrians/streetdesignmanual.shtml

Technical Release No. 20, U.S. Department of Agriculture, NRCS
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/null/?cid=stelprdb1042793

Technical Release No. 60, Earth Dams and Reservoirs, U.S. Department of Agriculture, NRCS
http://www.mde.state.md.us/assets/document/damsafety/NRCS/Earth%20Dams%20and%20Reservoirs.pdf

US Composting Council
www.compostingcouncil.org

USDA NRCS Conservation Engineering Division Technical Release 55 Urban Hydrology for Small Watersheds http://www.cpesc.org/reference/tr55.pdf ;
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?&cid=stelprdb1042901

Virginia DCR Stormwater Design Specification No. 2
http://chesapeakestormwater.net/wp-content/uploads/downloads/2012/02/DCR-BMP-Spec-No-2_SHEET-FLOW_Final-Draft_v1-9_03012011.pdf

Web Soil Survey
http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

Appendix B: Standard Details and Specifications

C.1: Bioretention Soil Mix
C.2: Stable Conveyance from Outfalls: Vegetated Filter Strip
C.3: Planting Matrices for Stormwater Management Facilities
C.4: Monitoring Gauge
C.5: Curb Bump Out
C.6: Micro-Bioretention Retrofit
C.7: Bioswales
C.8: Flow Splitter
C.9: Alternative Pavements

C.1: BIORETENTION SOIL MIX

C.1: BIORETENTION SOIL MIX

MATERIALS

A. Materials Furnished by the County

None.

B. Detailed Material Requirements

Bioretention Soil Mix (BSM) shall consist of a homogeneous mixture composed by loose volume of 5 parts Coarse Sand, 3 parts Base Soil, and 2 parts Fine Bark. BSM shall conform to the following:

1. Components. Components of BSM shall be sampled, tested and approved before mixing as follows:

   a. Coarse Sand. MSMT 356. Coarse Sand shall be washed silica sand or crushed glass that conforms to ASTM Fine Aggregate C-33. Coarse Sand shall include less than 1% by weight of clay or silt size particles, and less than 5% by weight of any combination of diabase, greystone, calcareous or dolomitic sand.

   b. Furnished Topsoil. Furnished Topsoil shall be tested and certified by the producer to conform to the requirements in the following table entitled **COMPOSITION – FURNISHED TOPSOIL**.

   c. Fine Bark. Fine Bark shall be the bark of hardwood trees that is milled and screened to a uniform particle size of 2 in. or less. Fine Bark shall be composted and aged for 6 months or longer, and be free from sawdust and foreign materials.

      A 1 to 2 lb sample of Fine Bark shall be submitted to the Landscape Operations Division for examination.

2. Composition. BSM shall be sampled and tested according to the requirements of MSMT 356 and conform to the requirements in the following table entitled **COMPOSITION – BIORETENTION SOIL MIX (BSM)**.

3. Amendment or Failure. BSM that does not conform to composition requirements for pH or nutrient analysis shall be amended as specified by the Nutrient Management Plan (NMP). BSM that exceeds maximum phosphorus concentration or fails other composition requirements will not be accepted, and shall not be delivered or used as BSM.

4. Storage. SHA 920.01.02(b). BSM shall be stored in a stockpile that is protected from weather under tarp or shed. BSM stored for 6 months or longer shall be resampled, retested, and reapproved before use.

5. Approval. SHA 920.01.02(c).

6. Certification and Delivery. SHA 920.0 1.02(d).

<table>
<tr><th colspan="6">COMPOSITION – FURNISHED TOPSOIL</th></tr>
<tr><th>TEST PROPERTY</th><th>TEST METHOD</th><th colspan="4">TEST VALUE AND AMENDMENT</th></tr>
<tr><td>Prohibited Weeds</td><td>--</td><td colspan="4">Free of seed and viable plant parts of species in SHA 920.06.02(a)(b)(c) when inspected.</td></tr>
<tr><td>Debris</td><td>--</td><td colspan="4">No observable content of cement, concrete, asphalt, crushed gravel, or construction debris when inspected.</td></tr>
<tr><td rowspan="4">Grading Analysis</td><td rowspan="4">T 87</td><td colspan="2">Sieve Size</td><td colspan="2">Passing by Weight Minimum %</td></tr>
<tr><td colspan="2">2 in.</td><td colspan="2">100</td></tr>
<tr><td colspan="2">No. 4</td><td colspan="2">90</td></tr>
<tr><td colspan="2">No. 10</td><td colspan="2">80</td></tr>
<tr><td rowspan="5">Textural Analysis</td><td rowspan="5">T 88</td><td colspan="2">Particle</td><td colspan="2">% Passing by Weight</td></tr>
<tr><td>Size</td><td>mm</td><td>Minimum</td><td>Maximum</td></tr>
<tr><td>Sand</td><td>2.0-.050</td><td>50</td><td>85</td></tr>
<tr><td>Silt</td><td>0.050-0.002</td><td>5</td><td>45</td></tr>
<tr><td>Clay</td><td>Less than 0.002</td><td>5</td><td>10</td></tr>
<tr><td>Soil pH</td><td>ASTM D 4972</td><td colspan="4">pH of 5.7 to 6.9.</td></tr>
<tr><td>Organic Matter</td><td>T 194</td><td colspan="4">1.0 to 10% by weight.</td></tr>
<tr><td>Soluble Salts</td><td>EC1:2 (V:V)</td><td colspan="4">500 ppm (0.78 mmhos/cm) or less</td></tr>
<tr><td>Harmful Materials</td><td>--</td><td colspan="4">SHA 920.01.01(c)</td></tr>
</table>

<table>
<tr><th colspan="7">COMPOSITION – BIORETENTION SOIL MIX (BSM)</th></tr>
<tr><th>TEST PROPERTY</th><th>TEST METHOD</th><th colspan="5">TEST VALUE AND AMENDMENT</th></tr>
<tr><td>Weeds</td><td>--</td><td colspan="5">Free of seed and viable plant parts of species in SHA 920.06.02(a)(b)(c) when inspected.</td></tr>
<tr><td>Debris</td><td>--</td><td colspan="5">SHA 920.01.05(b)</td></tr>
<tr><td rowspan="5">Textural Analysis</td><td rowspan="5">T 88</td><td colspan="2">Particle</td><td colspan="3">% Passing by Weight</td></tr>
<tr><td>Size</td><td>mm</td><td>Minimum</td><td colspan="2">Maximum</td></tr>
<tr><td>Sand</td><td>2.0-.050</td><td>55</td><td colspan="2">85</td></tr>
<tr><td>Silt</td><td>0.050-0.002</td><td>--</td><td colspan="2">20</td></tr>
<tr><td>Clay</td><td>Less than 0.002</td><td>1</td><td colspan="2">8</td></tr>
<tr><td>Soil pH</td><td>D 4972</td><td colspan="5">pH of 5.7 to 7.1.</td></tr>
<tr><td>Organic Matter</td><td>T 194</td><td colspan="5">Minimum 1.5% by weight</td></tr>
<tr><td rowspan="9">Nutrient Analysis and Soluble Salts Soluble Salts</td><td rowspan="8">Mehlich-3</td><td colspan="5">Concentration</td></tr>
<tr><td rowspan="2">Element</td><td colspan="2">Minimum</td><td colspan="2">Maximum</td></tr>
<tr><td>ppm</td><td>FIV</td><td>ppm</td><td>FIV</td></tr>
<tr><td>Calcium (Ca)</td><td>32</td><td>25</td><td>no limit</td><td>no limit</td></tr>
<tr><td>Magnesium (Mg)</td><td>15</td><td>25</td><td>no limit</td><td>no limit</td></tr>
<tr><td>Phosphorus (P)</td><td>18</td><td>25</td><td>92</td><td>100</td></tr>
<tr><td>Potassium (K)</td><td>22</td><td>25</td><td>no limit</td><td>no limit</td></tr>
<tr><td>Sulfur (SO_4)</td><td>25</td><td>n/a</td><td>no limit</td><td>no limit</td></tr>
<tr><td>EC1:2 (V:V)</td><td>Soluble Salts</td><td>40</td><td>n/a</td><td>500</td><td>n/a</td></tr>
<tr><td>Harmful Materials</td><td>--</td><td colspan="5">SHA 920.01.01(c)</td></tr>
</table>

Surface Storage Volume Tables for Bioretention, Bioswales, Rain Gardens, and Landscape Infiltration

Tables to be used with State Highway Administration (SHA) Bioretention Soil Mix (BSM)

Limitations and Guidance:

1) These tables are used for determining the amount of surface storage required above the media. The tables can only be used with State Highway Administration (SHA) Bioretention Soil Mix (BSM) with an infiltration rate of 1 inch/hour. The tables are not valid for media with an infiltration rate different than 1 inch/hour. If SHA BSM is not used, then 75% of the ESD volume (minimum) must be stored above the surface of the media. If SHA BSM is used but the designer elects to not use the tables, then 60% of the ESD volume (minimum) must be stored above the surface of the media.
2) The Pe correlates to the drainage area of the ESD facility.
3) The vertical column is selected based on the ratio of the surface area of the ESD facility (Af) to the impervious surface in the drainage area (Ai).
4) The horizontal row is selected based on the percentage of impervious area (% Imp) in the contributing drainage area to the ESD facility.
5) The resulting percentage is the required percentage of 100% of the ESDv that must be stored as temporary ponding above the surface of the ESD facility.
6) If the design satisfies these tables, and the minimum media depths are used from the Chapter 5 guidance, then the requirement to store 75% of the ESDv will be met.

Storage Volume (% of ESDv) required above surface for Pe = 0.1 inch

	Af/Ai										
% Imp	**2%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
5%	21%	10%	3%	0%	0%	0%	0%	0%	0%	0%	0%
10%	23%	12%	3%	0%	0%	0%	0%	0%	0%	0%	0%
15%	26%	14%	5%	0%	0%	0%	0%	0%	0%	0%	0%
20%	29%	17%	6%	0%	0%	0%	0%	0%	0%	0%	0%
25%	30%	17%	6%	0%	0%	0%	0%	0%	0%	0%	0%
30%	31%	17%	6%	0%	0%	0%	0%	0%	0%	0%	0%
35%	31%	18%	6%	0%	0%	0%	0%	0%	0%	0%	0%
40%	32%	18%	6%	0%	0%	0%	0%	0%	0%	0%	0%
45%	33%	18%	6%	0%	0%	0%	0%	0%	0%	0%	0%
50%	34%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
55%	34%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
60%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
65%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
70%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
75%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
80%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
85%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
90%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%
95%	35%	19%	6%	0%	0%	0%	0%	0%	0%	0%	0%

Storage Volume (% of ESDv) required above surface for Pe = 0.2 inch

	Af/Ai										
% Imp	**2%**	**5%**	**10%**	**15%**	**20%**	**25%**	**30%**	**35%**	**40%**	**45%**	**50%**
5%	32%	18%	10%	6%	3%	1%	0%	0%	0%	0%	0%
10%	32%	20%	12%	7%	3%	1%	0%	0%	0%	0%	0%
15%	35%	24%	14%	9%	5%	1%	0%	0%	0%	0%	0%
20%	38%	26%	17%	10%	6%	1%	0%	0%	0%	0%	0%
25%	39%	27%	17%	10%	6%	1%	0%	0%	0%	0%	0%
30%	39%	28%	17%	10%	6%	1%	0%	0%	0%	0%	0%
35%	40%	28%	18%	10%	6%	1%	0%	0%	0%	0%	0%
40%	41%	29%	18%	10%	6%	1%	0%	0%	0%	0%	0%
45%	42%	30%	18%	10%	6%	1%	0%	0%	0%	0%	0%
50%	42%	30%	19%	10%	6%	1%	0%	0%	0%	0%	0%
55%	43%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
60%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
65%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
70%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
75%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
80%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
85%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
90%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%
95%	44%	31%	19%	10%	6%	1%	0%	0%	0%	0%	0%

Storage Volume (% of ESDv) required above surface for Pe = 0.3 inch

	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	37%	24%	14%	10%	7%	5%	3%	1%	1%	0%	0%
10%	38%	25%	16%	12%	8%	6%	3%	1%	1%	0%	0%
15%	40%	29%	20%	14%	10%	7%	5%	2%	1%	0%	0%
20%	43%	32%	23%	17%	11%	9%	6%	3%	1%	0%	0%
25%	43%	32%	23%	17%	11%	8%	6%	3%	1%	0%	0%
30%	44%	33%	24%	17%	12%	8%	6%	3%	1%	0%	0%
35%	44%	34%	24%	18%	12%	8%	6%	3%	1%	0%	0%
40%	45%	35%	25%	18%	12%	8%	6%	3%	1%	0%	0%
45%	46%	36%	25%	18%	12%	8%	6%	3%	1%	0%	0%
50%	46%	36%	26%	19%	12%	8%	6%	3%	1%	0%	0%
55%	47%	37%	26%	19%	13%	9%	6%	3%	1%	0%	0%
60%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
65%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
70%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
75%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
80%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
85%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
90%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%
95%	47%	37%	27%	19%	13%	9%	6%	3%	1%	0%	0%

Storage Volume (% of ESDv) required above surface for Pe = 0.4 inch

	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	39%	28%	18%	13%	10%	8%	6%	4%	3%	2%	1%
10%	41%	29%	20%	15%	12%	9%	7%	5%	3%	1%	1%
15%	43%	32%	24%	18%	14%	11%	9%	7%	5%	3%	1%
20%	45%	35%	26%	21%	17%	13%	10%	8%	6%	3%	1%
25%	46%	36%	27%	22%	17%	13%	10%	8%	6%	3%	1%
30%	46%	37%	28%	22%	17%	13%	10%	8%	6%	3%	1%
35%	47%	38%	28%	22%	18%	13%	10%	8%	6%	3%	1%
40%	48%	38%	29%	23%	18%	13%	10%	8%	6%	3%	1%
45%	48%	39%	30%	23%	18%	13%	10%	8%	6%	3%	1%
50%	49%	40%	30%	24%	19%	14%	10%	8%	6%	3%	1%
55%	50%	41%	31%	24%	19%	14%	10%	8%	6%	3%	1%
60%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
65%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
70%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
75%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
80%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
85%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
90%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%
95%	50%	41%	31%	25%	19%	14%	10%	8%	6%	3%	1%

Storage Volume (% of ESDv) required above surface for Pe = 0.5 inch

	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	41%	32%	21%	16%	12%	10%	8%	7%	5%	4%	3%
10%	43%	32%	23%	18%	14%	12%	10%	8%	6%	5%	3%
15%	45%	35%	26%	21%	18%	14%	12%	9%	8%	6%	5%
20%	47%	38%	29%	24%	20%	17%	13%	11%	9%	7%	6%
25%	48%	39%	30%	24%	21%	17%	14%	11%	9%	7%	6%
30%	48%	39%	31%	25%	21%	17%	14%	11%	9%	7%	6%
35%	49%	40%	31%	26%	22%	18%	14%	11%	9%	7%	6%
40%	50%	41%	32%	26%	22%	18%	14%	11%	9%	7%	6%
45%	50%	42%	33%	27%	22%	18%	14%	11%	9%	7%	6%
50%	51%	42%	34%	28%	23%	19%	15%	11%	9%	7%	6%
55%	52%	43%	34%	28%	23%	19%	15%	12%	9%	7%	6%
60%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
65%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
70%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
75%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
80%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
85%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
90%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%
95%	52%	44%	35%	28%	23%	19%	15%	12%	9%	7%	6%

Storage Volume (% of ESDv) required above surface for Pe =							0.6	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	42%	34%	24%	18%	14%	12%	10%	9%	7%	6%	5%
10%	45%	35%	25%	20%	16%	14%	12%	10%	8%	7%	6%
15%	47%	37%	29%	24%	20%	17%	14%	12%	10%	9%	7%
20%	49%	40%	32%	26%	23%	20%	17%	14%	11%	10%	9%
25%	49%	41%	32%	27%	23%	20%	17%	14%	11%	10%	8%
30%	50%	41%	33%	28%	24%	20%	17%	14%	12%	10%	8%
35%	50%	42%	34%	28%	24%	21%	18%	15%	12%	10%	8%
40%	51%	43%	35%	29%	25%	21%	18%	15%	12%	10%	8%
45%	52%	44%	36%	30%	25%	22%	18%	15%	12%	10%	8%
50%	52%	44%	36%	30%	26%	22%	19%	15%	12%	10%	8%
55%	53%	45%	37%	31%	26%	22%	19%	16%	13%	10%	9%
60%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
65%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
70%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
75%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
80%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
85%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
90%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%
95%	53%	45%	37%	31%	27%	23%	19%	16%	13%	10%	9%

Storage Volume (% of ESDv) required above surface for Pe =							0.7	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	43%	36%	26%	20%	16%	14%	12%	10%	9%	8%	6%
10%	46%	37%	27%	22%	18%	16%	13%	12%	10%	9%	7%
15%	48%	39%	30%	25%	22%	19%	17%	14%	12%	10%	9%
20%	50%	42%	33%	28%	25%	22%	19%	17%	14%	12%	11%
25%	50%	42%	34%	29%	25%	22%	20%	17%	15%	12%	11%
30%	51%	43%	35%	30%	26%	23%	20%	17%	15%	12%	11%
35%	51%	44%	36%	30%	26%	23%	20%	18%	15%	12%	11%
40%	52%	44%	37%	31%	27%	24%	21%	18%	15%	13%	11%
45%	53%	45%	38%	32%	28%	24%	21%	18%	16%	13%	11%
50%	53%	46%	38%	33%	28%	25%	21%	19%	16%	13%	11%
55%	54%	46%	39%	33%	29%	25%	22%	19%	16%	13%	11%
60%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
65%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
70%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
75%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
80%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
85%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
90%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%
95%	55%	47%	39%	34%	29%	26%	22%	19%	16%	13%	11%

Storage Volume (% of ESDv) required above surface for Pe =							0.8	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	43%	38%	28%	22%	18%	15%	13%	11%	10%	9%	8%
10%	46%	38%	29%	24%	20%	17%	15%	13%	12%	10%	9%
15%	49%	41%	32%	27%	24%	21%	18%	16%	14%	12%	11%
20%	51%	43%	35%	30%	26%	23%	21%	19%	17%	15%	13%
25%	51%	44%	36%	31%	27%	24%	22%	19%	17%	15%	13%
30%	52%	44%	37%	32%	28%	24%	22%	20%	17%	15%	13%
35%	52%	45%	38%	32%	28%	25%	22%	20%	18%	15%	13%
40%	53%	46%	38%	33%	29%	26%	23%	20%	18%	16%	13%
45%	54%	46%	39%	34%	30%	26%	23%	21%	18%	16%	13%
50%	54%	47%	40%	35%	30%	27%	24%	21%	19%	16%	14%
55%	55%	48%	41%	35%	31%	28%	24%	21%	19%	16%	14%
60%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
65%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
70%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
75%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
80%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
85%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
90%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%
95%	55%	48%	41%	36%	31%	28%	25%	22%	19%	17%	14%

Storage Volume (% of ESDv) required above surface for Pe =							0.9	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	44%	39%	30%	24%	20%	17%	14%	13%	11%	10%	9%
10%	47%	40%	31%	25%	22%	19%	16%	15%	13%	12%	11%
15%	50%	42%	34%	29%	25%	22%	20%	18%	16%	14%	13%
20%	52%	44%	37%	32%	28%	25%	23%	21%	19%	17%	15%
25%	52%	45%	37%	32%	28%	25%	23%	21%	19%	17%	15%
30%	52%	45%	38%	33%	29%	26%	24%	22%	19%	17%	15%
35%	53%	46%	39%	34%	30%	27%	24%	22%	20%	18%	16%
40%	54%	47%	40%	35%	31%	27%	25%	22%	20%	18%	16%
45%	54%	47%	41%	36%	32%	28%	25%	23%	21%	18%	16%
50%	55%	48%	41%	36%	32%	29%	26%	23%	21%	19%	16%
55%	56%	49%	42%	37%	33%	29%	26%	24%	21%	19%	17%
60%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
65%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
70%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
75%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
80%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
85%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
90%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%
95%	56%	49%	42%	37%	33%	30%	27%	24%	21%	19%	17%

Storage Volume (% of ESDv) required above surface for Pe =							1	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	44%	39%	32%	26%	21%	18%	16%	14%	12%	11%	10%
10%	47%	41%	32%	27%	23%	20%	18%	16%	14%	13%	12%
15%	50%	43%	35%	30%	26%	24%	21%	19%	18%	16%	14%
20%	52%	45%	38%	33%	29%	26%	24%	22%	20%	19%	17%
25%	52%	46%	39%	34%	30%	27%	24%	23%	21%	19%	17%
30%	53%	46%	39%	35%	31%	28%	25%	23%	21%	19%	17%
35%	53%	47%	40%	35%	31%	28%	26%	23%	22%	20%	18%
40%	54%	48%	41%	36%	32%	29%	26%	24%	22%	20%	18%
45%	55%	48%	42%	37%	33%	30%	27%	25%	22%	20%	18%
50%	56%	49%	42%	38%	34%	30%	28%	25%	23%	21%	19%
55%	56%	50%	43%	38%	34%	31%	28%	26%	23%	21%	19%
60%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
65%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
70%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
75%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
80%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
85%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
90%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%
95%	57%	50%	44%	39%	35%	31%	28%	26%	23%	21%	19%

Storage Volume (% of ESDv) required above surface for Pe =							1.1	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	44%	40%	33%	27%	23%	19%	17%	15%	13%	12%	11%
10%	48%	42%	33%	28%	24%	21%	19%	17%	15%	14%	13%
15%	51%	44%	36%	31%	27%	25%	22%	21%	19%	17%	16%
20%	53%	46%	39%	34%	30%	27%	25%	23%	22%	20%	18%
25%	53%	47%	40%	35%	31%	28%	26%	24%	22%	20%	19%
30%	53%	47%	40%	36%	32%	29%	26%	24%	22%	21%	19%
35%	54%	48%	41%	37%	33%	30%	27%	25%	23%	21%	19%
40%	55%	48%	42%	37%	34%	30%	28%	26%	23%	22%	20%
45%	55%	49%	43%	38%	34%	31%	28%	26%	24%	22%	20%
50%	56%	50%	43%	39%	35%	32%	29%	27%	24%	22%	20%
55%	57%	50%	44%	39%	36%	33%	30%	27%	25%	23%	21%
60%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
65%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
70%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
75%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
80%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
85%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
90%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%
95%	57%	51%	45%	40%	36%	33%	30%	28%	25%	23%	21%

Storage Volume (% of ESDv) required above surface for Pe =							1.2	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	41%	34%	28%	24%	21%	18%	16%	14%	13%	12%
10%	48%	43%	35%	29%	25%	22%	20%	18%	16%	15%	14%
15%	51%	45%	37%	32%	29%	26%	24%	22%	20%	18%	17%
20%	53%	47%	40%	35%	32%	29%	26%	24%	23%	21%	20%
25%	53%	47%	41%	36%	32%	29%	27%	25%	23%	22%	20%
30%	54%	48%	41%	37%	33%	30%	28%	25%	24%	22%	20%
35%	54%	49%	42%	38%	34%	31%	28%	26%	24%	22%	21%
40%	55%	49%	43%	38%	35%	32%	29%	27%	25%	23%	21%
45%	56%	50%	44%	39%	36%	33%	30%	27%	25%	23%	22%
50%	56%	51%	44%	40%	36%	33%	30%	28%	26%	24%	22%
55%	57%	51%	45%	41%	37%	34%	31%	29%	26%	24%	22%
60%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
65%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
70%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
75%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
80%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
85%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
90%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%
95%	57%	52%	45%	41%	37%	34%	31%	29%	27%	25%	23%

Storage Volume (% of ESDv) required above surface for Pe =							1.3	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	41%	35%	30%	25%	22%	19%	17%	15%	14%	13%
10%	48%	43%	36%	30%	26%	23%	21%	19%	18%	16%	15%
15%	51%	46%	38%	33%	30%	27%	24%	23%	21%	19%	18%
20%	53%	48%	41%	36%	32%	30%	27%	25%	24%	22%	21%
25%	54%	48%	41%	37%	33%	30%	28%	26%	24%	23%	21%
30%	54%	49%	42%	38%	34%	31%	29%	27%	25%	23%	22%
35%	55%	49%	43%	38%	35%	32%	29%	27%	25%	24%	22%
40%	55%	50%	44%	39%	36%	33%	30%	28%	26%	24%	22%
45%	56%	50%	44%	40%	37%	34%	31%	29%	27%	25%	23%
50%	57%	51%	45%	41%	37%	34%	32%	29%	27%	25%	23%
55%	57%	52%	46%	41%	38%	35%	32%	30%	28%	26%	24%
60%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
65%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
70%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
75%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
80%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
85%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
90%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%
95%	58%	52%	46%	42%	38%	35%	33%	30%	28%	26%	24%

Storage Volume (% of ESDv) required above surface for Pe =							1.4	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	42%	36%	31%	26%	23%	20%	18%	16%	15%	14%
10%	49%	44%	37%	31%	27%	24%	22%	20%	18%	17%	16%
15%	52%	46%	39%	34%	30%	28%	25%	24%	22%	20%	19%
20%	54%	48%	42%	37%	33%	31%	28%	26%	25%	23%	22%
25%	54%	49%	42%	38%	34%	31%	29%	27%	25%	24%	22%
30%	55%	49%	43%	39%	35%	32%	30%	28%	26%	24%	23%
35%	55%	50%	44%	39%	36%	33%	30%	28%	26%	25%	23%
40%	56%	50%	44%	40%	37%	34%	31%	29%	27%	25%	24%
45%	56%	51%	45%	41%	38%	35%	32%	30%	28%	26%	24%
50%	57%	52%	46%	42%	38%	35%	33%	30%	28%	27%	25%
55%	58%	52%	46%	42%	39%	36%	33%	31%	29%	27%	25%
60%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
65%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
70%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
75%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
80%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
85%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
90%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%
95%	58%	53%	47%	43%	39%	36%	34%	31%	29%	27%	26%

Storage Volume (% of ESDv) required above surface for Pe =							1.5	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	42%	37%	32%	27%	24%	21%	19%	17%	16%	14%
10%	49%	45%	38%	32%	28%	25%	23%	21%	19%	18%	16%
15%	52%	47%	40%	35%	31%	29%	26%	24%	23%	21%	20%
20%	54%	49%	43%	38%	34%	32%	29%	27%	25%	24%	23%
25%	54%	49%	43%	39%	35%	32%	30%	28%	26%	24%	23%
30%	55%	50%	44%	39%	36%	33%	31%	29%	27%	25%	24%
35%	55%	50%	44%	40%	37%	34%	31%	29%	27%	26%	24%
40%	56%	51%	45%	41%	38%	35%	32%	30%	28%	26%	25%
45%	57%	52%	46%	42%	38%	36%	33%	31%	29%	27%	25%
50%	57%	52%	46%	42%	39%	36%	34%	32%	29%	28%	26%
55%	58%	53%	47%	43%	40%	37%	34%	32%	30%	28%	26%
60%	58%	53%	47%	44%	40%	37%	35%	33%	30%	28%	27%
65%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%
70%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%
75%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%
80%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%
85%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%
90%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%
95%	58%	53%	47%	44%	40%	37%	35%	32%	30%	28%	27%

Storage Volume (% of ESDv) required above surface for Pe =							1.6	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	42%	38%	33%	28%	25%	22%	20%	18%	16%	15%
10%	49%	45%	38%	33%	29%	26%	24%	22%	20%	19%	17%
15%	52%	47%	41%	36%	32%	29%	27%	25%	24%	22%	21%
20%	54%	49%	43%	39%	35%	32%	30%	28%	26%	25%	23%
25%	55%	50%	44%	39%	36%	33%	31%	29%	27%	25%	24%
30%	55%	50%	44%	40%	37%	34%	32%	29%	28%	26%	24%
35%	56%	51%	45%	41%	38%	35%	32%	30%	28%	27%	25%
40%	56%	51%	46%	42%	38%	36%	33%	31%	29%	27%	26%
45%	57%	52%	46%	42%	39%	36%	34%	32%	30%	28%	26%
50%	58%	53%	47%	43%	40%	37%	35%	33%	30%	29%	27%
55%	58%	53%	48%	44%	41%	38%	35%	33%	31%	29%	28%
60%	59%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
65%	59%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
70%	58%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
75%	58%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
80%	58%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
85%	58%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
90%	58%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%
95%	58%	54%	48%	44%	41%	38%	36%	34%	31%	30%	28%

Storage Volume (% of ESDv) required above surface for Pe =							1.7	inch			
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	43%	38%	34%	29%	26%	23%	21%	19%	17%	16%
10%	49%	45%	39%	34%	30%	27%	24%	23%	21%	19%	18%
15%	52%	48%	41%	37%	33%	30%	28%	26%	24%	23%	21%
20%	54%	50%	44%	39%	36%	33%	31%	29%	27%	25%	24%
25%	55%	50%	44%	40%	37%	34%	31%	29%	28%	26%	25%
30%	55%	50%	45%	41%	37%	35%	32%	30%	28%	27%	25%
35%	56%	51%	46%	41%	38%	36%	33%	31%	29%	28%	26%
40%	57%	52%	46%	42%	39%	36%	34%	32%	30%	28%	27%
45%	57%	53%	47%	43%	40%	37%	35%	33%	31%	29%	27%
50%	58%	53%	48%	44%	41%	38%	35%	33%	31%	29%	28%
55%	58%	54%	48%	44%	41%	38%	36%	34%	32%	30%	28%
60%	59%	54%	49%	45%	42%	39%	37%	34%	32%	31%	29%
65%	59%	54%	49%	45%	42%	39%	37%	34%	32%	31%	29%
70%	59%	54%	49%	45%	42%	39%	37%	34%	32%	31%	29%
75%	59%	54%	48%	45%	42%	39%	37%	34%	32%	31%	29%
80%	59%	54%	48%	45%	42%	39%	37%	34%	32%	31%	29%
85%	59%	54%	48%	45%	42%	39%	37%	34%	32%	31%	29%
90%	59%	54%	48%	45%	42%	39%	37%	34%	32%	31%	29%
95%	59%	54%	48%	45%	42%	39%	37%	34%	32%	31%	29%

Storage Volume (% of ESDv) required above surface for Pe = 1.8 inch											
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	43%	39%	34%	30%	27%	24%	22%	20%	18%	17%
10%	49%	46%	40%	35%	31%	28%	25%	23%	22%	20%	19%
15%	52%	48%	42%	37%	34%	31%	29%	27%	25%	24%	22%
20%	55%	50%	44%	40%	37%	34%	32%	30%	28%	26%	25%
25%	55%	50%	45%	41%	37%	35%	32%	30%	28%	27%	25%
30%	56%	51%	45%	41%	38%	36%	33%	31%	29%	28%	26%
35%	56%	51%	46%	42%	39%	36%	34%	32%	30%	28%	27%
40%	57%	52%	47%	43%	40%	37%	35%	33%	31%	29%	27%
45%	57%	53%	47%	44%	41%	38%	36%	33%	32%	30%	28%
50%	58%	54%	48%	44%	41%	39%	36%	34%	32%	30%	29%
55%	58%	54%	49%	45%	42%	39%	37%	35%	33%	31%	29%
60%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
65%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
70%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
75%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
80%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
85%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
90%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%
95%	59%	55%	49%	45%	42%	40%	37%	35%	33%	31%	30%

Storage Volume (% of ESDv) required above surface for Pe = 1.9 inch											
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	45%	43%	39%	35%	31%	28%	25%	22%	20%	19%	17%
10%	49%	46%	40%	35%	31%	28%	26%	24%	22%	21%	20%
15%	53%	49%	43%	38%	34%	32%	29%	27%	26%	24%	23%
20%	55%	51%	45%	41%	37%	34%	32%	30%	28%	27%	26%
25%	55%	51%	45%	41%	38%	35%	33%	31%	29%	28%	26%
30%	56%	51%	46%	42%	39%	36%	34%	32%	30%	28%	27%
35%	56%	52%	47%	43%	40%	37%	35%	33%	31%	29%	28%
40%	57%	53%	47%	43%	40%	38%	36%	33%	32%	30%	28%
45%	57%	53%	48%	44%	41%	38%	36%	34%	32%	31%	29%
50%	58%	54%	49%	45%	42%	39%	37%	35%	33%	31%	30%
55%	59%	55%	49%	45%	43%	40%	38%	36%	34%	32%	30%
60%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
65%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
70%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
75%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
80%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
85%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
90%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%
95%	59%	55%	50%	46%	43%	40%	38%	36%	34%	32%	31%

Storage Volume (% of ESDv) required above surface for Pe = 2 - 2.6 inches											
	Af/Ai										
% Imp	2%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
5%	46%	43%	39%	36%	32%	28%	26%	23%	21%	19%	18%
10%	50%	46%	41%	36%	32%	29%	27%	25%	23%	21%	20%
15%	53%	49%	43%	39%	35%	32%	30%	28%	26%	25%	24%
20%	55%	51%	45%	41%	38%	35%	33%	31%	29%	28%	26%
25%	55%	51%	46%	42%	39%	36%	34%	32%	30%	28%	27%
30%	56%	52%	46%	42%	39%	37%	35%	32%	31%	29%	28%
35%	56%	52%	47%	43%	40%	38%	35%	33%	31%	30%	28%
40%	57%	53%	48%	44%	41%	38%	36%	34%	32%	31%	29%
45%	58%	54%	48%	45%	42%	39%	37%	35%	33%	31%	30%
50%	58%	54%	49%	45%	42%	40%	38%	36%	34%	32%	30%
55%	59%	55%	50%	46%	43%	41%	38%	36%	34%	33%	31%
60%	59%	55%	50%	46%	44%	41%	39%	37%	35%	33%	31%
65%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%
70%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%
75%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%
80%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%
85%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%
90%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%
95%	59%	55%	50%	46%	43%	41%	39%	37%	35%	33%	31%

Sediment and Stormwater Plan Review Division
Application and Methodology of Surface Storage Volume Tables for Bioretention and Bioswale, Rain Garden, and Landscape Infiltration Facilities

Intent

Bioretention, bioswales, rain gardens, and landscape infiltration treat runoff by allowing stormwater to filter through a layer of planting soil that is rich with micro-organisms. To be filtered effectively by the facility, stormwater must enter the soil media. If the filtering practice is located in a swale there is uncertainty about whether the flow will enter the media or runoff down the swale and bypass treatment. The same concern extends to bioretention, rain gardens, and landscape infiltration because the Environmental Site Design (ESD) volume for any facility served by an overflow device has the potential to prematurely flow out of the facility and bypass treatment. The only way to allow the ESD volume adequate opportunity to enter the filter media is by providing surface storage above the filter media to detain the runoff. But how much storage is necessary?

The Sediment and Stormwater Plan Review Division with help from the State Highway Administration (SHA) examined this question by applying hydrologic/hydraulic principals for a bioswale to a basic reservoir analysis. A "calculator" was developed that modeled the stormwater flows to the bioswale, flow rates through the media, and storage volume. (Refer to "**Bio-Swale Storage Calculator"** for more information.) The resulting output provides surface storage volumes necessary for treating ESD volume. Storage requirements vary significantly depending on the target rainfall (P_E) being treated, the surface area of the filter, and the imperviousness of the drainage area. For example, a facility with a larger surface area requires less surface storage than one with a smaller surface area. Because of the complexity of the Calculator, tables for design purposes were developed from a broad range of simulations. (Refer to "**Development of Tables**" for an explanation of how the tables were developed.)

Limitations

The Calculator assumes that the filter media is comprised of SHA bio-soil mix (BSM) with an infiltration rate of 1 inch per hour. The Surface Storage Tables are not valid for use on treatment facilities that have a different infiltration rate than SHA BSM. If a filter planting media is used that has a different infiltration rate from the SHA BSM, then 75% of the ESD volume (ESDv) should be provided above the surface of the filter. The Calculator and Surface Storage Tables also assume that the layer of planting media (SHA BSM) will be the limiting factor in determining the overall facility infiltration rate. The Surface Storage Tables will not be accurate for treatment facilities without an underdrain located on soils with an infiltration rate of less than 1 in./hr. In this situation the surface storage volume shall be at least equal to the 75% ESDv treatment requirement.

Using the Surface Storage Volume Tables

From the twenty tables provided, select the appropriate table for the respective target P_E (in), ranging from 0.1 inch to 2.6 inches. Note that the P_E correlates to the drainage area of the ESD facility. Enter the left side of the table for the imperviousness [%Imp = impervious area draining to facility (A_i)/drainage area to facility (A) = 100(A_i /A)] of the contributing drainage area to the ESD facility (negating the area occupied by the facility itself). Enter the top of the table for the ratio of the surface area of the facility (A_f) to the impervious area draining to the facility (A_i). The point where these two values intersect is the minimum required surface storage volume, expressed as a percentage of the ESDv. Multiplying this percentage by **100% of the required ESDv** gives the ponding volume that must be temporarily stored above the filter bed surface of the ESD facility in order to fully treat the respective P_E.

If the ESD facility provides the required surface storage and the minimum media depths given in MDE guidance, then the design requirements, including the 75% of the ESDv treatment requirement, will be satisfied.

Example 1 (insufficient surface storage)

Drainage area criteria
A 10,000 square foot area drains to a proposed micro biorention facility. (The drainage area includes facility.) The drainage area contains 4000 ft^2 of impervious area, and the hydrologic soil group is C.

Calculate
$I = 4000\ ft^2/10{,}000\ ft^2 = 0.4 = 40\%$
$R_v = 0.05+0.009(I) = 0.05+0.009(40) = 0.41$
The target P_E for the drainage area to the facility is 1.8 inches.
$ESDv = (P_E)(R_v)(A)/12 = (1.8\ in)(0.41)(10{,}000\ ft^2)/(12in/ft) = 615\ ft^3$

Biorention facility geometry
The surface area of the filter is 800 ft^2.
The storage provided above the surface of the media is 185 ft^3.

Quantifying the target rainfall (P_E) treated
Using the table for P_E =1.8 inches, enter at %Imp = 40% and $A_f/A_i = 800\ ft^2/4000\ ft^2 = 20\%$.
Read the required surface storage as 40%.

The provided surface storage is only $185\ ft^3/615\ ft^3 = 30\%$. Therefore, the P_E of 1.8 inch is not being completely treated. At this point, the designer needs to either (1) revise the design of the facility so that the required surface storage is provided or (2) calculate the P_E treated (or achieved) based on the current design.

(1) Revising the design of the facility to treat the full target P_E can be accomplished by:
   a. Providing more surface storage;
   b. Increasing the surface area of the filter; and/or
   c. Reducing the % Impervious in the drainage area to the filter.

(2) Calculate the P_E treated
   The proposed facility does not provide enough surface storage to treat the target P_E of 1.8 inches. The P_E treated is based on providing a surface storage volume that is a certain percent of the ESDv, but that ESDv changes depending on the P_E. Therefore, determining the P_E treated is an iterative process. Continue the iterations until the actual storage and required storage are equal. This is best demonstrated in a table.

Iteration	P_E	ESDv	required % surface storage from tables	actual % surface storage = (185 ft^3 /ESDv)
1	1.8 in	615 ft^3	40 %	30 %
2	0.9 in	308 ft^3	31 %	60 %
3	1.2 in	410 ft^3	35 %	45 %
4	1.4 in	478 ft^3	37 %	39 %
5	1.5 in	512 ft^3	38 %	36 %

The achieved P_E for this example is 1.45 inches, and the ESDv attained by the facility is 495 ft^3.

Example 2 (excess surface storage)

Drainage area criteria
A 10,000 square foot area drains to a proposed micro biorention facility. (The drainage area includes facility.) The drainage area contains 4000 ft^2 of impervious area, and the hydrologic soil group is C.

Calculate $I = 4000\ ft^2/10{,}000\ ft^2 = 0.4 = 40\%$

$R_v = 0.05+0.009(I) = 0.05+0.009(40) = 0.41$

The target P_E for the drainage area to the facility is 1.8 inches.

$ESDv = (P_E)(R_v)(A)/12 = (1.8\ in)(0.41)(10{,}000\ ft^2)/(12in/ft) = 615\ ft^3$

Biorention facility geometry
The surface area of the filter is 800 ft^2.
The storage provided above the surface of the media is 280 ft^3.

Quantifying the target rainfall (P_E) treated
Using the table for P_E =1.8 inches, enter at %Imp = 40% and $A_f/A_i = 800\ ft^2/4000\ ft^2 = 20\%$.
Read the required surface storage as 40%.

The provided surface storage is $280\ ft^3/615\ ft^3 = 46\%$. Therefore, more than enough surface storage is being provided. The excess storage means that the P_E being treated is larger than the target.

The P_E treated is based on providing a surface storage volume that is a certain percent of the ESDv, but that ESDv changes depending on the P_E. Therefore, determining the P_E treated is an iterative process. Continue the iterations until the actual storage and required storage are equal. This is best demonstrated in a table.

Iteration	P_E	ESDv	required % surface storage from tables	actual % surface storage = (280 ft^3 /ESDv)
1	1.8 in	615 ft^3	40 %	46 %
2	1.9 in	649 ft^3	40 %	43 %
3	2.0 in	683 ft^3	41 %	41 %

The achieved P_E for this example is 2.0 inches, and the ESDv attained by the facility is 683 ft^3.

Bio-Swale Storage Calculator

The calculator modeled stormwater flows to a facility, flow rates through the media, and storage. Runoff was computed using SCS methodologies and the Method for Computing Peak Discharge for Water Quality Storm found in Appendix D.10 of the 2000 Maryland Stormwater Design Manual. This method was used to compute the Runoff Curve Number (CN) because conventional SCS methods underestimate the volume and rate of runoff for rainfall events less than 2 inches. The Ia/P value was calculated from the user-entered site information and based on Equations 2-2 and 2-4 found in Chapter 2 of the TR-55 Manual. The Calculator used the calculated Ia/P to determine the unit peak discharge that was used for each time interval. The Tabular Hydrograph Unit Discharges (csm/in) for Type II Rainfall Distribution tables from Chapter 5 of the TR-55 Manual for drainage areas with a Tc of 0.1 and an Ia/P of 0.1, 0.3, and 0.5 were included in the Calculator. The Calculator used linear interpolation to calculate the unit discharge for any drainage area with an Ia/P value between the Ia/P values supplied by the TR-55 tables. For Ia/P values smaller than 0.1 or larger than 0.5, the unit discharges corresponding to the Ia/P of 0.1 and 0.5 were used, respectively. An Excel forecast and match function was used to interpolate between the time intervals for the TR-55 supplied unit discharges to develop a table of unit discharges starting at hour 11 of the rainfall event to hour 26 at a constant time interval of 0.1 hour. The peak discharge into the bioswale was calculated at each time interval using equation 4.1 from Chapter 4 of the TR-55 Manual.

The volume of water that infiltrated into the media at each time interval was calculated using the surface area of the filter media (A_f) and a media filtration rate of 2 feet per day (1 inch per hour). This filtration rate was approved for use with SHA BSM in 2003. The porosity of the media was 40%. The bottom width of the bioswales was held at a constant 8 feet. The length of the bioswale was adjusted to achieve the A_f required to satisfy the user entered A_f /A_i ratio. The planting media depth was a constant 2 feet.

When the stormwater runoff volume that entered the treatment facility during the 0.1 hour time interval exceeded the volume of water infiltrated into the media bed, the volume of water that did not infiltrate was added to the temporary surface storage volume. As the temporary surface storage volume increased, the Calculator used Darcy's law to increase the infiltration rate slightly as the depth of the water stored above the filter bed surface generated hydraulic head. The Calculator assumed a constant surface storage depth across the entire treatment facility (i.e. 0% longitudinal bioswale slope). The Calculator also assumed that water is only stored directly above the filter bed (i.e., no side slopes). For every time interval where the volume of stormwater runoff that entered the treatment facility was greater than the volume of water that infiltrated into the filter bed media, the excess volume was added to the surface storage volume. Once the rate of the stormwater runoff entering the treatment facility decreased below the rate at which water infiltrated into the filter bed media, the water stored above the surface of the filter bed began to drain through the filter media. The surface storage volume used to calculate the surface storage requirement is the maximum surface storage volume achieved before the stormwater runoff entering the facility subsided to the point where the water stored above the surface will begin to decrease.

Development of Tables

The Calculator was used to develop the Surface Storage Volume Tables. Simulations were repeated for rainfalls ranging from 0.1 inches to 2.6 inches at 0.1 inch intervals. Each 24 hour rainfall rate was used to generate a separate surface storage table. The surface storage tables for rainfall from 2.0 to 2.6 inches were consolidated into one table because there were negligible differences between these tables. A drainage area of 1 acre was used. However, the drainage area does not affect the results of the Surface Storage Tables because the Calculator adjusts the surface area of the treatment facility (A_f) based on a user entered filter surface area to impervious area ratio (A_f /A_i). This causes the A_f to rise to match an increase in the drainage area. Within each target rainfall table, a specific A_f /A_i ratio and site impervious percent was used to calculate a surface storage volume requirement. This surface storage volume requirement is expressed as a percent of the 100% ESDv for the drainage area to the treatment facility.

C.2: STABLE CONVEYANCE FROM OUTFALLS:
VEGETATED FILTER STRIP

C.2: VEGETATED FILTER STRIPS

Designer Information

Critical to the development of a thorough stormwater management plan is the establishment of stable conveyance of stormwater runoff from all outfalls from a project site. Therefore, an important element of design is to select the correct point of investigation. The point of investigation (POI) should be located far enough below the project site to ensure that runoff from the site will not cause flooding, erosion, or sedimentation of the downstream properties.

Design Considerations

The following shall be considered when evaluating downstream impacts:

- The stream should be assessed using the County's Stream Assessment Protocol, which can be accessed at the following location:
- If the existing system downstream of the POI is already degraded, additional stormwater management volume may be required to protect from further degradation. The County may require improvements to the downstream system in addition to work within the project site.
- When evaluating downstream impacts, the volume of runoff must be considered in addition to management of peak flows, as increased volume will increase the duration that the downstream area is subjected to the peak flow.
- When bioswales are proposed as part of the project design, the outfall from the project site should be designed to convey flows for the 10-year storm event without erosion or flooding, assuming that the bioswale is not functioning.
- Refer to the County's Comprehensive Watershed Studies to determine if there are specific requirements for the impacted watersheds.

Gravel Diaphragm

1. A gravel diaphragm is required for sheet flow from an impervious area. If the project area is solely turf, the gravel diaphragm is optional.
2. A gravel diaphragm shall be located at the same elevation as the top of the filter strip.
3. Stone for sheet flow from project area slope:

   $<6\%$ use pea gravel
   $\geq 6\%$ use clean bank run gravel, #57 stone

Permeable Berm

1. The permeable berm shall consist of:

   40% excavated soils
   40% sand
   20% pea gravel

2. Stone may be needed to armor the top of the berm to handle larger storm events.

Soil Notes

1. A vegetated filter strip shall not be used in fill soils.
2. Compost soil amendments shall extend over the full length and width of the filter strip for Hydrologic Soil Group (HSG) B, C, and D soils.
3. Compost soil amendments are not recommended where:
    a. Soils are HSG A.
    b. Bedrock or water table is 1.5 feet or less below the finished surface elevation.
    c. Existing soils are saturated or seasonally wet.
    d. They would harm roots of existing trees (keep amendments out of the tree drip line).
    e. Downhill slope runs to an existing or proposed building foundation.
    f. The contributing impervious surface exceeds the surface area of the amended soils.
4. Soil tests are required during two stages of the compost amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The initial testing is used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, pH, salts, and soil nutrients. These tests should be conducted every 5,000 square feet, and are used to characterize potential drainage problems and determine what, if any, further soil amendments are needed. The second soil test is taken at least 1 week after the compost has been incorporated into the soils. This soil analysis should be conducted by a reputable laboratory to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. This soil analysis should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.
5. See table below to determine compost depth and incorporation depth.

Contributing Impervious Cover to Soil Amendment Area Ratio[1]				
	IC/SA=0 [2]	**IC/SA=0.5**	**IC/SA=0.75**	**IC/SA=1.0** [3]
Compost (in)[4]	2 to 4 [5]	3 to 6 [5]	4 to 8 [5]	6 to 10 [5]
Incorporation Depth (in)	6 to 10 [5]	8 to 12 [5]	15 to 18 [5]	18 to 24 [5]
Incorporation Method (in)	Rototiller	Tiller	Subsoiler	Subsoiler

Notes:
[1] IC = contributing impervious cover (sf) and SA = surface area of compost amendment (sf).
[2] For amendment of areas that do not receive impervious site runoff.
[3] In general, IC/SA ratios greater than 1 should be avoided.
[4] Average depth of compost added.
[5] Lower end for B soils, higher end for C/D soils.

Source: Virginia DCR Stormwater Design Specification No. 4, Soil Compost Amendment

6. Compost Specifications. The basic material specifications for compost amendments are outlined below:
    a. Compost shall be derived from plant material and provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program. See for a list of local providers.

b. The compost shall be the result of the biological degradation and transformation of plant derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the following criteria, as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor:
    i. 100% of the material must pass through a 1/2 inch screen
    ii. The pH of the material shall be between 6 and 8
    iii. Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0% by weight
    iv. The organic matter content shall be between 35% and 65%
    v. Soluble salt content shall be less than 6.0 mmhos/cm
    vi. Maturity should be greater than 80%
    vii. Stability shall be 7 or less
    viii. Carbon/nitrogen ratio shall be less than 25:1
    ix. Trace metal test result = “pass”
    x. The compost must have a dry bulk density ranging from 40 to 50 lb./cu. ft.

7. If slopes exceed 3%, install temporary soil stabilization matting to stabilize the site prior to runoff discharge.
8. The County may waive the requirement for compost amendments on HSG-B soils if (1) the designer can provide verification of the adequacy of the on-site soil type, texture, and profile to function as a filter strip, and (2) the area designated for the filter strip will not be disturbed during construction.

Planting and Vegetation Management Notes

1. Vegetated filter strips shall be planted at such a density to achieve a 90% grass/herbaceous cover after the second growing season.
2. Filter strips shall be seeded, not sodded. Seeding establishes deeper roots, and sod may have mucky soil that is not conducive to infiltration.
3. The filter strip vegetation may consist of turf grasses, meadow grasses, other herbaceous plants, shrubs, and trees, as long as the primary goal of at least 90% coverage with grasses and/or other herbaceous plants is achieved.
4. Designers should choose vegetation that stabilizes the soils and is salt tolerant.
5. Vegetation at the toe of the filter where temporary ponding may occur behind the permeable berm should be able to withstand both wet and dry periods.
6. The planting areas can be divided into zones to account for differences in inundation and slope.

Contractor Notes (Designer to Edit As Appropriate)

Suggested Construction Sequence: Vegetated filter strips can be within the limits of disturbance during construction. The following procedures shall be followed during construction:

1. Clearly mark vegetated filter strip boundaries before work begins.

2. Only vehicular traffic used for filter strip construction should be allowed within 10 feet of the filter strip boundary.
3. If existing topsoil is stripped during grading, it shall be stockpiled for future use.
4. Construction runoff should be directed away from the proposed filter strip site using a diversion dike or other approved method.
5. If included, construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter erosion and sediment controls have been removed and cleaned out.
6. Vegetated filter strips require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction. Topsoil and compost amendments shall be incorporated evenly across the filter strip area, stabilized with seed, and protected by temporary soil stabilization matting.
7. Stormwater should not be diverted into the filter strip until the turf cover is dense and well established.

Compost Placement

1. Compost amendments shall not be incorporated until the gravel diaphragm is installed.
2. Deep tilling to a depth of 12 to 18 inches is needed after final building lots have been graded.
3. It is important to have dry conditions at the site prior to incorporating compost.
4. An acceptable compost mix is then incorporated into the soil using a rototiller or similar equipment-designer to enter at the volumetric rate of 1 part compost to 2 parts soil.
5. The amended area shall be raked to achieve the most level slope possible without using heavy equipment.
6. Stabilize with perennial grass or herbaceous species.
7. Areas of compost amendments exceeding 2,500 square feet should employ simple erosion control measures, such as filter logs, to reduce the potential for erosion and trap sediment.
8. Construction Inspection is critical to obtain adequate spot elevations, to ensure the gravel diaphragm is completely level, on the same contour, and constructed to the correct design elevation. As-built surveys should be required to ensure compliance with design standards.
   a. Inspectors should evaluate the performance of the filter strip after the first big storm to look for evidence of gullies, outflanking, undercutting, or sparse vegetative cover.
   b. Spot repairs shall be made as needed.
   c. An example construction phase inspection checklist for Sheet Flow to a Filter Strip can be found on the Center for Watershed Protection website: (Tool 6: Plan Review, BMP Construction and Maintenance Checklists).

Maintenance

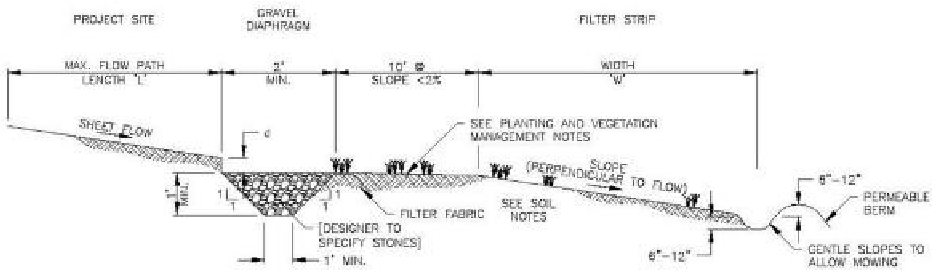
1. All vegetated filter strips must be covered by a drainage easement to allow inspection and maintenance. If located on a residential private lot, the existence and purpose of the filter strip shall be noted on the deed of record. Homeowners will need to be given a document that explains the purpose of the filter strip and routine maintenance needs. A deed restriction or other mechanism enforceable by the County must be in place to help ensure that the filter strips are

maintained and not converted or disturbed. The County shall have authority to access the property for inspection or corrective action.

2. Annual inspections are used to trigger maintenance operations such as sediment removal, spot revegetation, and level spreader repair. Ideally inspections should be conducted in the non-growing season when it is easier to see the flow path. Example maintenance inspection checklists can be accessed at the Center for Watershed Protection's website at: http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/sm.htm (Tool 6: Plan Review, BMP Construction and Maintenance Checklists). Inspectors should check to ensure that:

   - Flows through the filter strip do not short-circuit the overflow control section;
   - Debris and sediment does not build up at the top of the filter strip;
   - Foot or vehicular traffic does not compromise the gravel diaphragm;
   - Scour and erosion do not occur within the filter strip;
   - Sediments are cleaned out of any level spreaders, forebays, and flow splitters; and
   - Vegetative density exceeds a 90% cover in the boundary zone or grass filter.

3. Once established, vegetated filter strips have minimal maintenance needs outside of the spring cleanup, regular mowing, repair of check dams, and other measures to maintain the hydraulic efficiency of the strip and a dense, healthy grass cover. Vegetated filter strips that consist of grass/turf cover should be mowed at least twice a year to prevent woody growth.

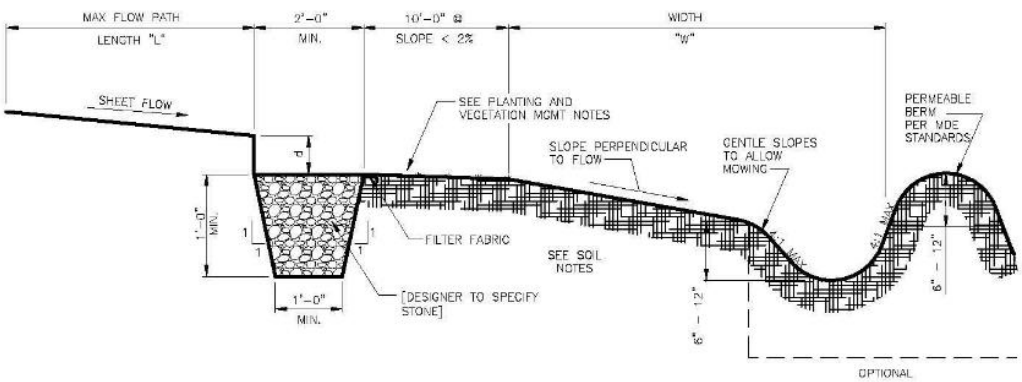


PROFILE VIEW
N.T.S.

PROJECT SITE	IMPERVIOUS	PERVIOUS
L	75 FEET	150 FEET
d	3 TO 4 INCHES	2 TO 4 INCHES
GRAVEL DIAPHRAGM	REQUIRED	OPTIONAL

FILTER STRIP	
SLOPE (⊥ TO FLOW)	MINIMUM WIDTH
1% TO 4%	35 FEET
4% TO 6%	50 FEET
6% TO 8%	65 FEET

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS STABLE CONVEYANCE VEGETATED FILTER STRIP	REVISED	NO. SW-15



N.T.S.

DESIGN TABLES

PROJECT SITE	IMPERVIOUS	PERVIOUS
L	75 FEET	150 FEET
d	3 TO 4 INCHES	2 TO 4 INCHES
GRAVEL DIAPHRAGM	REQUIRED	OPTIONAL

FILTER STRIP	
SLOPE (⊥ TO FLOW)	MINIMUM WIDTH
1% TO 4%L	35 FEET
4% TO 6%	50 FEET
6% TO 8%	65 FEET

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS STABLE CONVEYANCE VEGETATED FILTER STRIP	REVISED	NO. SW-16

C.3: PLANTING MATRICES FOR STORMWATER MANAGEMENT FACILITIES

Plant Selection for use in Bioswales

Assumptions: Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Mx)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
LARGE TREES							
Acer rubrum	Red Maple	35' X 25'	FAC	X			
Carpinus caroliniana	American Hornbeam	20' X 30'	FAC				
Chamaecyparis thyoides	Atlantic White Cedar	30' X 15'	OBL	X		X	
Gleditsia triacanthos var inermis	Honeylocust	35'X 20'	FACU			X	
Ilex opaca	American Holly	25' X 25'	FACU	X		X	
Liquidambar styraciflua	Sweetgum	35' X 25'	FAC	X			
Nyssa biflora	Swamp Tupelo	40' X 30'	FACW+	X			
Nyssa sylvatica	Blackgum	40' X 30'	FACW+	X			
Pinus rigida ssp. serotina	Pond Pine	80' X 25'	OBL	X			
Pinus taeda	Loblolly Pine	100' X 35'	FAC-	X			
Platanus occidentalis	American Sycamore	40' X 60'	FACW-	X		X	
Quercus bicolor	Swamp White Oak	100' X 35'	FACW+	X			
Quercus imbricaria	Shingle Oak	45' X 30'	FAC	X			
Quercus laurifolia	Laurel Oak	70' X 45'	FACW- ,FACW	X			
Quercus lyrata Walter	Overcup Oak	45' X 35'	OBL	X			
Quercus macrocarpa	Burr Oak	70' X 70'	FAC-	X			
Quercus palustris	Pin Oak	60' X 40'	FACW				
Quercus phellos	Willow Oak	60' X 40'	FAC+			X	
Quercus shumardii var. shumardii	Shumard Oak	50' X 40'	FAC+				
Salix nigra	Black Willow	40' X 30'	FACW+	X			
Salix sericea	Silky Willow	12' X 6'	OBL				

Plant Selection for use in Bioswales Assumptions: Flowing Water; Bioretention Soil Mix							
PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Mx)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
Sambucus nigra	American Black Elderberry	20' X 12'	FACU,FACU+	X			
Taxodium distichum	Bald Cypress	45' X 25'	OBL			X	
SMALL TREES							
Amelanchier arborea var. arborea	Common Serviceberry	25' X 20'	FAC-	X		X	
Chionanthus virginicus	White Fringetree	20' X 15'	FAC			X	
Crataegus phaenopyrum	Washington Hawthorn	25' X 20'	FAC			X	
Diospyros virginiana	Common Persimmon	40' X 30'	FAC	X			
Magnolia virginiana	Sweetbay	20' X10'	FACU,FAC			X	
Thuja occidentalis	American Arborvitae	20' X 12'	FACW			X	
LARGE / MEDIUM SHRUBS							
Alnus serrulata	Hazel Alder	15' X 12'	OBL				
Cephalanthus occidentalis	Common Buttonbush	8' X 6'	OBL	X			
Clethra alnifolia	Coastal Sweetpepperbush	8' X 6'	FAC+	X			
Cornus amomum	Silky Dogwood	12' X 8'	FACW	X		X	
Cornus racemosa	Gray Dogwood	12' X 8'	FAC+	X			
Cornus sericea	Redosier Dogwood	8' X 6'	FACU-			X	
Cornus sericea L. ssp. sericea	Redosier Dogwood	8' X 6'	FACU-			X	
Ilex glabra	Inkberry	8' X 8'	FACW-			X	
Ilex verticillata	Common Winterberry	12' X 8'	FACW+	X			
Ilex verticillata 'Red Sprite' (female)	Red Sprite Winterberry	10' X 6'	FACW+				
Itea virginica	Virginia Sweetspire	5' X 4'	OBL			X	

Plant Selection for use in Bioswales Assumptions: Flowing Water; Bioretention Soil Mix							
PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Mx)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	COMMON NAME						
Iva frutescens	Jesuit's Bark	6' X 6'	FACW+				
Lindera benzoin var. benzoin	Spicebush	10' X 8'	FACW-	X		X	
Morella caroliniensis	Southern Bayberry	10' X 10'	FAC	X			
Morella cerifera	Wax Myrtle	12' X 12'	FAC,FAC+				
Morella pensylvanica	Northern Bayberry	10' X 10'	FAC	X		X	
Photinia melanocarpa	Black Chokeberry	5' X 4'	FAC	X			
LARGE / MEDIUM SHRUBS (cont.)							
Photinia pyrifolia	Red Chokeberry	10' X 5'	FACW	X			
Physocarpus opulifolius	Common Ninebark	10' X 8'	FACW-	X		X	
Rosa palustris	Swamp Rose	8' X 4'	OBL			X	
Spiraea tomentosa	Steeplebush	5' X 5'	FACW				
Viburnum dentatum	Southern Arrowwood	12' X 8'	FAC	X			
Viburnum dentatum var. dentatum	Southern Arrowwood	12' X 8'	FAC	X			
Viburnum dentatum var. venosum	Southern Arrowwood	12' X 8'	FACU	X			
Viburnum lentago	Nannyberry	15' X 8'	FAC	X			
Viburnum nudum var. nudum	Possumhaw	15' X 12'	OBL	X			
Viburnum nudum var. cassinoides	Withe-Rod	6' X 5'	FAC				
Viburnum opulus var. americanum	American Cranberrybush	10' X 12'	FACU			X	
PERENNIALS / ORNAMENTAL GRASSES							
Boltonia asteroides	White Doll's Daisy	2' X 1.5'	OBL				X
Lolium perenne L. ssp. multiflorum	Italian Ryegrass	2.5' X 1.5'	FACU				X
GRASSES (BY SEEDING)							
Carex comosa	Longhair Sedge	5'	OBL	X			

Plant Selection for use in Bioswales Assumptions: Flowing Water; Bioretention Soil Mix							
PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Mx)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	COMMON NAME						
Carex lurida	Shallow Sedge	3.2'	OBL	X			
Carex vulpinoidea Michx. var. vulpinoidea	Fox Sedge	3.2'	OBL	X			
Dichanthelium clandestinum	Deertongue	2'	FACU	X			X
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL	X			
Juncus effusus var. conglomeratus	Common Rush	2'	FACW+	X			X
Juncus effusus var. decipiens	Lamp Rush	2'	FACW+	X			X
Juncus effusus var. pylaei	Common Rush	2'	FACW+	X			X
Juncus effusus var. solutus	Lamp Rush	2'	FACW+	X			X
Leersia oryzoides	Rice Cutgrass	5'	OBL	X			
Panicum virgatum	Switchgrass	5'	FAC	X			
Panicum virgatum var. virgatum	Switchgrass	5'	FAC	X			
Panicum virgatum var. spissum	Switchgrass	5'	FAC	X			
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	4'	FAC	X			
Panicum virgatum 'Shelter'	Shelter Switchgrass	4'	FAC	X			
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC	X			
Poa pratensis	Kentucky Bluegrass	1.5'	FACU	X			X
Poa trivialis	Rough Bluegrass	2.5'	FACU	X			X
Schedonorus phoenix	Tall Fescue	2'	FAC	X	X		X
Scirpus cyperinus Kunth	Woolgrass	4.9'	FACW+	X			
Senna marilandica	Maryland Senna	6.6'	FAC+	X			
Spartina alterniflora	Smooth Cordgrass	3.5'	OBL	X			
Spartina patens	Saltmeadow Cordgrass	2'	FACW+	X			X
Tripsacum dactyloides	Eastern Gamagrass	5'	FAC	X			
PLUGS (FORBS)							

Plant Selection for use in Bioswales

Assumptions: Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Mx)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
Chelone glabra	White Turtlehead	4'	OBL			X	
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW			X	
Eupatoriadelphus maculatus var. maculatus	Spotted Trumpetweed	3'	FACW			X	X
Eupatoriadelphus fistulosus	Trumpetweed	3'	FACW			X	X
Eupatorium perfoliatum var. perfoliatum	Common Boneset	2.5'	FACW			X	X
Euthamia graminifolia	Flat-Top Goldenrod	3.5'	FAC			X	
Euthamia graminifolia var. hirtipes	Flat-Top Goldenrod	3'	FAC			X	X
Helianthus angustifolius	Swamp Sunflower	5.6'	FACW			X	
Helianthus tuberosus	Jerusalem Artichoke	9.8'	FACU			X	
Hibiscus laevis	Halberdleaf Rosemallow	8'	OBL			X	
Hibiscus moscheutos	Crimsoneyed Rosemallow	6'	OBL			X	
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL			X	
Liatris spicata Willd.	Dense Blazing Star	4.5'	FAC			X	
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW			X	
Ludwigia alternifolia	Seedbox	4'	OBL			X	
Mimulus ringens var. ringens	Allegheny Monkeyflower	3.5'	OBL			X	
Panicum virgatum	Switchgrass	5'	FAC			X	
Panicum virgatum var. virgatum	Switchgrass	5'	FAC			X	
Panicum virgatum var. spissum	Switchgrass	5'	FAC			X	
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	3' - 5'	FAC			X	
Panicum virgatum 'Shelter'	Shelter Switchgrass	3' - 5'	FAC			X	

Plant Selection for use in Bioswales Assumptions: Flowing Water; Bioretention Soil Mix							
PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Mx)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC			**X**	
Penstemon digitalis	Talus Slope Penstemon	3' - 5'	FAC			**X**	
Phystostegia virginiana	Obedient Plant	2'	FACW			**X**	**X**
Rudbeckia fulgida	Orange Coneflower	2'	FAC			**X**	**X**
Rudbeckia fulgida 'Goldsturm'	Goldsturm Orange Coneflower	2'	FAC			**X**	**X**
Symphyotrichum novae-angliae	New England Aster	2'	FAC			**X**	**X**
Symphyotrichum novi-belgii var. elodes	New York Aster	2' - 4'	OBL			**X**	
Symphyotrichum novi-belgii var. novi-belgii	New York Aster	6'	OBL			**X**	
Symphyotrichum novi-belgii var. villicaule	New York Aster	6'	OBL			**X**	
Thalictrum pubescens	King Of The Meadow	6'	FACW			**X**	
Vaccinium corymbosum	Highbush Blueberry	6'	FACW			**X**	
Verbena hastata var. hastata	Swamp Verbena	4'	FAC				
Vernonia noveboracensis	New York Ironweed	4'	FACW				

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
LARGE TREES							
Acer rubrum	Red Maple	35' X 25'	FAC	**X**		**X**	
Carpinus caroliniana	American Hornbeam	20' X 30'	FAC	**X**			
Chamaecyparis thyoides	Atlantic White Cedar	30' X 15'	OBL	**X**			
Gleditsia triacanthos var inermis	Honeylocust	35'X 20'	FACU			**X**	
Ilex opaca	American Holly	25' X 25'	FACU	**X**		**X**	
Liquidambar styraciflua	Sweetgum	35' X 25'	FAC	**X**			
Nyssa biflora	Swamp Tupelo	40' X 30'	FACW+	**X**			
Nyssa sylvatica	Blackgum	40' X 30'	FACW+	**X**			
Pinus rigida ssp. serotina	Pond Pine	80' X 25'	OBL	**X**			
Pinus taeda	Loblolly Pine	100' X 35'	FAC-	**X**			
Platanus occidentalis	American Sycamore	40' X 60'	FACW-	**X**		**X**	
Quercus bicolor	Swamp White Oak	100' X 35'	FACW+	**X**			
Quercus imbricaria	Shingle Oak	45' X 30'	FAC	**X**			
Quercus laurifolia	Laurel Oak	70' X 45'	FACW- ,FACW	**X**			
Quercus lyrata Walter	Overcup Oak	45' X 35'	OBL	**X**			

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
Quercus macrocarpa	Burr Oak	70' X 70'	FAC-	**X**			
Quercus palustris	Pin Oak	60' X 40'	FACW			**X**	
Quercus phellos	Willow Oak	60' X 40'	FAC+			**X**	
Quercus shumardii var. shumardii	Shumard Oak	50' X 40'	FAC+	**X**			
Salix nigra	Black Willow	40' X 30'	FACW+	**X**			
Salix sericea	Silky Willow	12' X 6'	OBL	**X**			
Sambucus nigra	American Black Elderberry	20' X 12'	FACU,FACU+	**X**			
Taxodium distichum	Bald Cypress	45' X 25'	OBL	**X**		**X**	
SMALL TREES							
Amelanchier arborea var. arborea	Common Serviceberry	25' X 20'	FAC-	**X**		**X**	
Chionanthus virginicus	White Fringetree	20' X 15'	FAC	**X**		**X**	
Crataegus phaenopyrum	Washington Hawthorn	25' X 20'	FAC	**X**		**X**	
Diospyros virginiana	Common Persimmon	40' X 30'	FAC	**X**			
Magnolia virginiana	Sweetbay	20' X10'	FACU,FAC			**X**	
Thuja occidentalis	American Arborvitae	20' X 12'	FACW			**X**	

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
LARGE / MEDIUM SHRUBS							
Alnus serrulata	Hazel Alder	15' X 12'	OBL	**X**			
Cephalanthus occidentalis	Common Buttonbush	8' X 6'	OBL	**X**			
Clethra alnifolia	Coastal Sweetpepperbush	8' X 6'	FAC+	**X**			
Cornus amomum	Silky Dogwood	12' X 8'	FACW	**X**		**X**	
Cornus racemosa	Gray Dogwood	12' X 8'	FAC+	**X**		**X**	
Cornus sericea	Redosier Dogwood	8' X 6'	FACU-			**X**	
Cornus sericea L. ssp. sericea	Redosier Dogwood	8' X 6'	FACU-			**X**	
Ilex glabra	Inkberry	8' X 8'	FACW-			**X**	
Ilex verticillata	Common Winterberry	12' X 8'	FACW+				
Ilex verticillata 'Red Sprite' (female)	Red Sprite Winterberry	10' X 6'	FACW+				
Itea virginica	Virginia Sweetspire	5' X 4'	OBL			**X**	
Iva frutescens	Jesuit's Bark	6' X 6'	FACW+	**X**			
Lindera benzoin var. benzoin	Spicebush	10' X 8'	FACW-	**X**			
Morella caroliniensis	Southern Bayberry	10' X 10'	FAC	**X**		**X**	
Morella cerifera	Wax Myrtle	12' X 12'	FAC,FAC+	**X**			
Morella pensylvanica	Northern Bayberry	10' X 10'	FAC	**X**		**X**	

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
Photinia melanocarpa	Black Chokeberry	5' X 4'	FAC	**X**			
Photinia pyrifolia	Red Chokeberry	10' X 5'	FACW	**X**			
Physocarpus opulifolius	Common Ninebark	10' X 8'	FACW-	**X**			
Rosa palustris	Swamp Rose	8' X 4'	OBL	**X**		**X**	
Spiraea tomentosa	Steeplebush	5' X 5'	FACW	**X**			
Viburnum dentatum	Southern Arrowwood	12' X 8'	FAC	**X**		**X**	
Viburnum dentatum var. dentatum	Southern Arrowwood	12' X 8'	FAC	**X**			
Viburnum dentatum var. venosum	Southern Arrowwood	12' X 8'	FACU	**X**			
Viburnum lentago	Nannyberry	15' X 8'	FAC	**X**			
Viburnum nudum var. nudum	Possumhaw	15' X 12'	OBL	**X**			
Viburnum nudum var. cassinoides	Withe-Rod	6' X 5'	FAC				
Viburnum opulus var. americanum	American Cranberrybush	10' X 12'	FACU			**X**	
PERENNIALS / ORNAMENTAL GRASSES							
Boltonia asteroides	White Doll's Daisy	2' X 1.5'	OBL			**X**	**X**
Lolium perenne L. ssp. multiflorum	Italian Ryegrass	2.5' X 1.5'	FACU			**X**	**X**
GRASSES (BY SEEDING)							
Carex comosa	Longhair Sedge	5'	OBL	**X**			
Carex lurida	Shallow Sedge	3.2'	OBL	**X**			
Carex vulpinoidea Michx. var. vulpinoidea	Fox Sedge	3.2'	OBL	**X**			

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
Dichanthelium clandestinum	Deertongue	2'	FACU	X			X
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL				X
Juncus effusus var. conglomeratus	Common Rush	2'	FACW+	X			X
Juncus effusus var. decipiens	Lamp Rush	2'	FACW+	X			X
Juncus effusus var. pylaei	Common Rush	2'	FACW+	X			X
Juncus effusus var. solutus	Lamp Rush	2'	FACW+	X			X
Leersia oryzoides	Rice Cutgrass	5'	OBL	X			
Panicum virgatum	Switchgrass	5'	FAC		X	X	
Panicum virgatum var. virgatum	Switchgrass	5'	FAC		X	X	
Panicum virgatum var. spissum	Switchgrass	5'	FAC		X	X	
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	4'	FAC		X	X	
Panicum virgatum 'Shelter'	Shelter Switchgrass	4'	FAC		X	X	
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC		X	X	
Poa pratensis	Kentucky Bluegrass	1.5'	FACU		X	X	X
Poa trivialis	Rough Bluegrass	2.5'	FACU		X		X
Schedonorus phoenix	Tall Fescue	2'	FAC		X		X
Scirpus cyperinus Kunth	Woolgrass	4.9'	FACW+	X			X
Senna marilandica	Maryland Senna	6.6'	FAC+	X			
Spartina alterniflora	Smooth Cordgrass	3.5'	OBL	X			
Spartina patens	Saltmeadow Cordgrass	2'	FACW+	X			X
Tripsacum dactyloides	Eastern Gamagrass	5'	FAC	X			

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
PLUGS (FORBS)							
Chelone glabra	White Turtlehead	4'	OBL				
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW				
Eupatoriadelphus maculatus var. maculatus	Spotted Trumpetweed	3'	FACW				
Eupatoriadelphus fistulosus	Trumpetweed	3'	FACW				
Eupatorium perfoliatum var. perfoliatum	Common Boneset	2.5'	FACW				**X**
Euthamia graminifolia	Flat-Top Goldenrod	3.5'	FAC				**X**
Euthamia graminifolia var. hirtipes	Flat-Top Goldenrod	3'	FAC				**X**
Helianthus angustifolius	Swamp Sunflower	5.6'	FACW				
Helianthus tuberosus	Jerusalem Artichoke	9.8'	FACU				
Hibiscus laevis	Halberdleaf Rosemallow	8'	OBL				
Hibiscus moscheutos	Crimsoneyed Rosemallow	6'	OBL				
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL				**X**
Liatris spicata Willd.	Dense Blazing Star	4.5'	FAC				
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW				
Ludwigia alternifolia	Seedbox	4'	OBL				
Mimulus ringens var. ringens	Allegheny Monkeyflower	3.5'	OBL				**X**
Panicum virgatum	Switchgrass	5'	FAC				
Panicum virgatum var. virgatum	Switchgrass	5'	FAC				

Plant Selection for use in Bioretention (Includes Curb Extensions)

Assumptions: No Flowing Water; Bioretention Soil Mix

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Mx (No mowing/ low visibility)	Low Mx (Occasional Mowing)	High Visibil-ity	High Visibility (with low growing plants)
BOTANICAL NAME	**COMMON NAME**						
Panicum virgatum var. spissum	Switchgrass	5'	FAC				
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	3' - 5'	FAC				
Panicum virgatum 'Shelter'	Shelter Switchgrass	3' - 5'	FAC				
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC				
Penstemon digitalis	Talus Slope Penstemon	3' - 5'	FAC				
Phystostegia virginiana	Obedient Plant	2'	FACW				**X**
Rudbeckia fulgida	Orange Coneflower	2'	FAC				**X**
Rudbeckia fulgida 'Goldsturm'	Goldsturm Orange Coneflower	2'	FAC				**X**
Rudbeckia fulgida	New England Aster	2'	FAC				**X**
Symphyotrichum novi-belgii var. elodes	New York Aster	2' - 4'	OBL				**X**
Symphyotrichum novi-belgii var. novi-belgii	New York Aster	6'	OBL				
Symphyotrichum novi-belgii var. villicaule	New York Aster	6'	OBL				
Thalictrum pubescens	King Of The Meadow	6'	FACW				
Vaccinium corymbosum	Highbush Blueberry	6'	FACW				
Verbena hastata var. hastata	Swamp Verbena	4'	FAC				
Vernonia noveboracensis	New York Ironweed	4'	FACW				

Plant Selection for use in Dry Ponds

Plant Selections for use in the bottom of a dry pond

PLANT SELECTION		Mature Height	Indicator Status	Low Visibility Area (Low Maintenance)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
GRASSES (BY SEEDING)							
Carex comosa	Longhair Sedge	5'	OBL	**X**			
Carex lurida	Shallow Sedge	3.2'	OBL	**X**			
Carex vulpinoidea Michx. var. vulpinoidea	Fox Sedge	3.2'	OBL	**X**			**X**
Dichanthelium clandestinum	Deertongue	2'	FACU	**X**			**X**
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL				**X**
Juncus effusus var. conglomeratus	Common Rush	2'	FACW+	**X**			**X**
Juncus effusus var. decipiens	Lamp Rush	2'	FACW+	**X**			**X**
Juncus effusus var. pylaei	Common Rush	2'	FACW+	**X**			**X**
Juncus effusus var. solutus	Lamp Rush	2'	FACW+	**X**			**X**
Leersia oryzoides	Rice Cutgrass	5'	OBL	**X**			
Panicum virgatum	Switchgrass	5'	FAC		**X**	**X**	
Panicum virgatum var. virgatum	Switchgrass	5'	FAC		**X**	**X**	
Panicum virgatum var. spissum	Switchgrass	5'	FAC		**X**	**X**	
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	4'	FAC		**X**	**X**	
Panicum virgatum 'Shelter'	Shelter Switchgrass	4'	FAC		**X**	**X**	

Plant Selection for use in Dry Ponds

Plant Selections for use in the bottom of a dry pond

PLANT SELECTION		Mature Height	Indicator Status	Low Visibility Area (Low Maintenance)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC		**X**	**X**	
Poa pratensis	Kentucky Bluegrass	1.5'	FACU		**X**	**X**	**X**
Poa trivialis	Rough Bluegrass	2.5'	FACU		**X**		**X**
Schedonorus phoenix	Tall Fescue	2'	FAC		**X**		**X**
Scirpus cyperinus Kunth	Woolgrass	4.9'	FACW+	**X**			
Senna marilandica	Maryland Senna	6.6'	FAC+	**X**			
Spartina alterniflora	Smooth Cordgrass	3.5'	OBL	**X**			**X**
Spartina patens	Saltmeadow Cordgrass	2'	FACW+	**X**			**X**
Tripsacum dactyloides	Eastern Gamagrass	5'	FAC	**X**			
PLUGS (FORBS)							
Chelone glabra	White Turtlehead	4'	OBL			**X**	
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW			**X**	
Eupatoriadelphus maculatus var. maculatus	Spotted Trumpetweed	3'	FACW			**X**	**X**
Eupatoriadelphus fistulosus	Trumpetweed	3'	FACW			**X**	**X**
Eupatorium perfoliatum var. perfoliatum	Common Boneset	2.5'	FACW			**X**	**X**
Euthamia graminifolia	Flat-Top Goldenrod	3.5'	FAC			**X**	**X**
Euthamia graminifolia var. hirtipes	Flat-Top Goldenrod	3'	FAC			**X**	
Helianthus angustifolius	Swamp Sunflower	5.6'	FACW			**X**	

Plant Selection for use in Dry Ponds

Plant Selections for use in the bottom of a dry pond

PLANT SELECTION BOTANICAL NAME	 COMMON NAME	Mature Height	Indicator Status	Low Visibility Area (Low Maintenance)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
Helianthus tuberosus	Jerusalem Artichoke	9.8'	FACU			X	
Hibiscus laevis	Halberdleaf Rosemallow	8'	OBL			X	
Hibiscus moscheutos	Crimsoneyed Rosemallow	6'	OBL			X	
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL			X	
Liatris spicata Willd.	Dense Blazing Star	4.5'	FAC			X	
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW			X	
Ludwigia alternifolia	Seedbox	4'	OBL			X	
Mimulus ringens var. ringens	Allegheny Monkeyflower	3.5'	OBL			X	
Panicum virgatum	Switchgrass	5'	FAC			X	
Panicum virgatum var. virgatum	Switchgrass	5'	FAC			X	
Panicum virgatum var. spissum	Switchgrass	5'	FAC			X	
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	3' - 5'	FAC			X	
Panicum virgatum 'Shelter'	Shelter Switchgrass	3' - 5'	FAC			X	
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC			X	
Penstemon digitalis	Talus Slope Penstemon	3' - 5'	FAC			X	
Phystostegia virginiana	Obedient Plant	2'	FACW			X	X
Rudbeckia fulgida	Orange Coneflower	2'	FAC			X	X
Rudbeckia fulgida 'Goldsturm'	Goldsturm Orange Coneflower	2'	FAC			X	X

Plant Selection for use in Dry Ponds

Plant Selections for use in the bottom of a dry pond

PLANT SELECTION		Mature Height	Indicator Status	Low Visibility Area (Low Maintenance)	Visible Area (Occasional Mowing)	High Visibility Area	High Visibility Area / Low Growing
BOTANICAL NAME	COMMON NAME						
Rudbeckia fulgida	New England Aster	2'	FAC			X	X
Symphyotrichum novi-belgii var. elodes	New York Aster	2' - 4'	OBL			X	X
Symphyotrichum novi-belgii var. novi-belgii	New York Aster	6'	OBL			X	
Symphyotrichum novi-belgii var. villicaule	New York Aster	6'	OBL			X	
Thalictrum pubescens	King Of The Meadow	6'	FACW			X	
Vaccinium corymbosum	Highbush Blueberry	6'	FACW			X	
Verbena hastata var. hastata	Swamp Verbena	4'	FAC				
Vernonia noveboracensis	New York Ironweed	4'	FACW				

Plant Selection for use in Wetlands

Assumptions: No Mowing

PLANT SELECTION							
BOTANICAL NAME	**COMMON NAME**	Mature Height X Spread	Indicator Status	Low Visibil-ity Area (Low Mx)	Visible Area (Occasion-al Mowing)	High Visibil-ity Area	High Visibility Area / Low Growing
LARGE TREES							
Acer rubrum	Red Maple	35' X 25'	FAC	X	X		
Carpinus caroliniana	American Hornbeam	20' X 30'	FAC	X			
Chamaecyparis thyoides	Atlantic White Cedar	30' X 15'	OBL		X		
Gleditsia triacanthos var inermis	Honeylocust	35'X 20'	FACU	X	X		
Ilex opaca	American Holly	25' X 25'	FACU	X	X		
Liquidambar styraciflua	Sweetgum	35' X 25'	FAC	X			
Nyssa biflora	Swamp Tupelo	40' X 30'	FACW+	X		X	
Nyssa sylvatica	Blackgum	40' X 30'	FACW+	X		X	
Pinus rigida ssp. serotina	Pond Pine	80' X 25'	OBL	X			
Pinus taeda	Loblolly Pine	100' X 35'	FAC-	X			
Platanus occidentalis	American Sycamore	40' X 60'	FACW-		X	X	
Quercus bicolor	Swamp White Oak	100' X 35'	FACW+	X		X	
Quercus imbricaria	Shingle Oak	45' X 30'	FAC	X			
Quercus laurifolia	Laurel Oak	70' X 45'	FACW- ,FACW	X		X	
Quercus lyrata Walter	Overcup Oak	45' X 35'	OBL	X			
Quercus macrocarpa	Burr Oak	70' X 70'	FAC-	X			
Quercus palustris	Pin Oak	60' X 40'	FACW		X	X	
Quercus phellos	Willow Oak	60' X 40'	FAC+		X	X	
Quercus shumardii var. shumardii	Shumard Oak	50' X 40'	FAC+	X		X	
Salix nigra	Black Willow	40' X 30'	FACW+	X		X	
Salix sericea	Silky Willow	12' X 6'	OBL	X			
Sambucus nigra	American Black Elderberry	20' X 12'	FACU,FACU +	X		X	
Taxodium distichum	Bald Cypress	45' X 25'	OBL	X	X		
SMALL TREES							
Amelanchier arborea var. arborea	Common Serviceberry	25' X 20'	FAC-	X	X		

Plant Selection for use in Wetlands

Assumptions: No Mowing

PLANT SELECTION BOTANICAL NAME	COMMON NAME	Mature Height X Spread	Indicator Status	Low Visibil-ity Area (Low Mx)	Visible Area (Occasion-al Mowing)	High Visibil-ity Area	High Visibility Area / Low Growing
Chionanthus virginicus	White Fringetree	20' X 15'	FAC	X	X		
Crataegus phaenopyrum	Washington Hawthorn	25' X 20'	FAC	X	X		
Diospyros virginiana	Common Persimmon	40' X 30'	FAC	X			
Magnolia virginiana	Sweetbay	20' X10'	FACU,FAC	X	X	X	
Thuja occidentalis	American Arborvitae	20' X 12'	FACW	X	X	X	
LARGE / MEDIUM SHRUBS							
Alnus serrulata	Hazel Alder	15' X 12'	OBL	X			
Cephalanthus occidentalis	Common Buttonbush	8' X 6'	OBL	X			
Clethra alnifolia	Coastal Sweetpepperbush	8' X 6'	FAC+	X		X	
Cornus amomum	Silky Dogwood	12' X 8'	FACW	X	X	X	
Cornus racemosa	Gray Dogwood	12' X 8'	FAC+	X	X	X	
Cornus sericea	Redosier Dogwood	8' X 6'	FACU-	X	X		
Cornus sericea L. ssp. sericea	Redosier Dogwood	8' X 6'	FACU-	X	X		
Ilex glabra	Inkberry	8' X 8'	FACW-	X	X	X	
Ilex verticillata	Common Winterberry	12' X 8'	FACW+	X		X	
Ilex verticillata 'Red Sprite' (female)	Red Sprite Winterberry	10' X 6'	FACW+	X		X	
Itea virginica	Virginia Sweetspire	5' X 4'	OBL	X	X	X	
Iva frutescens	Jesuit's Bark	6' X 6'	FACW+	X		X	
Lindera benzoin var. benzoin	Spicebush	10' X 8'	FACW-	X	X	X	
Morella caroliniensis	Southern Bayberry	10' X 10'	FAC	X			
Morella cerifera	Wax Myrtle	12' X 12'	FAC,FAC+	X		X	
Morella pensylvanica	Northern Bayberry	10' X 10'	FAC	X	X		
Photinia melanocarpa	Black Chokeberry	5' X 4'	FAC	X			
Photinia pyrifolia	Red Chokeberry	10' X 5'	FACW	X		X	

Plant Selection for use in Wetlands

Assumptions: No Mowing

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibil-ity Area (Low Mx)	Visible Area (Occasion-al Mowing)	High Visibil-ity Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
Physocarpus opulifolius	Common Ninebark	10' X 8'	FACW-	X		X	
Rosa palustris	Swamp Rose	8' X 4'	OBL	X	X	X	
Spiraea tomentosa	Steeplebush	5' X 5'	FACW	X		X	
Viburnum dentatum	Southern Arrowwood	12' X 8'	FAC	X		X	
Viburnum dentatum var. dentatum	Southern Arrowwood	12' X 8'	FAC	X			
Viburnum dentatum var. venosum	Southern Arrowwood	12' X 8'	FACU	X			
Viburnum lentago	Nannyberry	15' X 8'	FAC	X	X		
Viburnum nudum var. nudum	Possumhaw	15' X 12'	OBL	X		X	
Viburnum nudum var. cassinoides	Withe-Rod	6' X 5'	FAC	X			
Viburnum opulus var. americanum	American Cranberrybush	10' X 12'	FACU	X	X		
PERENNIALS / ORNAMENTAL GRASSES							
Boltonia asteroides	White Doll's Daisy	2' X 1.5'	OBL		X		
Lolium perenne L. ssp. multiflorum	Italian Ryegrass	2.5' X 1.5'	FACU		X		
GRASSES (BY SEEDING)							
Carex comosa	Longhair Sedge	5'	OBL	X			
Carex lurida	Shallow Sedge	3.2'	OBL	X			
Carex vulpinoidea Michx. var. vulpinoidea	Fox Sedge	3.2'	OBL	X			
Dichanthelium clandestinum	Deertongue	2'	FACU	X			
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL				
Juncus effusus var. conglomeratus	Common Rush	2'	FACW+	X		X	
Juncus effusus var. decipiens	Lamp Rush	2'	FACW+	X		X	
Juncus effusus var. pylaei	Common Rush	2'	FACW+	X		X	
Juncus effusus var. solutus	Lamp Rush	2'	FACW+	X		X	
Leersia oryzoides	Rice Cutgrass	5'	OBL	X			

Plant Selection for use in Wetlands

Assumptions: No Mowing

PLANT SELECTION BOTANICAL NAME	COMMON NAME	Mature Height X Spread	Indicator Status	Low Visibil-ity Area (Low Mx)	Visible Area (Occasion-al Mowing)	High Visibil-ity Area	High Visibility Area / Low Growing
Panicum virgatum	Switchgrass	5'	FAC		X	X	
Panicum virgatum var. virgatum	Switchgrass	5'	FAC		X	X	
Panicum virgatum var. spissum	Switchgrass	5'	FAC		X	X	
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	4'	FAC		X	X	
Panicum virgatum 'Shelter'	Shelter Switchgrass	4'	FAC		X	X	
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC		X	X	
Poa pratensis	Kentucky Bluegrass	1.5'	FACU		X	X	
Poa trivialis	Rough Bluegrass	2.5'	FACU		X		
Schedonorus phoenix	Tall Fescue	2'	FAC		X		
Scirpus cyperinus Kunth	Woolgrass	4.9'	FACW+	X			
Senna marilandica	Maryland Senna	6.6'	FAC+	X			
Spartina alterniflora	Smooth Cordgrass	3.5'	OBL	X			
Spartina patens	Saltmeadow Cordgrass	2'	FACW+	X			
Tripsacum dactyloides	Eastern Gamagrass	5'	FAC	X			
PLUGS (FORBS)							
Chelone glabra	White Turtlehead	4'	OBL			X	
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW			X	
Eupatoriadelphus maculatus var. maculatus	Spotted Trumpetweed	3'	FACW			X	
Eupatoriadelphus fistulosus	Trumpetweed	3'	FACW			X	
Eupatorium perfoliatum var. perfoliatum	Common Boneset	2.5'	FACW			X	
Euthamia graminifolia	Flat-Top Goldenrod	3.5'	FAC			X	
Euthamia graminifolia var. hirtipes	Flat-Top Goldenrod	3'	FAC			X	
Helianthus angustifolius	Swamp Sunflower	5.6'	FACW			X	

Plant Selection for use in Wetlands

Assumptions: No Mowing

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibil-ity Area (Low Mx)	Visible Area (Occasion-al Mowing)	High Visibil-ity Area	High Visibility Area / Low Growing
BOTANICAL NAME	**COMMON NAME**						
Helianthus tuberosus	Jerusalem Artichoke	9.8'	FACU			X	
Hibiscus laevis	Halberdleaf Rosemallow	8'	OBL			X	
Hibiscus moscheutos	Crimsoneyed Rosemallow	6'	OBL			X	
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL			X	
Liatris spicata Willd.	Dense Blazing Star	4.5'	FAC			X	
Eupatoriadelphus dubius	Coastal Plain Joe Pye Weed	4'	FACW			X	
Ludwigia alternifolia	Seedbox	4'	OBL			X	
Mimulus ringens var. ringens	Allegheny Monkeyflower	3.5'	OBL			X	
Panicum virgatum	Switchgrass	5'	FAC			X	
Panicum virgatum var. virgatum	Switchgrass	5'	FAC			X	
Panicum virgatum var. spissum	Switchgrass	5'	FAC			X	
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	3' - 5'	FAC			X	
Panicum virgatum 'Shelter'	Shelter Switchgrass	3' - 5'	FAC			X	
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC			X	
Penstemon digitalis	Talus Slope Penstemon	3' - 5'	FAC			X	
Phystostegia virginiana	Obedient Plant	2'	FACW			X	X
Rudbeckia fulgida	Orange Coneflower	2'	FAC			X	X
Rudbeckia fulgida 'Goldsturm'	Goldsturm Orange Coneflower	2'	FAC			X	X
Rudbeckia fulgida	New England Aster	2'	FAC			X	X
Symphyotrichum novi-belgii var. elodes	New York Aster	2' - 4'	OBL			X	
Symphyotrichum novi-belgii var. novi-belgii	New York Aster	6'	OBL			X	

Plant Selection for use in Wetlands

Assumptions: No Mowing

PLANT SELECTION BOTANICAL NAME	COMMON NAME	Mature Height X Spread	Indicator Status	Low Visibil-ity Area (Low Mx)	Visible Area (Occasion-al Mowing)	High Visibil-ity Area	High Visibility Area / Low Growing
Symphyotrichum novi-belgii var. villicaule	New York Aster	6'	OBL			X	
Thalictrum pubescens	King Of The Meadow	6'	FACW			X	
Vaccinium corymbosum	Highbush Blueberry	6'	FACW			X	
Verbena hastata var. hastata	Swamp Verbena	4'	FAC				
Vernonia noveboracensis	New York Ironweed	4'	FACW				

Plant Selection for use in Gravel Wetlands

Assumptions: No Mowing

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Maintenance)	High Visibility Area
BOTANICAL NAME	**COMMON NAME**				
LARGE TREES					
Acer rubrum	Red Maple	35' X 25'	FAC	X	X
Carpinus caroliniana	American Hornbeam	20' X 30'	FAC	X	
Chamaecyparis thyoides	Atlantic White Cedar	30' X 15'	OBL		X
Gleditsia triacanthos var inermis	Honeylocust	35'X 20'	FACU	X	X
Ilex opaca	American Holly	25' X 25'	FACU	X	X
Liquidambar styraciflua	Sweetgum	35' X 25'	FAC	X	
Nyssa biflora	Swamp Tupelo	40' X 30'	FACW+	X	
Nyssa sylvatica	Blackgum	40' X 30'	FACW+	X	
Pinus rigida ssp. serotina	Pond Pine	80' X 25'	OBL	X	
Pinus taeda	Loblolly Pine	100' X 35'	FAC-	X	
Platanus occidentalis	American Sycamore	40' X 60'	FACW-		X
Quercus bicolor	Swamp White Oak	100' X 35'	FACW+	X	
Quercus imbricaria	Shingle Oak	45' X 30'	FAC	X	
Quercus laurifolia	Laurel Oak	70' X 45'	FACW-,FACW	X	
Quercus lyrata Walter	Overcup Oak	45' X 35'	OBL	X	
Quercus macrocarpa	Burr Oak	70' X 70'	FAC-	X	
Quercus palustris	Pin Oak	60' X 40'	FACW		X
Quercus phellos	Willow Oak	60' X 40'	FAC+		X
Quercus shumardii var. shumardii	Shumard Oak	50' X 40'	FAC+	X	
Salix nigra	Black Willow	40' X 30'	FACW+	X	
Salix sericea	Silky Willow	12' X 6'	OBL	X	
Sambucus nigra	American Black Elderberry	20' X 12'	FACU,FACU+	X	
Taxodium distichum	Bald Cypress	45' X 25'	OBL	X	X
SMALL TREES					
Amelanchier arborea var. arborea	Common Serviceberry	25' X 20'	FAC-	X	X
Chionanthus virginicus	White Fringetree	20' X 15'	FAC	X	X
Crataegus phaenopyrum	Washington Hawthorn	25' X 20'	FAC	X	X

Plant Selection for use in Gravel Wetlands

Assumptions: No Mowing

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Maintenance)	High Visibility Area
BOTANICAL NAME	**COMMON NAME**				
Diospyros virginiana	Common Persimmon	40' X 30'	FAC	X	
Magnolia virginiana	Sweetbay	20' X10'	FACU,FAC	X	X
Thuja occidentalis	American Arborvitae	20' X 12'	FACW	X	X
LARGE / MEDIUM SHRUBS					
Alnus serrulata	Hazel Alder	15' X 12'	OBL		
Cephalanthus occidentalis	Common Buttonbush	8' X 6'	OBL	X	
Clethra alnifolia	Coastal Sweetpepperbush	8' X 6'	FAC+	X	
Cornus amomum	Silky Dogwood	12' X 8'	FACW		X
Cornus racemosa	Gray Dogwood	12' X 8'	FAC+		X
Cornus sericea	Redosier Dogwood	8' X 6'	FACU-		X
Cornus sericea L. ssp. sericea	Redosier Dogwood	8' X 6'	FACU-		X
Ilex glabra	Inkberry	8' X 8'	FACW-		X
Ilex verticillata	Common Winterberry	12' X 8'	FACW+	X	
LARGE / MEDIUM SHRUBS (cont.)					
Ilex verticillata 'Red Sprite' (female)	Red Sprite Winterberry	10' X 6'	FACW+	X	
Itea virginica	Virginia Sweetspire	5' X 4'	OBL	X	X
Iva frutescens	Jesuit's Bark	6' X 6'	FACW+	X	
Lindera benzoin var. benzoin	Spicebush	10' X 8'	FACW-	X	X
Morella caroliniensis	Southern Bayberry	10' X 10'	FAC		
Morella cerifera	Wax Myrtle	12' X 12'	FAC,FAC+		
Morella pensylvanica	Northern Bayberry	10' X 10'	FAC		X
Photinia melanocarpa	Black Chokeberry	5' X 4'	FAC		
Photinia pyrifolia	Red Chokeberry	10' X 5'	FACW		
Physocarpus opulifolius	Common Ninebark	10' X 8'	FACW-		
Rosa palustris	Swamp Rose	8' X 4'	OBL	X	X
Spiraea tomentosa	Steeplebush	5' X 5'	FACW	X	
Viburnum dentatum	Southern Arrowwood	12' X 8'	FAC	X	

Plant Selection for use in Gravel Wetlands

Assumptions: No Mowing

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Maintenance)	High Visibility Area
BOTANICAL NAME	**COMMON NAME**				
Viburnum dentatum var. dentatum	Southern Arrowwood	12' X 8'	FAC	X	
Viburnum dentatum var. venosum	Southern Arrowwood	12' X 8'	FACU	X	
Viburnum lentago	Nannyberry	15' X 8'	FAC	X	X
Viburnum nudum var. nudum	Possumhaw	15' X 12'	OBL	X	
Viburnum nudum var. cassinoides	Withe-Rod	6' X 5'	FAC	X	
Viburnum opulus var. americanum	American Cranberrybush	10' X 12'	FACU	X	X
PERENNIALS / ORNAMENTAL GRASSES					
Boltonia asteroides	White Doll's Daisy	2' X 1.5'	OBL		X
Lolium perenne L. ssp. multiflorum	Italian Ryegrass	2.5' X 1.5'	FACU		X
GRASSES (BY SEEDING)					
Carex comosa	Longhair Sedge	5'	OBL	X	
Carex lurida	Shallow Sedge	3.2'	OBL	X	
Carex vulpinoidea Michx. var. vulpinoidea	Fox Sedge	3.2'	OBL	X	
Dichanthelium clandestinum	Deertongue	2'	FACU	X	
Glyceria canadensis	Rattlesnake Mannagrass	3.2'	OBL		
Juncus effusus var. conglomeratus	Common Rush	2'	FACW+	X	
Juncus effusus var. decipiens	Lamp Rush	2'	FACW+	X	
Juncus effusus var. pylaei	Common Rush	2'	FACW+	X	
Juncus effusus var. solutus	Lamp Rush	2'	FACW+	X	
Leersia oryzoides	Rice Cutgrass	5'	OBL	X	
Panicum virgatum	Switchgrass	5'	FAC		X
Panicum virgatum var. virgatum	Switchgrass	5'	FAC		X
Panicum virgatum var. spissum	Switchgrass	5'	FAC		X
Panicum virgatum 'Blackwell'	Blackwell Switchgrass	4'	FAC		X

Plant Selection for use in Gravel Wetlands

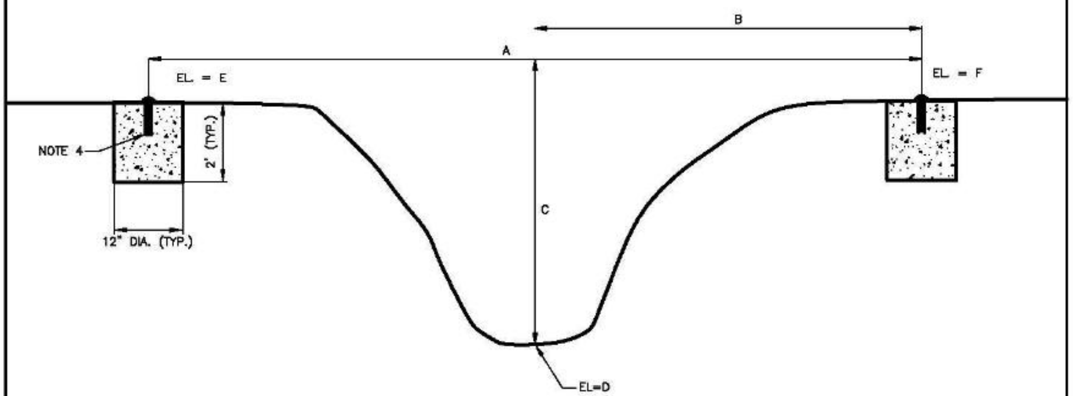
Assumptions: No Mowing

PLANT SELECTION		Mature Height X Spread	Indicator Status	Low Visibility Area (Low Maintenance)	High Visibility Area
BOTANICAL NAME	**COMMON NAME**				
Panicum virgatum 'Shelter'	Shelter Switchgrass	4'	FAC		X
Panicum virgatum 'Shenandoah'	Shenandoah Switchgrass	4'	FAC		X
Poa pratensis	Kentucky Bluegrass	1.5'	FACU		X
Poa trivialis	Rough Bluegrass	2.5'	FACU		X
Schedonorus phoenix	Tall Fescue	2'	FAC		X
Scirpus cyperinus Kunth	Woolgrass	4.9'	FACW+	X	
Senna marilandica	Maryland Senna	6.6'	FAC+	X	
Spartina alterniflora	Smooth Cordgrass	3.5'	OBL	X	
Spartina patens	Saltmeadow Cordgrass	2'	FACW+	X	
Tripsacum dactyloides	Eastern Gamagrass	5'	FAC	X	

C.4: MONITORING GAUGE

C.4: Monitoring Gauge

Refer to Figures SW-19 and SW-20. Two gauges shall be located outside of the flow path. Permanent cross sections will be established after construction in coordination with the design consultant and the County Project Manager (e.g., three cross-sections for first 500 feet, with additional cross-sections every 250 feet or as specified by design consultant and PM). The As-built plans shall include elevations and offsets as identified in the detail. These will serve to permanently locate and benchmark the channel elevations.



CHANNEL SECTION - LOOKING DOWNSTREAM

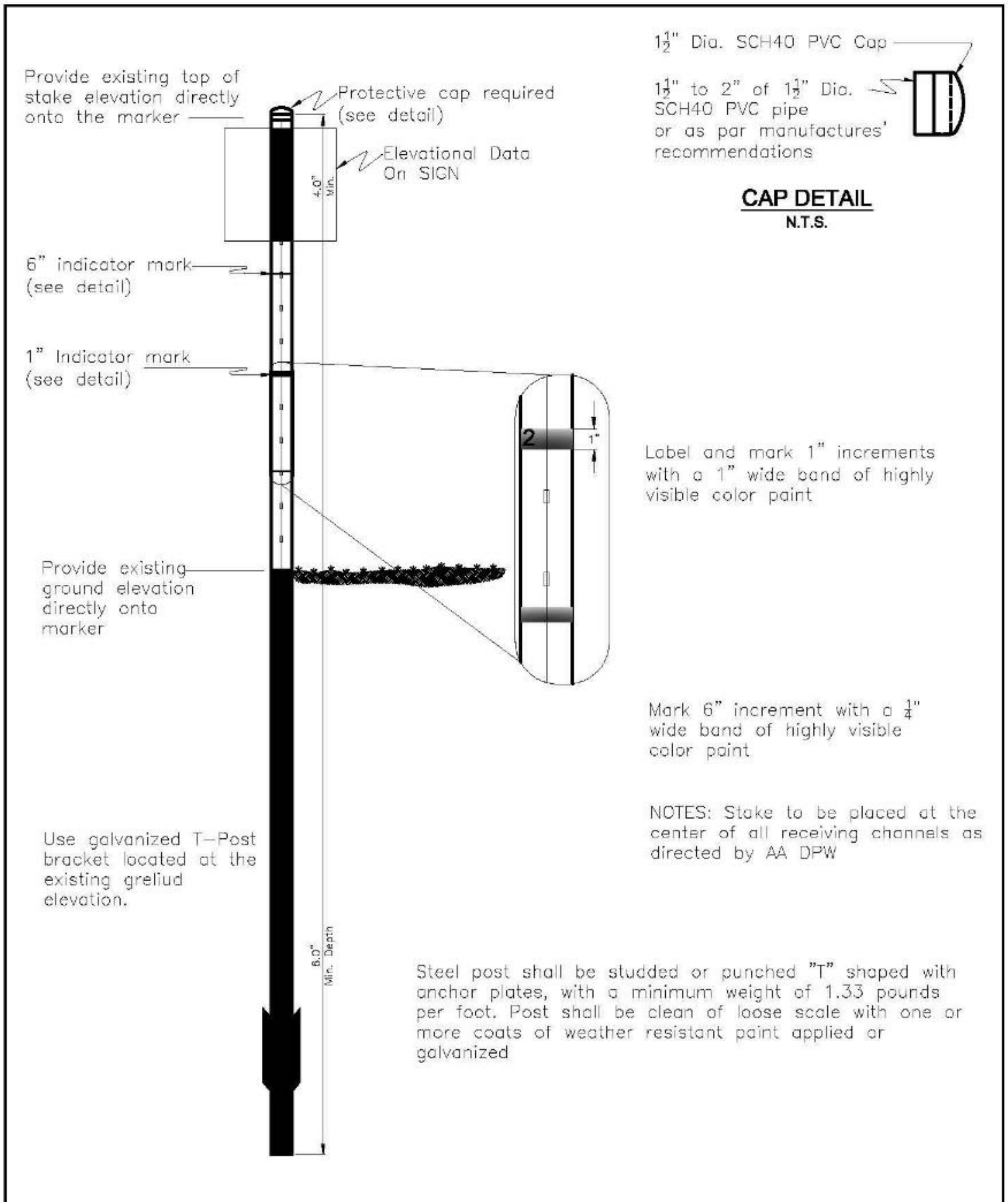
NOTES:

1. Channel section(s) to be placed and monitored downstream of development/stormwater management features.
2. Section location(s) to be approved by DPW reviewer.
3. Channel section(s) shall be drawn to scale and placed on stormwater plans.
4. 6-in carriage bolt placed in ready mix concrete.

CHANNEL SECTION DIMENSIONS		
A		FT
B		FT
C		FT
D		FT
E		FT
F		FT

Geodetic Ref:

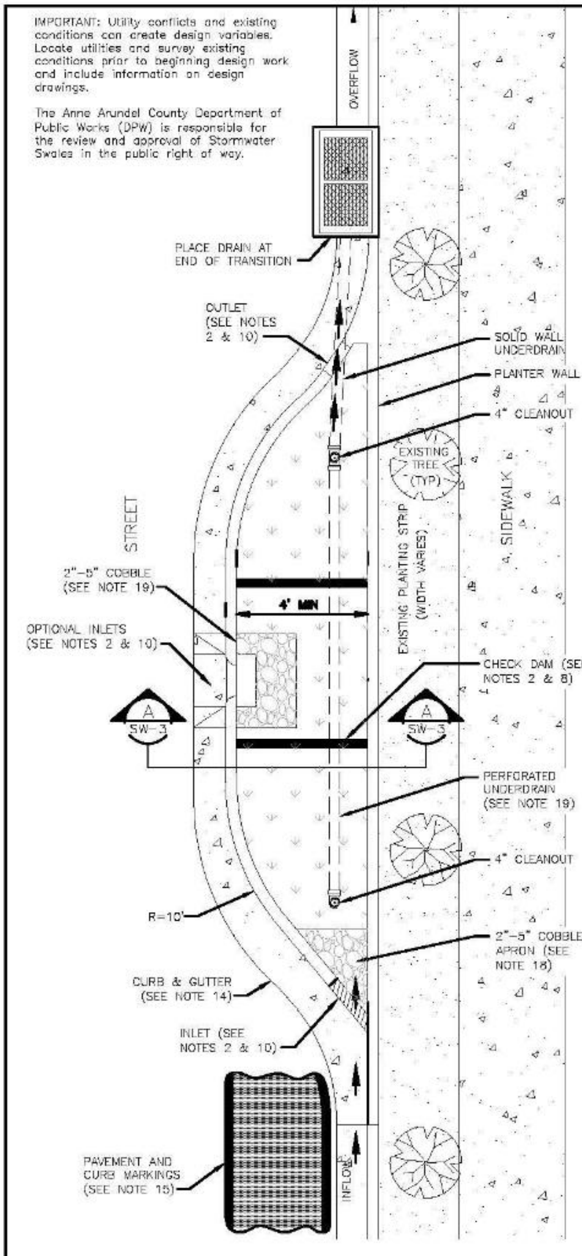
ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS EROSION MONITORING DEVICE DETAIL (OUT OF STREAM)	REVISED	NO. SW-19



N.T.S.

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS EROSION MONITORING DEVICE DETAIL	REVISED	NO. SW-20

C.5: CURB BUMP OUT



PLAN VIEW
N.T.S.

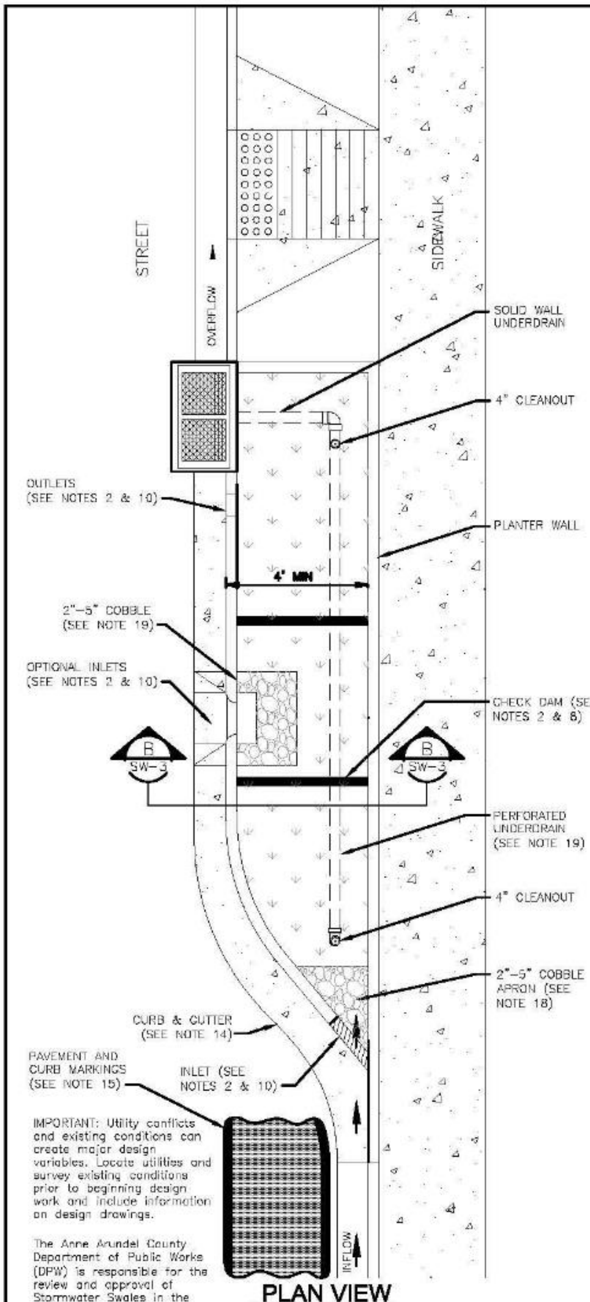
DESIGNER INFORMATION

1. Adapt plan view example to your engineered design.
2. Provide beginning and ending station for each facility. Provide station and/or dimensions and elevations at each inlet, outlet, check dam, planter corners, and sidewalk notches.
3. Longitudinal slope of the curb and tops of check dams matches road. The longitudinal slope of the facility bottom shall be terraced to provide a flat bottom within each cell between check dams.
4. Sidewalk elevation must be set above calculated 10–yr water surface elevations to allow overflow to drain to street before sidewalk. Must include consideration for weir flow (or submerged weir flow) over each check dam.
5. Existing utility lines must be sleeved or relocated. Proposed utility lines to be located out of facility.
6. Area and depth of facility are based on engineering calculations and right–of–way constraints. See Chapter 6 – General SWM Design Guidance of the Anne Arundel County Stormwater Management Practices and Procedures Manual. Follow applicable guidelines for micro–bioretention facilities sizing and design requirements.
7. Gutter spread for the design storm shall not exceed the recommended distance. See Anne Arundel County Design Manual: Chapter V – Storm Drains for maximum gutter spread and design storm frequency. Gutter spread for the roadway design storm shall not account for the flow rate into the bioretention facility. Assume the facility will be full during the peak design flow rate and it will pass around the facility along the gutter line.

ADDITIONAL DETAILS REQUIRED

8. Check Dam details.
9. Planter Wall detail.
10. Inlet/Outlet detail – Modify Standard Curb Opening Detail Curb & Gutter Section.
11. Special requirements for water lines, meters, and fire hydrants detail.
12. Use Bioretention Facility.
13. Stormwater facility construction and soil requirements, see Bioretention Top Soil – Anne Arundel County Design Manual Chapter VI.
14. Curb and gutter – Modify DPW Standard Combination Curb & Gutter (I/24). To Provide.
15. Taper pavement markings according to the latest lane reduction guidance from the Maryland Manual on Uniform Traffic Control Devices (MdMUTCD) as roadway type and design speed suggest. For areas with on–street parking, no taper is required. In both cases paint curb according to the latest Curb Markings section in the MdMUTCD to indicate a "No–Parking" area.
16. Where tree and tall shrub plantings are used, follow the 2011 AASHTO Policy on Geometric Design of Highways and Streets – Section 9.5 – Intersection Sight Distance.
17. Refer to Maryland SHA Bicycle and Pedestrian Design Guidelines – Chapter 10: Roadway Crossing Design for guidance on curb extension placement.
18. Size the 2"–5" Cobble Apron per the MDE Erosion and Sediment Control Outlet Protection Guidelines. Use anticipated 10–yr discharge.
19. Maintain a minimum 1–ft clearance between perforated pipe and the sides of the facility.
20. Maintain a minimum 2–way travel width of 20' to 26'. Minimum 12' travel width for one–way travel may be acceptable in some places.
21. Bump outs should not interfere with travel or marked bicycle lanes.
22. Consider the on–street parking impacts. Community involvement shall be initiated at concept level.
23. The space between bump outs shall allow at least one car to park and maneuver.
24. At intersections, analyze the turning movements of larger vehicles expected along the street. Also, provide ADA pedestrian compliance.
25. Install warning sign to indicate narrowing of road.
26. Design the facility to be less than 18" deep. In special cases (only with County approval) where the depth from the top of curb to the top of bioretention facility is greater than 18" and the curb extension is adjacent to moving vehicles, provide safety rails or sloped transition. Where curb extension is adjacent to pedestrian walk ways, provide 4–inch curb or sloped transition for all facility depths. For drops from the sidewalk to the top of facility greater than 18", provide safety rails or 4–inch curb with a sloped transition. See sections on SW–3 for guidance.

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS IN STREET PLAN VIEW MID-BLOCK CURB EXTENSIONS	REVISED	NO. SW-1



PLAN VIEW
N.T.S.

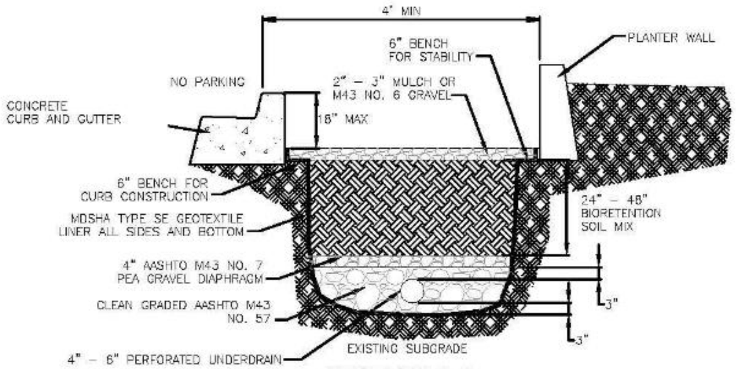
DESIGNER INFORMATION

1. This design is for a curb extension adjacent to a pedestrian ramp. Adapt plan view example to your engineered design.
2. Provide beginning and ending station for each facility. Provide station and/or dimensions and elevations at each inlet, outlet, check dam, planter corners, and sidewalk notches.
3. Longitudinal slope of the curb and tops of check dams matches road. The longitudinal slope of the facility bottom shall be terraced to provide a flat bottom within each cell between check dams.
4. Sidewalk elevation must be set above calculated 10–yr water surface elevations to allow overflow to drain to street before sidewalk. Must include consideration for weir flow (or submerged weir flow) over each check dam.
5. Existing utility lines must be sleeved or relocated. Proposed utility lines to be located out of facility.
6. Area and depth of facility are based on engineering calculations and right–of–way constraints. See Chapter 6 – General SWM Design Guidance of the Anne Arundel County Stormwater Management Practices and Procedures Manual. Follow applicable guidelines for micro–bioretention facilities sizing and design requirements.
7. Gutter spread for the design storm shall not exceed the recommended distance. See Anne Arundel County Design Manual: Chapter V – Storm Drains for maximum gutter spread and design storm frequency. Gutter spread for the roadway design storm shall not account for the flow rate into the bioretention facility. Assume the facility will be full during the peak design flow rate and it will pass around the facility along the gutter line.

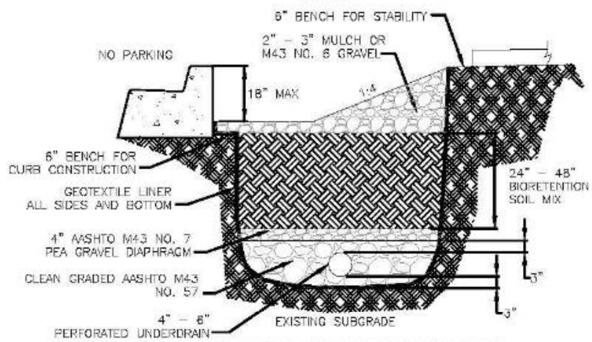
ADDITIONAL DETAILS REQUIRED WITH AVAILABLE RESOURCES

8. Check Dam details.
9. Planter Wall detail.
10. Inlet/Outlet detail – Modify Standard Curb Opening Detail Curb & Gutter Section.
11. Special requirements for water lines, meters, and fire hydrants detail.
12. Use Bioretention Facility.
13. Stormwater facility construction and soil requirements, see Bioretention Top Soil – Anne Arundel County Design Manual Chapter VI.
14. Curb and gutter – Modify DPW Standard Combination Curb & Gutter (I/24). To Provide.
15. Taper pavement markings according to the latest lane reduction guidance from the Maryland Manual on Uniform Traffic Control Devices (MdMUTCD) as roadway type and design speed suggest. For areas with on–street parking, no taper is required. In both cases paint curb according to the latest Curb Markings section in the MdMUTCD to indicate a "No–Parking" area.
16. Where tree and tall shrub plantings are used, follow the latest AASHTO Policy on Geometric Design of Highways and Streets – Section 9.5 – Intersection Sight Distance.
17. Refer to Maryland SHA Bicycle and Pedestrian Design Guidelines – Chapter 10: Roadway Crossing Design for guidance on curb extension placement.
18. Size the 2"–5" Cobble Apron per the MDE Erosion and Sediment Control Outlet Protection Guidelines. Use anticipated 10–yr discharge.
19. Maintain a minimum 1–ft clearance between perforated pipe and the sides of the facility.
20. Maintain a minimum 2–way travel width of 20' to 26'. Minimum 12' travel width for one–way travel may be acceptable in some places.
21. Bump outs should not interfere with travel or marked bicycle lanes.
22. Consider the on–street parking impacts. Community involvement shall be initiated at concept level.
23. The space between bump outs shall allow at least one car to park and maneuver.
24. At intersections, analyze the turning movements of larger vehicles expected along the street. Also, provide ADA pedestrian compliance.
25. Install warning sign to indicate narrowing of road.
26. Design the facility to be less than 18" deep. In special cases (only with County approval) where the depth from the top of curb to the top of bioretention facility is greater than 18" and the curb extension is adjacent to moving vehicles, provide safety rails or sloped transition. Where curb extension is adjacent to pedestrian walk ways, provide 4–inch curb or sloped transition for all facility depths. For drops from the sidewalk to the top of facility greater than 18", provide safety rails or 4–inch curb with a sloped transition. See sections on SW–3 for guidance.

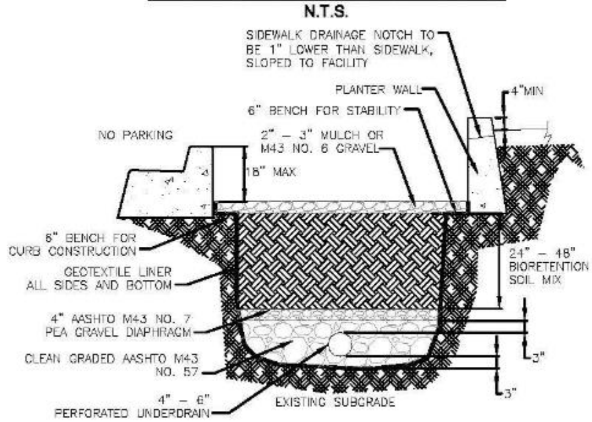
ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS IN STREET PLAN VIEW CURB EXTENSION AT PEDESTRIAN RAMP	REVISED	NO.
				SW-2



SECTION A-A
N.T.S.



SECTION B-B OPEN SIDEWALK
N.T.S.



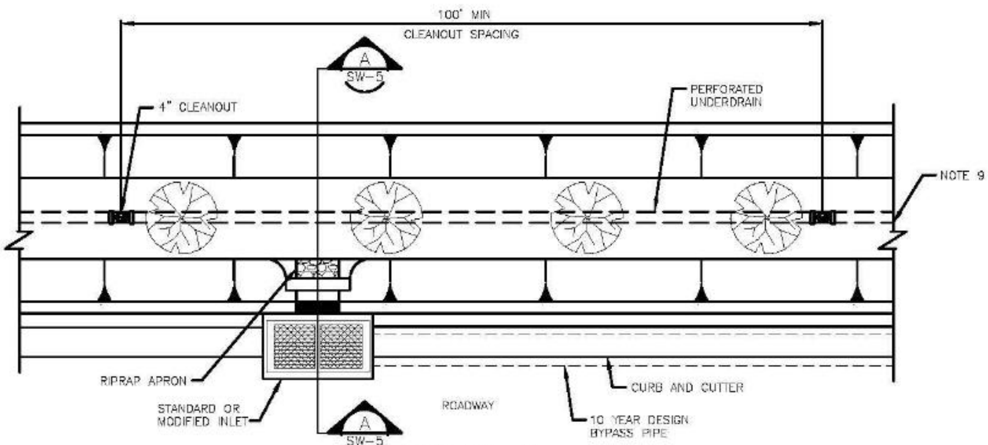
SECTION B-B CLOSED SIDEWALK
N.T.S.

CONSTRUCTION NOTE

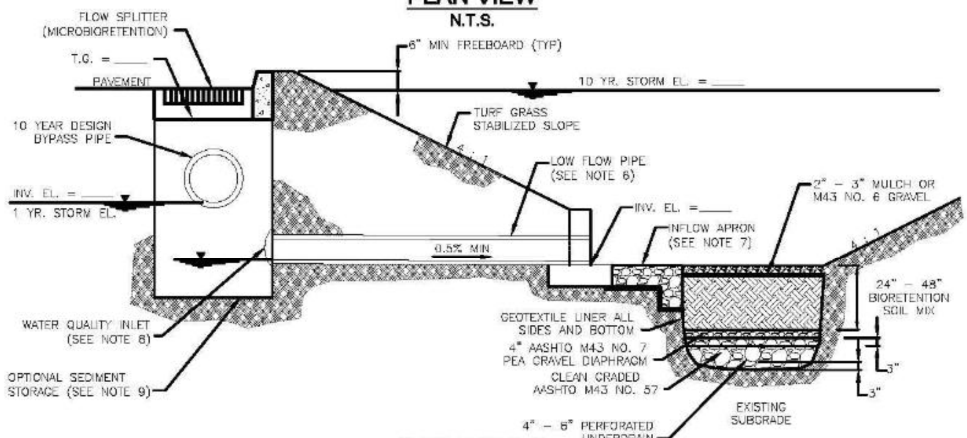
Scarify the native soil following initial excavation and before placing soil or rock

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS SECTION VIEWS CURB EXTENSIONS	REVISED	NO. SW-3

C.6: MICRO-BIORETENTION RETROFIT



PLAN VIEW
N.T.S.

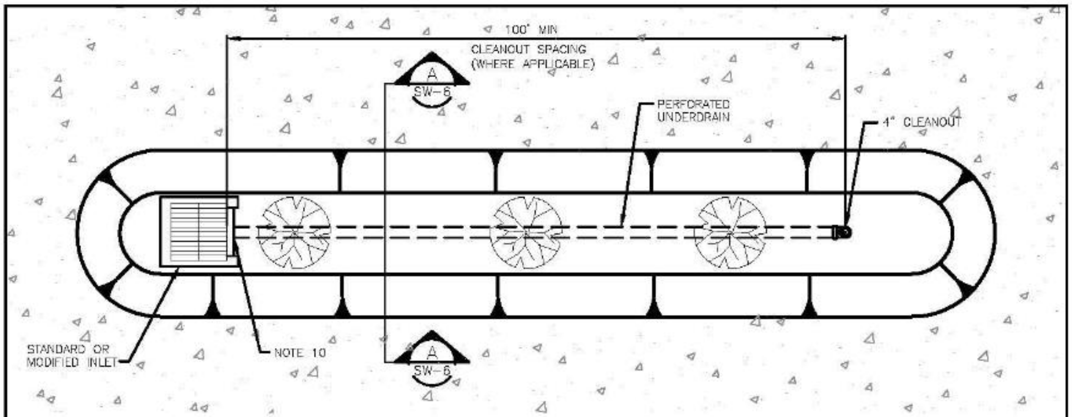


SECTION A-A
N.T.S.

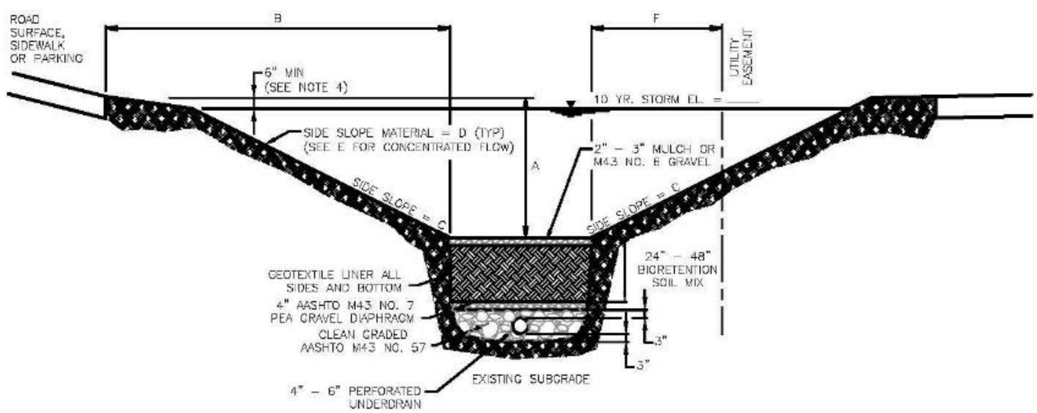
DESIGNER INFORMATION

1. Adapt plan view example to your engineered design.
2. Provide beginning and ending station for each facility. Provide station and/or dimensions and elevations at each inlet, outlet, cleanouts, facility corners, and sidewalk notches.
3. Size bypass system for the design storm, ignoring flow into the bioretention facility.
4. Minimum freeboard of 6 inches must be provided. Review Anne Arundel County Design Manual: Chapter V Storm Drains for the necessary roadway and drainage network freeboard and hydraulic grade line requirements.
5. Existing utility lines must be sleeved or relocated. Proposed utility lines to be located out of facility.
6. Size the Low Flow Pipe for the 1-yr peak discharge rate with the following assumptions:
   a. 75% of the ESDv is in the facility (including soil voids)
   b. The 1-yr must pass through the pipe(s) with a headwater below the bypass pipe invert.
7. Size the Low Flow Pipe inflow apron using the Maryland Erosion and Sediment Control Guidelines under the following assumptions:
   a. The 10-yr head in the drainage network with 75% ESDv in the facility.
   b. The 10-yr head in the drainage network with no water in the facility.
8. Provide flow splitter for microbioretention facilities. Pretreatment for micro-bioretention (< 1/2 acre drainage area) is optional. For retrofit bioretention facilities with limited space for pretreatment, a standard inlet with Trash Rack over the low flow pipe is a possible solution for providing pretreatment and keeping the facility offline.
9. A through F:
   Refer to the microbioretention and bioswale schedule (SW-6A). Underdrain shall discharge to a storm drain structure (preferred) or to a 5" concrete gutter for underdrain outlet (DPW Detail D-1).

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS MICROBIORETENTION/ BIORETENTION RETROFIT CLOSED SECTION	REVISED	NO. SW-5



PLAN VIEW
N.T.S.



SECTION A-A
N.T.S.

DESIGNER INFORMATION

1. Adapt plan view example to your engineered design.
2. Provide beginning and ending station for each facility. Provide station and/or dimensions and elevations at each inlet, outlet, cleanouts, facility corners, and sidewalk notches.
3. Size bypass system for the design storm, ignoring flow into the bioretention facility.
4. Minimum freeboard of 6 inches must be provided. Review Anne Arundel County Design Manual: Chapter V Storm Drains for the necessary roadway and drainage network freeboard and hydraulic grade line requirements.
5. Existing utility lines must be sleeved or relocated. Proposed utility lines to be located out of facility.
6. Size the Low Flow Pipe for the 1-yr peak discharge rate with the following assumptions:
   a. 75% of the ESDv is in the facility (including soil voids)
   b. The 1-yr must pass through the pipe(s) with a headwater below the bypass pipe invert.
7. Size the Low Flow Pipe inflow apron using the Maryland Erosion and Sediment Control Guidelines under the following assumptions:
   a. The 10-yr head in the drainage network with 75% ESDv in the facility.
   b. The 10-yr head in the drainage network with no water in the facility.
8. Provide flow splitter for microbioretention facilities. Pretreatment for micro-bioretention (< 1/2 acre drainage area) is optional. For retrofit bioretention facilities with limited space for pretreatment, a standard inlet with Trash Rack over the low flow pipe is a possible solution for providing pretreatment and keeping the facility offline.
9. A through F:
   Refer to the Microbioretention and Bioswale Schedule (SW-6A).
10. Underdrain shall discharge to a storm drain structure (preferred) or to a 5" concrete gutter for underdrain outlet (DPW Detail D-1)

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS MICROBIORETENTION & BIOSWALE OPEN SECTION DETAIL	REVISED	NO. SW-6

MICROBIORETENTION AND BIOSWALE SCHEDULE

	OPEN ROAD SECTION	OPEN SIDEWALK	OPEN PARKING CURB STOPS		CLOSED WITH CURB CUTS		CLOSED WITH INLET	
A – MAXIMUM SLOPE HEIGHT (FT)	2 FT	2 FT	5 FT		5 FT		–	
B – DISTANCE FROM DRIVE LANE TO FACILITY BOTTOM SLOPE HEIGHT (FT)	10'	N/A	N/A		N/A		–	
C – SLOPE	4 : 1	4 : 1	3 : 1	4 : 1	3 : 1	4 : 1	3 : 1	4 : 1
D – SIDE MATERIAL	TURF GRASS	TURF COBBLE PEA GRAVEL	COBBLE/ RIPRAP	ANY	COBBLE/ RIPRAP	ANY	NOT GRASS	ANY
E – INFLOW POINT MAT	*COBBLE	*COBBLE	*RIPRAP	*COBBLE	RIPRAP	COBBLE/ RIPRAP	N/A	N/A
F – PARALLEL UTILITY EASEMENT	5 FT	5 FT	5 FT	5 FT	5 FT	5 FT	–	–

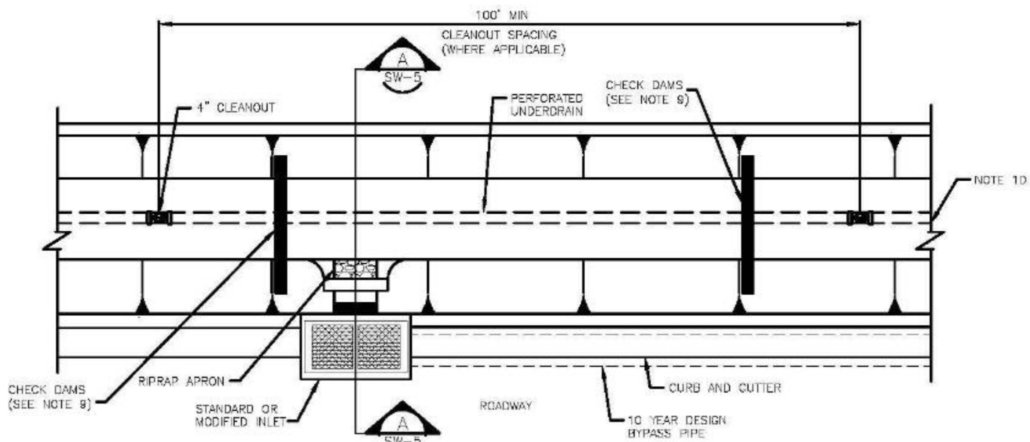
* SUMPS/LOW POINTS REQUIRE RIPRAP.

NOTES:

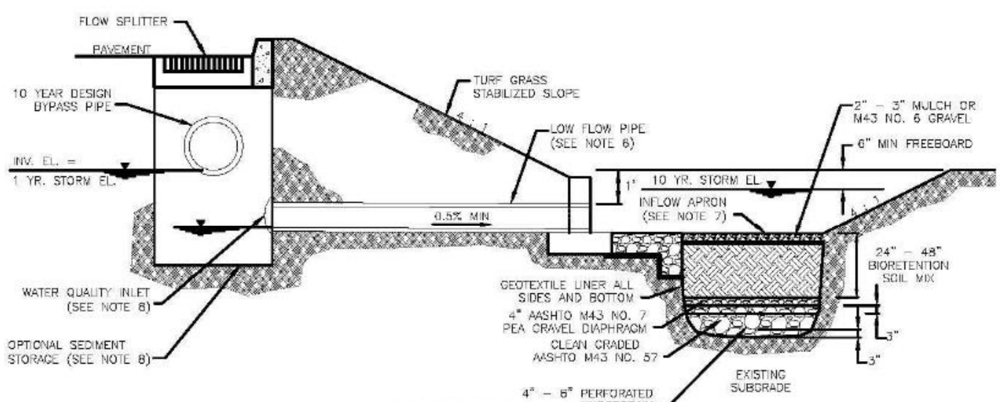
1. PROVIDE 10' FOR CARS TO PARK IF ROAD IS NOT STRIPED USE EOP.
2. SET STANDARDS FOR DISTANCE BETWEEN GRASS.

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS MICROBIORETENTION AND BIOSWALE SCHEDULE	REVISED	NO. SW-6A

C.7: BIOSWALES



PLAN VIEW
N.T.S.



SECTION A-A
N.T.S.

DESIGNER INFORMATION

1. Adapt plan view example to your engineered design.
2. Provide beginning and ending station for each facility. Provide station and/or dimensions and elevations at each inlet, outlet, facility corners, and sidewalk notches.
3. Size bypass system for the design storm, ignoring flow into bioswale.
4. Minimum freeboard of 6 inches must be provided. Review Anne Arundel County Design Manual: Chapter V Storm Drains for the necessary roadway and drainage network freeboard and hydraulic grade line requirements.
5. Existing utility lines must be sleeved or relocated. Proposed utility lines to be located out of facility.
6. Size the Low Flow Pipe for the 1-yr peak discharge rate with the following assumptions:
   a. 75% of the ESDv is in the facility (including soil voids)
   b. The 1-yr must pass through the pipe(s) with a headwater below the bypass pipe invert.
7. Size the Low Flow Pipe inflow apron using the Maryland Erosion and Sediment Control Guidelines under the following assumptions:
   a. The 10-yr head in the drainage network with 75% ESDv in the facility.
   b. The 10-yr head in the drainage network with no water in the facility.
8. Provide flow splitter for bioswale facilities. Pretreatment for bioswale (< 1/2 acre drainage area) is optional. For retrofit facilities require pretreatment with limited space for pretreatment, a standard inlet with storage below the low flow pipe invert and a Trash Rack over the low flow pipe is a possible solution for providing pretreatment and keeping the facility offline.
9. Check dams to meet MDE criteria for scour and shall pass the 10-yr or design storm, whichever is greater.
10. Underdrain shall discharge to a storm drain structure (preferred) or to a 5" concrete cutter for underdrain outlet (DPW Detail D-1).

ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS **BIOSWALE CLOSED SECTION**	REVISED	NO. SW-7

C.8: FLOW SPLITTER GUIDANCE

(Source, Montgomery County)

C.8: Flow Splitting Devices

1. Surface Flow Splitters
   At a storm drain outfall, place a shallow, concrete wall containment area. The containment area shall be designed as an energy dissipator (e.g., stilling basin or riprap basin/apron) per Hydraulic Engineering Circular 14 (HEC-14) – “Hydraulic Design of Energy Dissipators” to avoid erosion and minimize the unpredictable water levels at the splitter wall caused by turbulence. On one wall, design a low-flow orifice sized to allow for the ESDv or WQv to enter the treatment facility and to completely drain the containment area. Another wall shall be designed with a weir that is activated once the ESDv or WQv volume/rate is delivered to the treatment facility. This weir will bypass the larger flows to a quantity control facility or stable conveyance channel. If the weir discharges to an open channel, the channel shall be designed using the Emergency Spillway guidance in HEC-22, “Urban Drainage Manual.” For a closed bypass system, a raised yard inlet within the containment area may be used.
2. Underground Storm Drain Structure Splitter

   Using a standard County storm drain structure, place a low flow pipe at the lowest invert to deliver the ESDv or WQv to the treatment facility. Once the treatment volume is delivered, the larger flows will exit the structure through a storm drain sized for the required design storm. This method is preferred for underground quality treatment structures but may be used for aboveground facilities where site conditions dictate.

Flow Splitting Methods

1. Storage Method

   The storage method is the preferred method for diverting storm drain runoff into a water quality facility. The water surface level in the facility is controlled by the bypass pipe in the flow splitter. The benefit to this method is that no spillway is required; the bypass pipe acts as the principle spillway. As a result, high flows do not pass through the facility. This method typically works best for smaller drainage areas (e.g., ESD BMP). If using the storage method results in a facility with an embankment that requires MD-378 design, the designer should consider the Flow Restriction Method below to avoid the need for MD-378 design and review.
2. Flow Restriction Method

   The flow restriction method shall be used when site conditions preclude the use of the Storage Method. Oftentimes, an unacceptable volume of runoff in excess of the WQv/ESDv enters the facility during bypass storm events, requiring a higher embankment or the need for an outfall directly from the treatment facility. To minimize the flow through the facility that would re-suspend sediment and pollutants, the inflow is restricted to allow only WQv and ESDv peak discharge before activating the bypass pipe. Additionally, flow that enters the facility during high-flow storms is discharged through a spillway in the treatment facility.

Flow Splitting Design Approach

While there are two methods that may be employed—the Storage Method and the Flow Restriction Method—both methods require the following design approach to minimize the amount of flow in excess of the ESDv or WQv that enters the treatment facility.

1. Determine the water surface elevation (WSEL) in the treatment facility for the WQv, ESDv or other design volume. This elevation will be used as the flow splitter tailwater for the pipe/orifice analysis.

2. Determine the peak treatment discharge for the WQv or ESDv (Q_P). Peak rate calculations will depend on the rainfall (P_E) of the treatment storm.
   - $P_E < 2$ inches –Appendix D.10 in the Maryland Stormwater Design Manual
   - $P_E \geq 2$ inches –NRCS methods
3. Size the low flow pipe or orifice and determine the headwater needed to pass Q_P into the treatment facility using the WSEL from Step 1 as the tailwater and the following:
   a. Pipe culverts – FHWA Hydraulic Design Series (HDS) 5 (e.g., HY-8 or CulvertMaster)
   b. Orifices – HEC-22

   The designer shall prioritize minimizing the head necessary given the known tailwater. For pipe culverts, this is often achieved by setting the inverts so that the culvert is near the inlet/outlet control threshold for Q_P, i.e., the outfall is partially submerged to the point that tailwater has no effect on the headwater.

   NOTE: Pipes shall be no smaller than 6 inches in diameter. Orifices used in surface flow splitters may be a minimum of 3 inches in diameter.
4. Size the bypass pipe or outfall weir for the 10-year storm by setting the invert or crest at the elevation of the headwater determined for Q_P in Step 3. The 10-year WSEL shall be 1 foot below the top of the facility embankment (for embankments that are MD-378 exempt). The WSEL in the flow splitter and the treatment facility are assumed to be the same.
   a. The designer shall select an appropriate method for determining hydraulic losses in the flow splitter. Guidance for drainage structure losses are provided in HEC-22. Analyzing the bypass pipe as a culvert with static head using the HDS-5 approach will yield reasonable, conservative results.
   b. The facility design must meet the stormwater facility requirements in the MDE Stormwater Design Manual, Chapter 5.
5. If the embankment height determined in Step 4 is feasible, use the Storage Method. This is achieved by increasing the pipe size determined in Step 3 by one standard size or by increasing the low flow orifice area by 30%. All other bypass designs remain the same.
6. If the embankment height determined in Step 4 is not feasible, use the Flow Restriction Method. This is achieved by using the low flow device size determined in Step 3 and constructing an outfall structure or spillway in the treatment facility. The spillway shall be set at the elevation of the ESDv or WQv. Earthen spillways shall be placed in cut soils only and shall be armored (e.g., riprap, gabion, concrete).

Materials

Flow splitting pipes typically range in size between 6 and 12 inches; however, larger pipes may also be used. The minimum pipe size allowed is 6 inches. When splitting from a publicly maintained manhole, a maximum distance of 12 inches is allowed between the invert of the 10-year outgoing storm drainpipe and the crown of the first flush pipe. Weirs are not allowed in public structures.

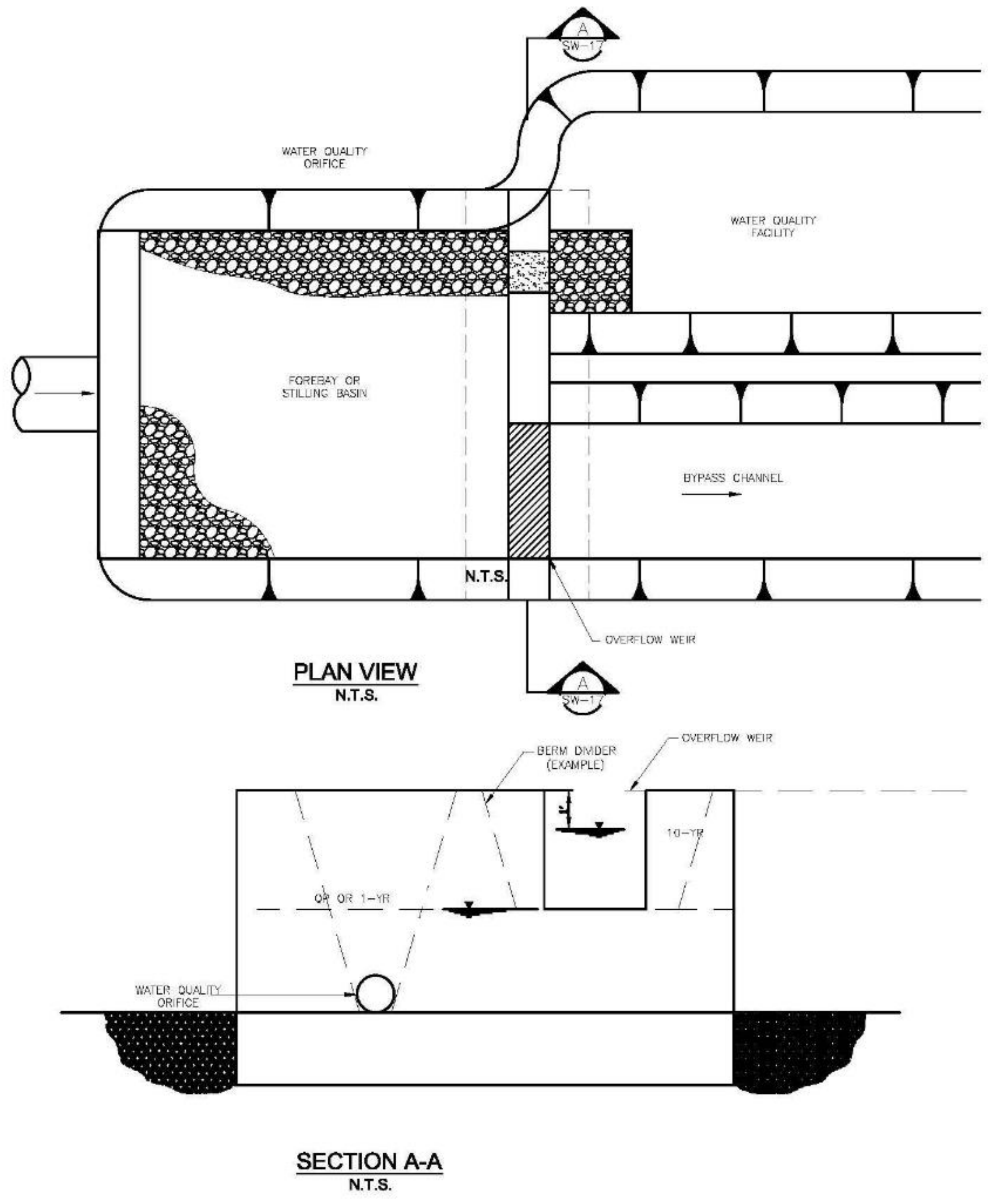
Trash Rack Criteria

Trash racks must be designed to be self-flushing whenever possible. Refer to the detail entitled "Diversion Structure Manhole Detail" following. All flow split delivery openings or pipes smaller than 15 inches in diameter require trash racks. If the flow split delivery opening or pipe is 15 inches or larger in diameter, a trash rack is not required. Trash racks may be either expanded metal or rebar. All trash racks must be removable.

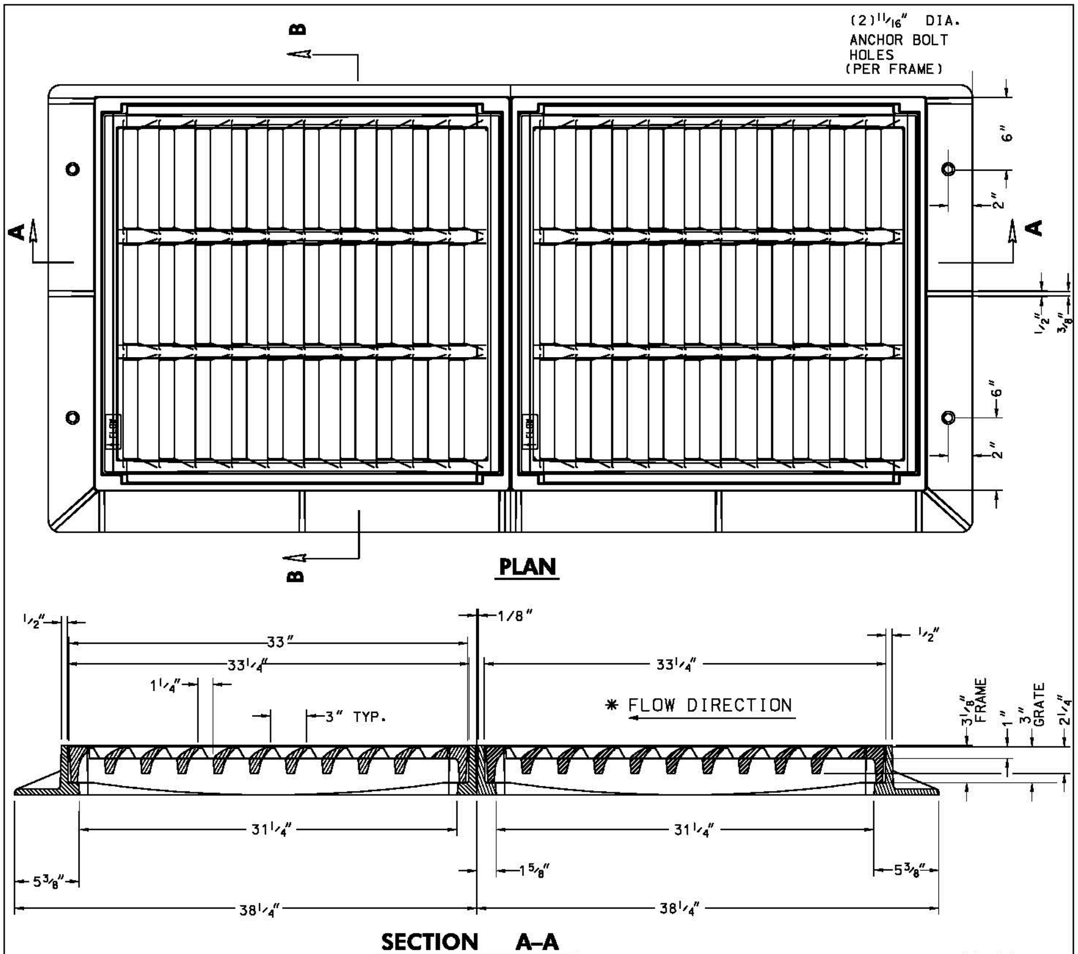
Construction Notes on Plans

It is extremely important that flow splitters be built correctly. Please ensure the detailed plans reflect the following:

1. The sequence of construction must specifically identify the flow splitter by structure number.
2. Add the actual dimension between the invert of the flow splitter pipe and the invert of the overflow pipe to the detail on the plans.
3. Add a note to the detail calling for “the contractor to verify that dimension prior to backfilling around the structure, and to notify the design engineer immediately if there is a discrepancy.”



ANNE ARUNDEL COUNTY DEPARTMENT OF PUBLIC WORKS	APPROVED CHIEF ENGINEER DESIGN ENGINEER DATE:	STORMWATER MANAGEMENT MANUAL TYPICAL DETAILS SURFACE FLOW SPLITTER	REVISED	NO. SW-17

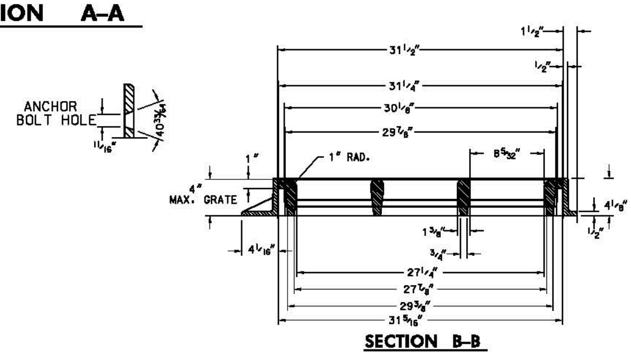


NOTES:

MATERIAL: CAST GRAY IRON ASTM A-48, CLASS 35B
FINISH: NO PAINT
WEIGHT (MIN.): FRAME 152#, FRAME 152#, GRATE 295# EA.

FRAMES TO BE CASTING WITH FLANGE CUT, AS SHOWN, WHEN INLET TO BE PLACED ADJACENT TO CURB OPENING. FOR FULL FLANGE/DETAILS, REFER TO THE RESPECTIVE STANDARD PLATES FOR TYPE "S" INLET.

✱ CONTRACTOR IS RESPONSIBLE FOR CORRECT ORIENTATION OF THE CV-GRATE TOWARD THE DIRECTION OF FLOW.



SPECIFICATION 305

APPROVED — DIRECTOR – OFFICE OF HIGHWAY DEVELOPMENT

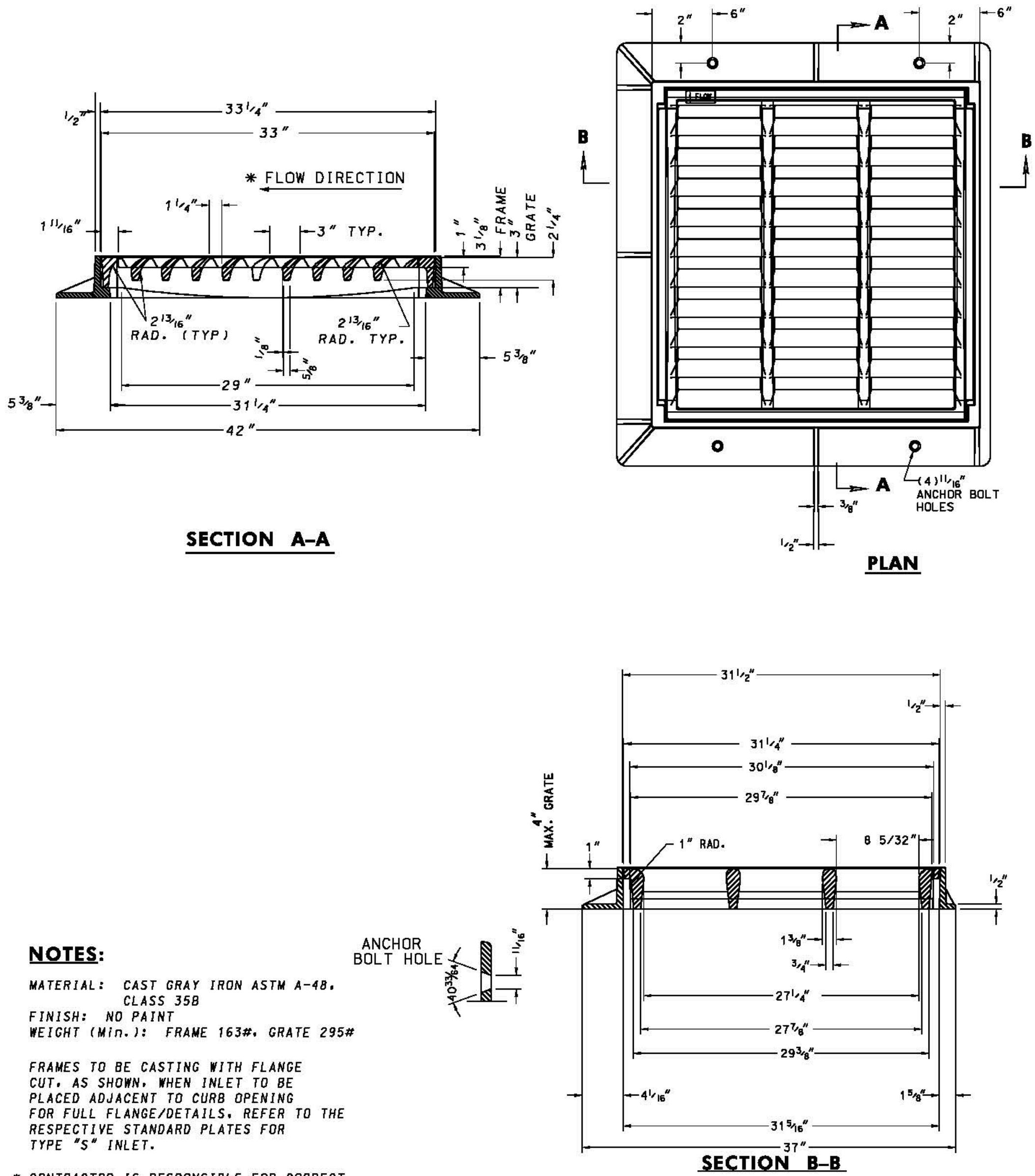
APPROVAL • SHA REVISIONS		APPROVAL • FEDERAL HIGHWAY ADMINISTRATION	
APPROVAL	2-10-04	APPROVAL	3-31-04
REVISED	7-1-09	REVISED	7-27-09
REVISED		REVISED	
REVISED		REVISED	

SHA State Highway Administration

Maryland Department of Transportation
STATE HIGHWAY ADMINISTRATION
STANDARDS FOR HIGHWAYS AND INCIDENTAL STRUCTURES

CURVE VANE GRATES WITH FRAME FOR DOUBLE TYPE "S" INLET (S2-CV)

STANDARD NO. MD 379.05-01



NOTES:

MATERIAL: CAST GRAY IRON ASTM A-48, CLASS 35B
FINISH: NO PAINT
WEIGHT (Min.): FRAME 163#, GRATE 295#

FRAMES TO BE CASTING WITH FLANGE CUT, AS SHOWN, WHEN INLET TO BE PLACED ADJACENT TO CURB OPENING FOR FULL FLANGE/DETAILS, REFER TO THE RESPECTIVE STANDARD PLATES FOR TYPE "S" INLET.

* CONTRACTOR IS RESPONSIBLE FOR CORRECT ORIENTATION OF THE CV-GRATE TOWARD THE DIRECTION OF FLOW.

SPECIFICATION 305		**Maryland Department of Transportation**
APPROVED	Kirk G. McClelland DIRECTOR – OFFICE OF HIGHWAY DEVELOPMENT	**STATE HIGHWAY ADMINISTRATION** STANDARDS FOR HIGHWAYS AND INCIDENTAL STRUCTURES
SHA State Highway Administration	APPROVAL • SHA REVISIONS	APPROVAL • FEDERAL HIGHWAY ADMINISTRATION
	APPROVAL 2-10-04	APPROVAL 3-31-04
	REVISED 7-1-09	REVISED 7-27-09
	REVISED	REVISED
	REVISED	REVISED

CURVE VANE GRATE WITH FRAME FOR SINGLE TYPE S INLET (S-CV)

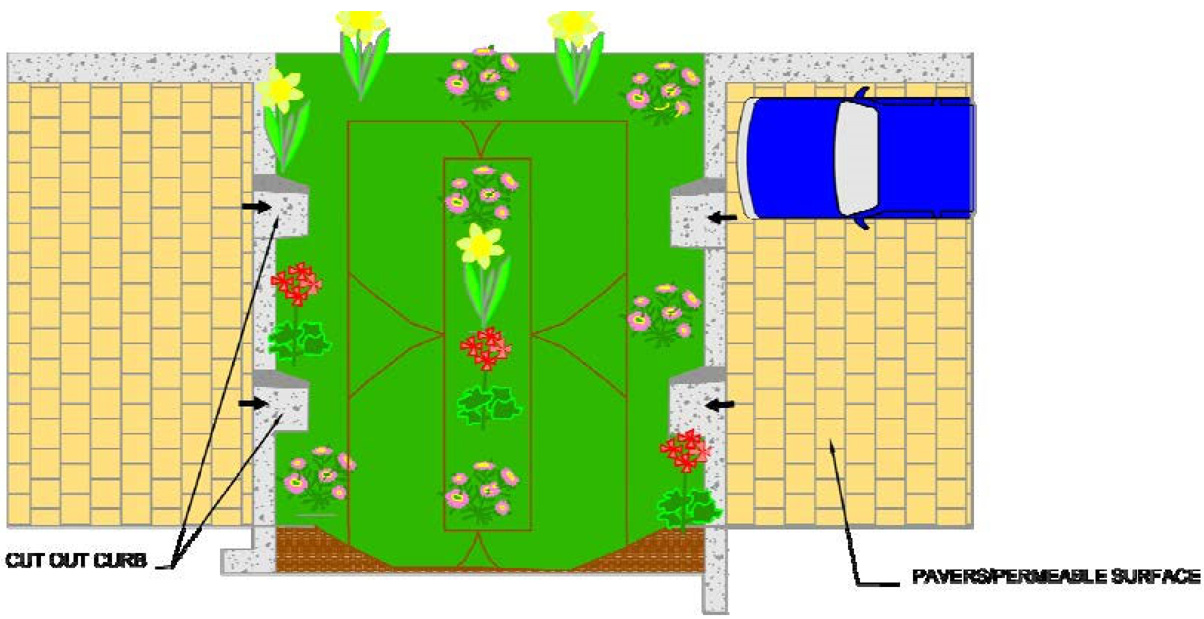
STANDARD NO. MD 379.02-01

C.9: ALTERNATIVE PAVEMENTS

Source: http://www.nyc.gov/html/dot/html/pedestrians/streetdesignmanual.shtml#download

Alternative Paving Systems

Alternative Surfaces – an effective method to reduce imperiousness in residential, commercial, and industrial applications is to use more permeable alternatives.



Porous Asphalt

Usage: Pilot

Asphaltic concrete in which the amount of fine particles is kept to a minimum and in which the binder content is low, allowing water to pass through into an open-graded reservoir.

Voids in between stones allow water to pass through (Note. for demonstration purposes, this example shows a clear resin, not asphalt, to bind the aggregate particles)

Conventional asphalt causes rainwater to pool while porous asphalt allows it to permeate the ground below

Benefits

- See benefits of ASPHALTIC CONCRETE (3.4.1)
- Reduces impermeable surface, thereby increasing water infiltration
- Exhibits structural properties similar to conventional asphalt
- Reduces peak discharge during storm events
- Reduces likelihood of ponding and slick or icy road conditions
- Helps reduce urban heat-island effect

Considerations

- See considerations for ASPHALTIC CONCRETE (3.4.1)
- Not recommended for use where there is water-sensitive sub-surface infrastructure
- Only certain soil types are appropriate as sub-bases for infiltration
- Porosity of pavement can convey harmful chemicals into the soil
- Requires vacuuming of surface to restore permeability when clogged
- Sand should not be applied to surface

Application

- Can be proposed for use in parking lanes, parking lots, and recreational paths
- Most effective on slopes less than 5%
- Must have adequate sub-surface conditions to detain stormwater
- Avoid "stormwater hotspots"—sites where there is high potential for soil and groundwater contamination
- Not recommended for implementation over significant underground utility corridors
- Use of this material generally requires a maintenance agreement

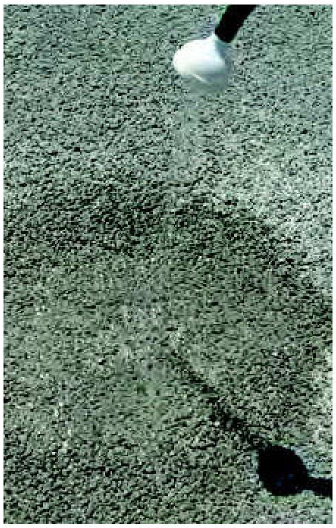
Design

- Minimum 3-inch-thick wearing course, typically
- Roadway should be crowned to drain stormwater from the road surface
- Aggregate should be no smaller than 600 µm, or the No. 30 sieve
- Asphaltic cement should be 5.75–6.75% bituminous asphalt content by weight
- Do not seal coat
- Typically, a 12–30-inch open graded stone infiltration bed is recommended.
- Bottom of infiltration bed should be at least 2 feet above high water table and 2 feet above bedrock

Porous Concrete

Usage: Pilot

Concrete mixture using minimal cementitious paste to coat the aggregate, and using little or no sand or fine aggregate, leaving substantial void content. This allows water to pass through to an open-graded reservoir underneath.



Porous concrete lets water permeate down to the subsurface soil

Benefits

- See benefits of UNPIGMENTED CONCRETE (3.1.1)
- Reduces impermeable surface, thereby increasing water infiltration
- Reduces peak discharge during storm events
- Reduces likelihood of ponding and slick or icy conditions
- Helps reduce urban heat-island effect

Considerations

- See considerations for UNPIGMENTED CONCRETE (3.1.1)
- Pervious concrete has reduced strength compared to conventional concrete applications
- Not appropriate for use where there is water-sensitive sub-surface infrastructure
- Only certain soil types are appropriate as sub-bases for infiltration
- Porosity of the concrete can convey harmful chemicals into the soil
- Requires routine vacuuming of surface to restore permeability
- Sand should not be applied to surface
- Contractors should be certified to install porous concrete
- Slump and air content tests are not applicable to pervious concrete

Application

- Most effective on slopes less than 5%
- Must have adequate sub-surface conditions to detain stormwater and level bottom to allow for uniform infiltration
- Can be used to pave an entire sidewalk or just hardscape between CONNECTED TREE BEDS (6.1.1b)
- Avoid "stormwater hotspots"— sites where there is potential for soil and groundwater contamination
- Not recommended for implementation over significant underground utility corridors
- Use of this material generally requires a maintenance agreement

Design

- See design guidance for UNPIGMENTED CONCRETE (3.1.1)
- Typically an 8- to 24-inch open graded stone infiltration bed is recommended
- Generally 4 – 8 inches thick
- Pervious concrete should maintain a 15 – 25% void content ratio
- Bottom of infiltration bed should be at least 2 feet above high water table and 2 feet above bedrock

Appendix D: Applicable Checklists, Forms, and Data Sheets

Information Located on the County Website

County Inspection & Permits Checklist, Forms, and Instructions are located at this website: http://www.aacounty.org/IP/Forms.cfm.

Information Located in the Practices and Procedures Manual

- Concept Plan Requirements: Chapter 3
- Site Development Plan Requirements: Chapter 4
- Final Plan Requirements: Chapter 5
- Maintenance Inspection Schedule: Private Facilities, Section 9.3; Public Facilities, Section 10.2.3.B
- Construction Inspection Schedule: Section 10.2
- Outfall Statement Requirements: Section 11.6.1
- General Stormwater Management Notes: Section 11.6.2
- Stormwater Management Note (for each drainage area to each study point where stormwater runoff is discharged from the site): Section 11.6.3
- Stormwater Management Summary Table: Section 11.6.3
- Stormwater Management Structure and Stream Restoration Summary Sheet: Section 11.7
- Maintenance and Inspection Notes for Private SWM Practices: Section 11.8

Design Guidelines for Step Pool Stormwater Conveyance (SPSC) Systems

May 2022

Bureau of Watershed Protection and Restoration

Anne Arundel County Department of Public Works

Anne Arundel County
Bureau of Watershed
Protection
& Restoration

Cover Photograph:

Step Pool Stormwater Conveyance System. Dairy Farm Road Outfall (Anne Arundel County).

Acknowledgements

This document supersedes the Anne Arundel County *Regenerative Step Pool Storm Conveyance (SPSC) Design Guidelines* (Revision 5a: Updated 2012). This version of the SPSC guidelines builds upon and updates the original manual to include corrections, revisions, and current best practice for design. The original guidance was prepared by Hala Flores, P.E., Dennis McMonigle, and Keith Underwood (Underwood & Associates, Inc.); and updated by Ken Pensyl. This update was supervised by Joe Arrowsmith, P.E. (AKRF/Straughan Joint Venture), under the direction of Jens Geratz and the Bureau of Watershed Protection & Restoration (BWPR) staff.

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"What are we trying to achieve when we sit down to design an SPSC? When the designer fully understands the philosophy – only then does the SPSC design guidance document become a tool. If the philosophy is not understood, then many of the guiding principles in this document may be mistaken and misused."

~ Keith Underwood ~

Preface

This document features design guidelines and procedural steps to aid designers in sizing a Step Pool Stormwater Conveyance (SPSC) system. It is the responsibility of the designer to check the feasibility and acceptability for using these systems at their project site. SPSCs can be used in lieu of storm drains as roadside conveyance/attenuation systems. SPSCs may be used for peak flow management or steep slope stability treatment and are considered structural Stormwater Best Management Practices (BMPs) if they are sized to accommodate the volume control requirements specified in Chapter 2 of the 2000 Maryland Stormwater Design Manual, Volumes I and II (the State Manual) (Maryland Department of the Environment, 2000). SPSC systems are also commonly used to secure credit as a Total Maximum Daily Load (TMDL) retrofit practice towards Municipal Separate Stormwater Sewer System (MS4) goals.

SPSCs may be used as a structural stormwater management device to provide water quality treatment as part of the treatment train or at the downstream outfall after all Environmental Site Design (ESD) techniques have been exhausted to the Maximum Extent Practicable (MEP) as dictated in the State Manual. Under special circumstances, the SPSC may be used as part of the ESD when the design conforms to the criteria found in Chapter 5 of the State Manual for microbioretention or bio-swale and the general configuration conforms to the principles of ESD, i.e., using small-scale practices distributed uniformly around the site to capture runoff close to the source. Stormwater quality and treatment are discussed in detail in Section 7.0 Use of SPSCs as a Stormwater BMP and MS4 Retrofit.

This document represents a major update to the existing Anne Arundel County "Design Guidelines for Regenerative Step Pool Storm Conveyance" previously revised in 2012. This document supersedes the 2012 guidance and is the current approved guidance for SPSC design in Anne Arundel County. This manual is henceforth incorporated into the County's Stormwater Practices and Procedures Manual as Section 11.4.5.

While many core principles from the 2012 guidance remain unchanged, this document has been updated to:

Re-organize the document to follow the typical design process for plan set development.

- Address inconsistencies and re-evaluate minimum and maximum thresholds for design dimensions.
- Refresh typical sections and design details to represent current best practice and dimensions to scale.

- Provide a workflow for sizing of structures (riffle and cascade weirs, pools).
- Provide clarity on acceptable material used in SPSC construction.
- Provide updated guidance on Erosion & Sediment Control design and enhanced guidance on Planting Plan design.
- Update references to current guidelines for stormwater and TMDL crediting.
- Update the SPSC calculator spreadsheet tool (included as a supplement to this document).

The goal of this updated guidance is to incorporate the knowledge acquired over a decade of progress and experience in SPSC design and construction in Anne Arundel County and improve the consistency in approach and outcomes for future projects.

1.0 Introduction

SPSC systems are a form of open channel conveyance and stormwater treatment characterized by an alternating sequence of stone grade control structures (i.e., riffle and cascade weirs) and pools underlain by a seepage filter made from a sand and woodchip mix. SPSC systems combine the benefits of step-pool morphology with the subsurface filtration capability of a bioretention practice. Although this approach is closely related to other stormwater and ecological restoration practices, the SPSC approach as defined and described in this guidance is primarily limited to upland and outfall channel locations. When used as a stormwater practice, SPSC systems are exclusive to ephemeral channels and outfalls. Appendix B: Site Photos contains photos of various SPSC projects completed within Anne Arundel County.

SPSC systems are generally best suited in natural ravines or storm-driven gullies and are Anne Arundel County's preferred method of stormwater conveyance on a developed site. The most typical use for a SPSC is to provide a stable surface and subsurface link between the upland (i.e., top of slope) and the valley bottom, generally originating at a storm drain outfall or concentrated discharge point and connecting to an intermittent or perennial stream channel or floodplain. Generally, SPSC channels have an average bed slope ranging from moderate to steep and are confined between steep valley (or gully) side slopes with limited access to a floodplain. SPSCs may be implemented as a replacement or complement to standard drainage (e.g., swales/pipes) and stormwater management practices (e.g., bioswales) and can be incorporated as part of a stormwater treatment train.

When properly designed, SPSCs provide stability along steep conveyance pathways while repairing and preventing bed erosion from headcut propagation. Research in the Chesapeake Bay watershed indicates that bed and bank erosion can account for up to 70 percent of annual sub-watershed sediment yield with most of that erosion attributed to headwater streams (Donovan, Miller, Baker, & Gellis, 2015). In 2019, both the State of Maryland and the Chesapeake Bay Program approved MS4 program TMDL credit for projects that stabilize outfalls and gullies, in recognition of the value of preventing loss of sediment and nutrients due to headwater stream erosion. The SPSC approach is an approved outfall and gully stabilization approach and can be credited both as a stormwater retrofit and as an "Outfall and Gully Stabilization Project" (Chesapeake Bay Program Urban Storwmater Work Group, 2019, 10 05).

This document outlines methods for the design and sizing of SPSC systems within Anne Arundel County, including the definition of typical design components, the proper calculation of hydraulic relationships, development of profile and grading plans, material sizing, and the development of erosion and sediment control and planting plans.

While SPSC channels have commonality with step-pool morphology observed in nature, this approach is not based on empirical studies of natural reference conditions. However, it is of utmost importance to note that the SPSC approach was conceived to mimic natural processes. Most importantly, the core value of the SPSC approach is to foster filtration and infiltration of surface water and interaction with near surface groundwater through sandy soils. Conversion of surface water to groundwater is the fundamental philosophy that underpins and explains the chosen construction materials and methods including and especially the resulting community of native plants.

Nomenclature and relationships with similar practices

The SPSC technique has previously been described (and interchangeably referred to) as a "Coastal Plain Outfall" given its initial development as an outfall stabilization practice in the Coastal Plain of Maryland. However, the "Step Pool Stormwater Conveyance" nomenclature has since been formally adopted by Anne Arundel County to better reflect the broader applicability of the practice beyond the Coastal Plain physiographic province.

The SPSC approach shares principles and overlaps with a design approach for stream valley restoration known as Regenerative Stream Conveyance (RSC). Both SPSC and RSC are similarly characterized by an alternating sequence of pools and weir structures built atop fill. Indeed, due to its close relationship with the RSC practice, the Chesapeake Bay Program defines SPSC projects as "Dry Channel RSC" projects. The primary difference between an RSC and a SPSC is the location where the practice is implemented. SPSC systems connect uplands to lowlands, while RSCs are typically applied to valley bottom streams with access to a floodplain.

The typical RSC configuration is best suited for intermittent or perennial streams. Consistent with their landscape position, SPSCs are typically confined by narrow valley walls and lack access to a floodplain or terrace. The objective of an RSC is to promote direct and perennial interaction between the stream and its floodplain by lifting the channel invert up to the existing floodplain terrace and, in some instances, diverting and impounding water directly onto the floodplain using small berms to mimic sand-seepage wetlands.

Although existing guidance documents and research papers do not consistently make a clear distinction between SPSC and RSC, the County defines the practices as separate and has limited the scope of this guidance to the SPSC configuration. While some of the guidance contained in this document has broad applicability beyond the SPSC approach, designers should note that this guidance is not meant to serve as a stream restoration manual for low-gradient channels or as an RSC design manual.

2.0 Design of SPSC Systems

The most important part of SPSC design is setting up the opportunity for the project to fit the natural landscape, not forcing the natural landscape to fit the project. With that said, that rule does not always apply when the landscape has been drastically altered through human development. In some cases, all ecological function on site has been lost and the design should reflect the need to completely rebuild the system.

SPSC structures consist of an open channel conveyance system with alternating grade control weirs and pools. These systems are best suited for channels with longitudinal profile slopes ranging between two and ten percent. However, the design can be adapted for sites with slope outside that range. While typically designed as a retrofit within or near an existing degraded channel, SPSC systems can also be implemented pre-emptive of channel erosion to provide grade control and water storage (e.g., when paired with site development to satisfy stable outfall conditions). The County Stormwater Practices and Procedures Manual requires that all new stormwater outfalls that discharge to open channels shall be constructed as SPSCs whenever it is feasible (Anne Arundel County, 2017).

SPSC systems combine the benefits of step-pool morphology with the subsurface filtration capability of a bioretention practice. The elevation head differential from connecting tiered surface pools to a continuous subsurface sand filter helps to recharge groundwater and convert a portion of surface discharge to subsurface flow (spring head seepage). Excess surface flow is conveyed safely over the grade control weir to the lower receiving pool.

The SPSC design is commonly used as a retrofit practice for existing eroded stormwater outfalls channels and is the preferred approach by the County for intervention to correct gully erosion. As a retrofit practice, it can provide retrofit storage volume, impervious acre treatment credit, and Chesapeake Bay TMDL nutrient reduction credit. Information on stormwater and retrofit crediting is discussed in more detail in Section 7.0 Use of SPSCs as a Stormwater BMP and MS4 Retrofit.

The dimensions of riffle and cascade weirs and pool features are designed in a manner to ensure adequate and safe conveyance of the design flow and promote sustainable and resilient outfall conditions. Although the design of SPSC systems may be customized to achieve a variety of goals, the primary objective of an SPSC is to provide resiliency over time. Stable outfalls are a requirement for all proposed developments and retrofit projects.

This document has been formulated to aid the designer in preparing the minimum design elements for the SPSC. It should be noted that the computations presented in this document are minimum design guidelines to ensure that the constructed system will not degrade. It is important to acknowledge that each site has unique and defining features that require site-specific design and analysis. The guidance in this document is intended to provide the fundamentals for sizing the facility to meet the regulatory requirements. It is not intended to be a substitute for engineering judgment regarding the validity and feasibility associated with site-specific implementation. Designers must be familiar with the hydrologic and hydraulic engineering principles that are the foundation of the design, and they should also enlist the expertise of qualified individuals in stormwater management, stream restoration, and native plant ecology to develop a comprehensive plan.

2.1 Typical SPSC Components

The SPSC system is composed of a sequence of riffles or cascades weirs (e.g., grade controls) separated by pools. A typical cascade weir, riffle weir, and pool sequence labeled with dimensions and components is shown in Figure 1. This section is an introduction to the individual components typical to SPSCs, including typical dimensions, detail drawings, and design guidance. For a consolidated summary of dimension criteria, please refer to Appendix C: Minimum and Maximum Design Dimensions. Anne Arundel County has developed standard design details as a companion to these guidelines. These details are available for download at www.aarivers.org.

2.1.1 Riffle Weirs

Riffle weirs are parabolic channel sections armored with stone which provide grade control while traversing vertical heights of 1.5 feet or less. Height is the vertical distance between the upstream (US) and downstream (DS) inverts of the riffle weir as labeled on the profile shown in Figure 1. Figure 2 shows a photograph of a series of riffle weirs separated by pools. Typically, riffle weirs traverse vertical heights of one foot. Riffle weirs serve as the stable connection between pools. Schematic drawings of a riffle weir in plan and section view are provided as Figure 3 and Figure 4, respectively.

Standard one-foot riffle weir

This guidance document includes references to a “standard one-foot riffle weir” as part of the iterative design process. A standard one-foot riffle weir is defined as a site-specific riffle weir with a riffle height of 1-foot, sized to safely convey the design flow in conformance with these guidelines. The designer will solve an iterative process for each reach on their site and size this typical riffle weir with standardized dimensions. Although the designer is not required to use standard one-foot riffle weirs exclusively in their final design, the County recommends that riffle weirs typically conform to these dimensions to simplify the basis of design, improve constructability, and simplify sizing of other facet features.

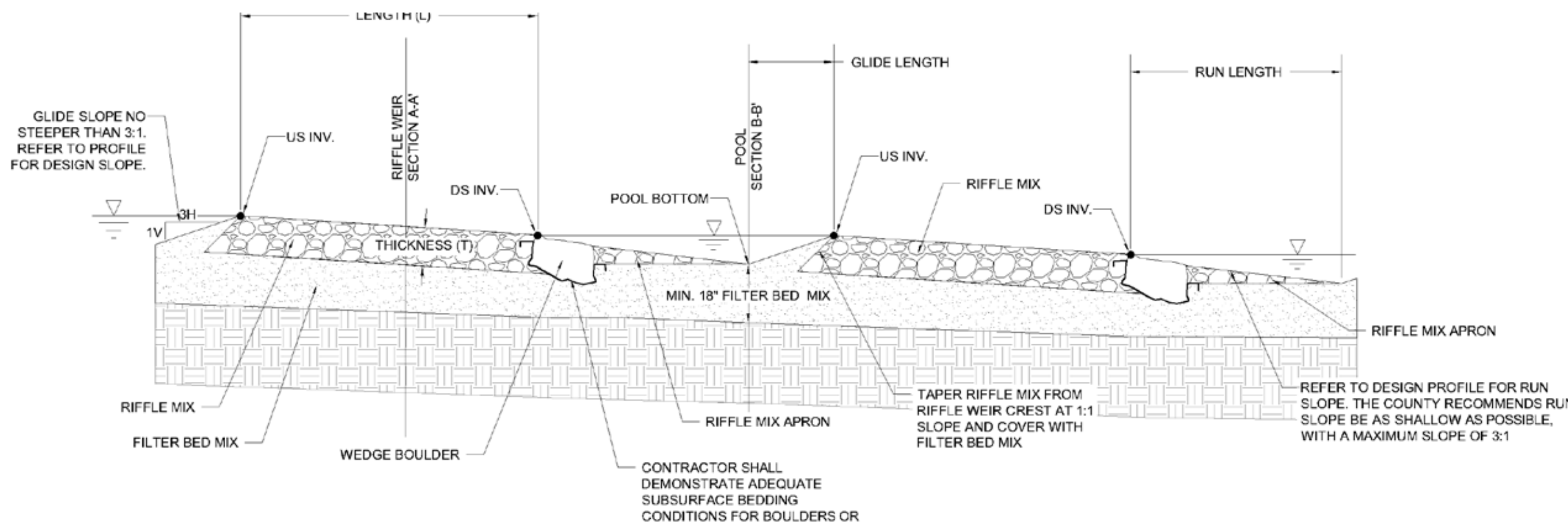

Figure 1: Typical SPSC profile with low flow water surface (riffle weir-pool-riffle weir sequence)

Figure 2: Riffle weir and pool sequence (Cape St. Claire SPSC)

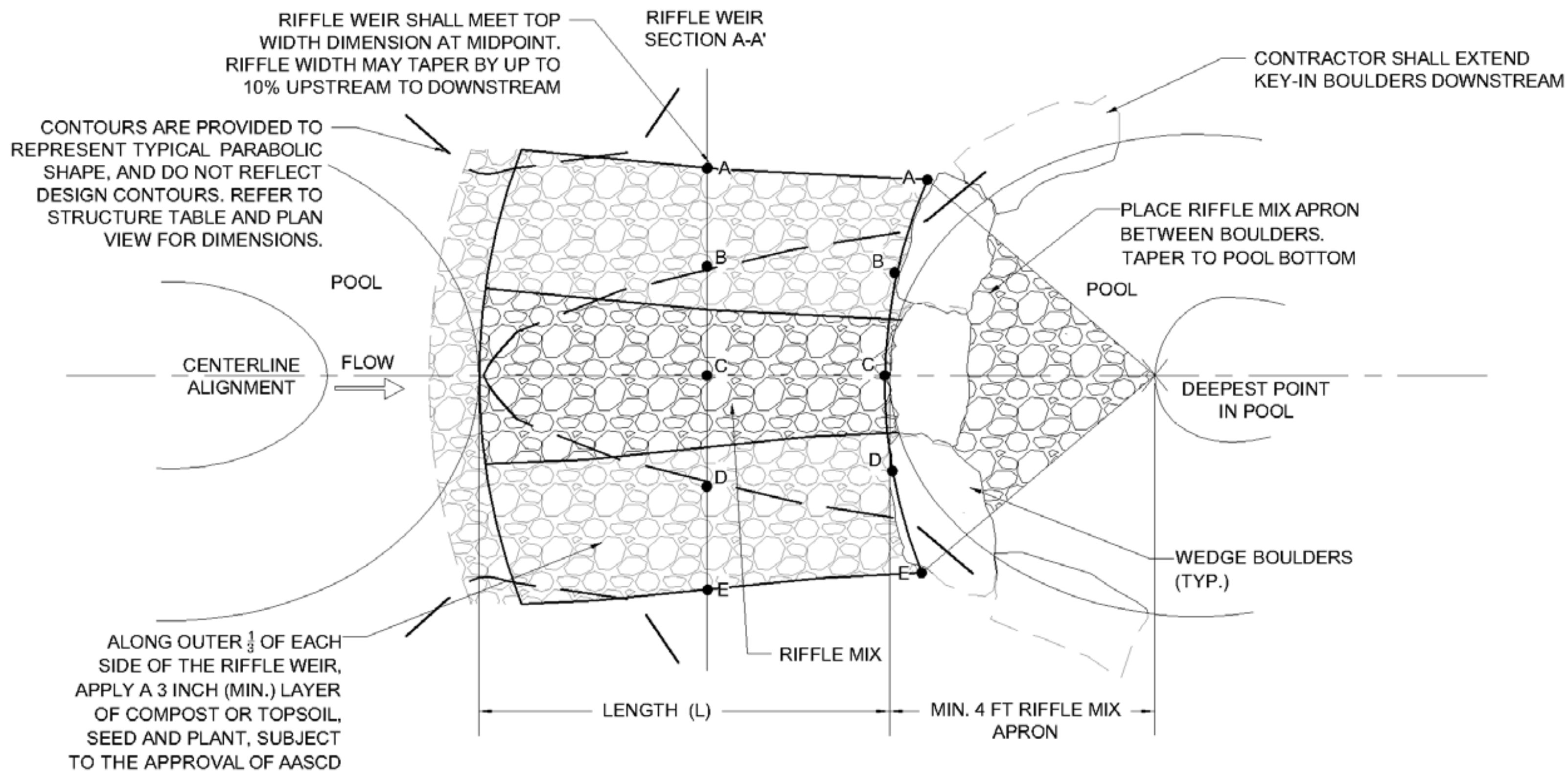

Figure 3: Schematic of a standard riffle weir in plan view

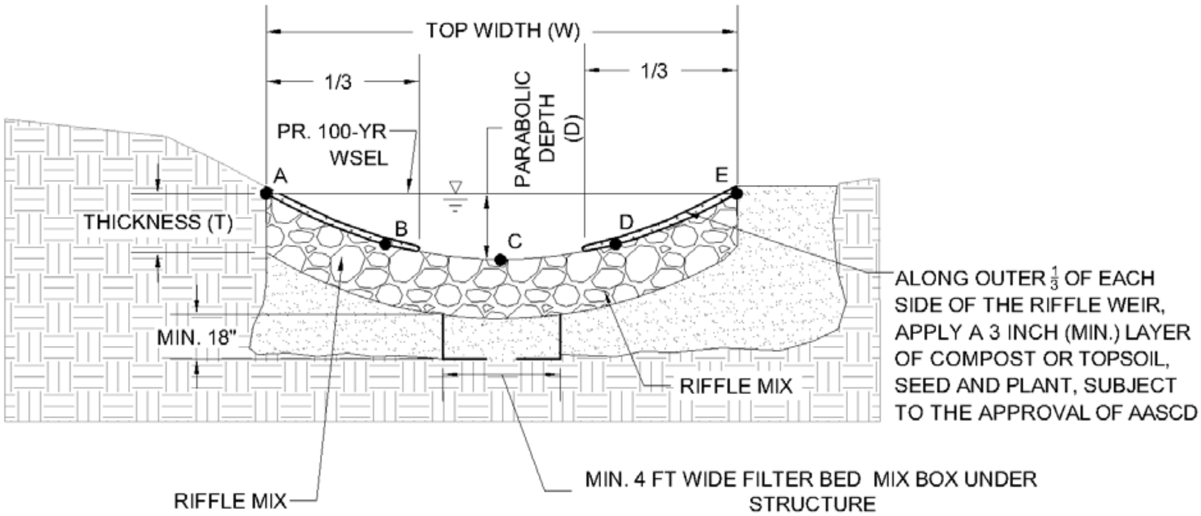

Figure 4: Schematic of a standard riffle weir in cross section (Section A-A' from Figure 10)

Key dimensions and features for the riffle weir include:

- **Berm:** is a raised lateral extension of the riffle weir used to tie the structure into the valley wall (see Figure 5). The berm serves several purposes including: facilitates the impoundment of larger flows; helps spread flows over banks (floodplains); directs flow to the riffle preventing end-around cuts. These low profile berms are traditionally constructed of sandy soil and typically do not exceed a 2 feet in height (contingent on the 100-year water surface elevation [WSEL]).
- **Glide slope:** bed slope measured along the transition from pool to riffle weir (see Figure 1). The recommended glide slope is 3H:1V, but no steeper.
- **Parabolic depth:** measured as the maximum depth of the riffle weir section flowing full (at the top of bank). The riffle weir section maintains a parabolic shape and the maximum depth occurs at the center of the channel (see Figure 4).
- **Riffle height:** the vertical distance between the upstream and downstream inverts of the riffle weir (see Figure 1). The standard riffle height is one foot to simplify design and constructability, however, the designer may vary individual structure heights if desired. The maximum height of a riffle weir is 1.5 feet. Designers should employ cascade weirs to traverse heights exceeding 1.5 feet, refer to Section 2.1.2 Cascade Weirs.
- **Riffle length:** measured horizontally along the proposed profile from the upstream crest of the riffle weir (upstream invert) to where it meets the design low-flow water surface of the receiving pool (downstream invert). The minimum riffle weir length is 10 feet (see Figure 1).

Figure 5: Riffle weir with berm (Forked Creek, Anne Arundel County)

The 10-foot minimum riffle weir length prevents excessively steep structures and ensures that the riffles and any associated tie-in grading are constructible and robust. In comparison, excessively short and steep riffle weirs often take on a form more analogous to a check dam or earth dike which may create higher risk to long term stability.

- **Riffle Mix, D_{50}:** the median diameter of riffle mix material (see Figure 1, Figure 2, and Figure 3). The designer shall select a value for D_{50} appropriate to remain immobile during the design flow event (typically the 100-year storm). The typical minimum D_{50} for a riffle mix is 6 inches, and the typical maximum is 24 inches. For additional information on appropriate riffle mix, particle distribution, and wash-in material refer to Section 3.2 Stone Mix, Size, and Particle Distribution.
- **Riffle slope:** the percentage of vertical elevation change along the riffle weir length. Riffle slope equals the riffle height divided by the riffle length (see Figure 1). The standard riffle slope is 10 percent.

- **Riffle top width:** the standard width of the parabolic cross-section flowing full (generally synonymous with the 100-year WSEL) (see Figure 4). In plan view, riffle weirs are generally crescent-like trapezoidal in shape, where the top width is the typical or average top width within the section (see Figure 3). The minimum top width is 10 feet. Constructed riffle weirs should be slightly wider upstream and incorporate taper from upstream to downstream to direct flow into the receiving pool. The recommended upstream flare and downstream taper should not exceed 10 percent.
- **Run slope:** bed slope measured along the transition from riffle weir to pool (see Figure 1). When conditions allow, the designer is encouraged to minimize run slopes within the available length of pool. The run slope for the standard riffle approaches the slope of the riffle (i.e., 10 percent). The steepest recommended run slope is 3H:1V.
- **Soil cover:** The outer one-third of each riffle weir shall be covered with a 3-inch layer of either sand or topsoil (preferably salvaged) to promote a soil matrix that is readily colonized and stabilized by vegetation (see Figure 4). Incorporation of compost or other organic matter into the soil cover mix would be dependent on the nutrient status of the placed soil and other factors.
- **Thickness:** measurement of the depth of the riffle mix layer (see Figure 1 and Figure 4). The minimum thickness of stone is the greater of 18 inches or 2 x D_{50}.
- **Wedge boulders:** all riffles are anchored on the downstream end by a row of wedge boulders (see Figure 1). The purpose of the wedge boulders is to serve as a “wedge” to pack the riffle mix behind and hold it in place. The wedge boulders should be tilted on their axis downstream along the run slope. A stone apron should be provided beneath the wedge boulders to transition from the boulders to the bottom of the receiving pool. For additional information on appropriate stone material and size requirements refer to Section 3.2 Stone Mix, Size, and Particle Distribution.
- **Width-depth ratio:** calculated by dividing the riffle top width by the parabolic depth (see Figure 4). The width- depth ratio shall not be less than 10, to avoid extremely deep riffle weir sections with steep side slopes. A ratio higher than 10 (i.e., greater than 15) is strongly encouraged when feasible.

2.1.2 Cascade Weirs

Cascade weirs are parabolic channel sections formed from large boulders which traverse vertical heights greater than 1.5 feet. Boulders are placed in an irregular offset pattern to promote maximum roughness and dynamic flow within the structures (as opposed to a smooth “chute” configuration where boulders are tilted so that the smooth side conforms to the axis of flow) (see Figure 6 and Figure 7). A photograph of a typical cascade is provided in Figure 7. Cascade weirs may be used to rapidly traverse grade and are an invaluable tool to navigate steep outfall channels. Schematic drawings of cascade weirs in profile, plan, and section view are provided as Figure 8, Figure 9, and Figure 10.

Figure 6: Cascade weirs during construction (Washington, DC)

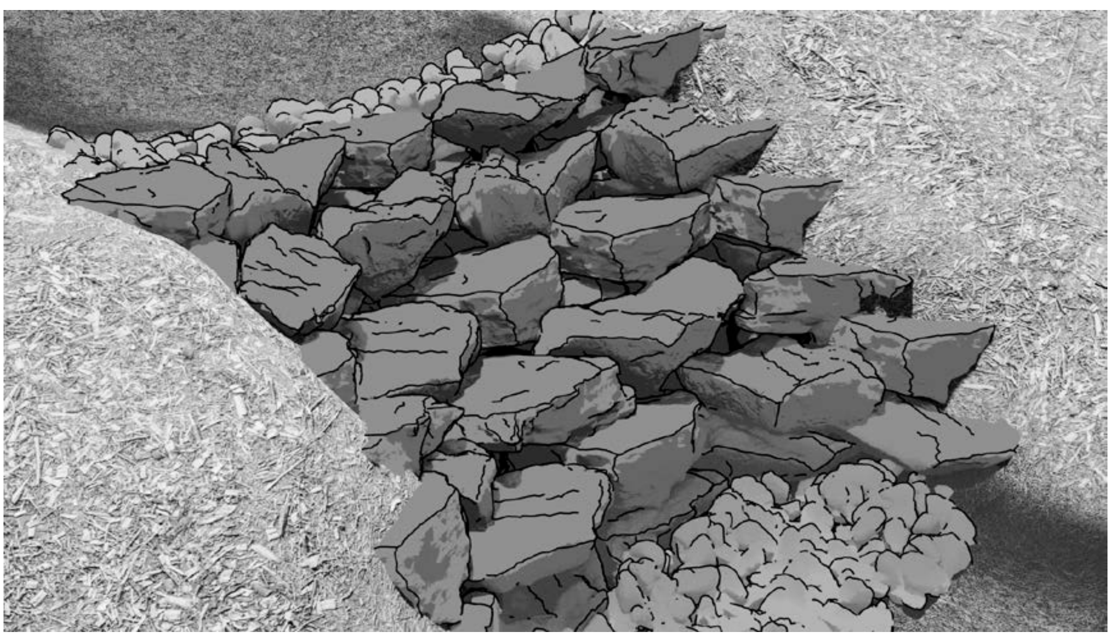

Figure 7: Isometric view of cascade weir (drawn by Phillip Capon)

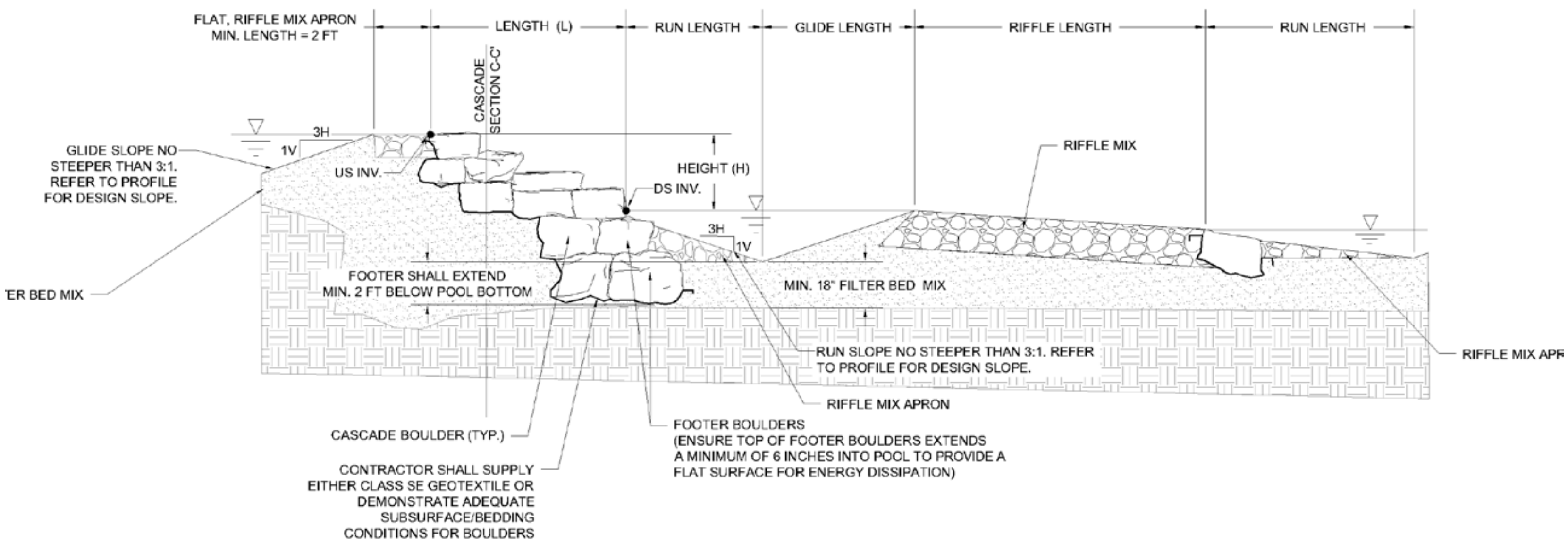

Figure 8: Schematic of cascade weir in profile view

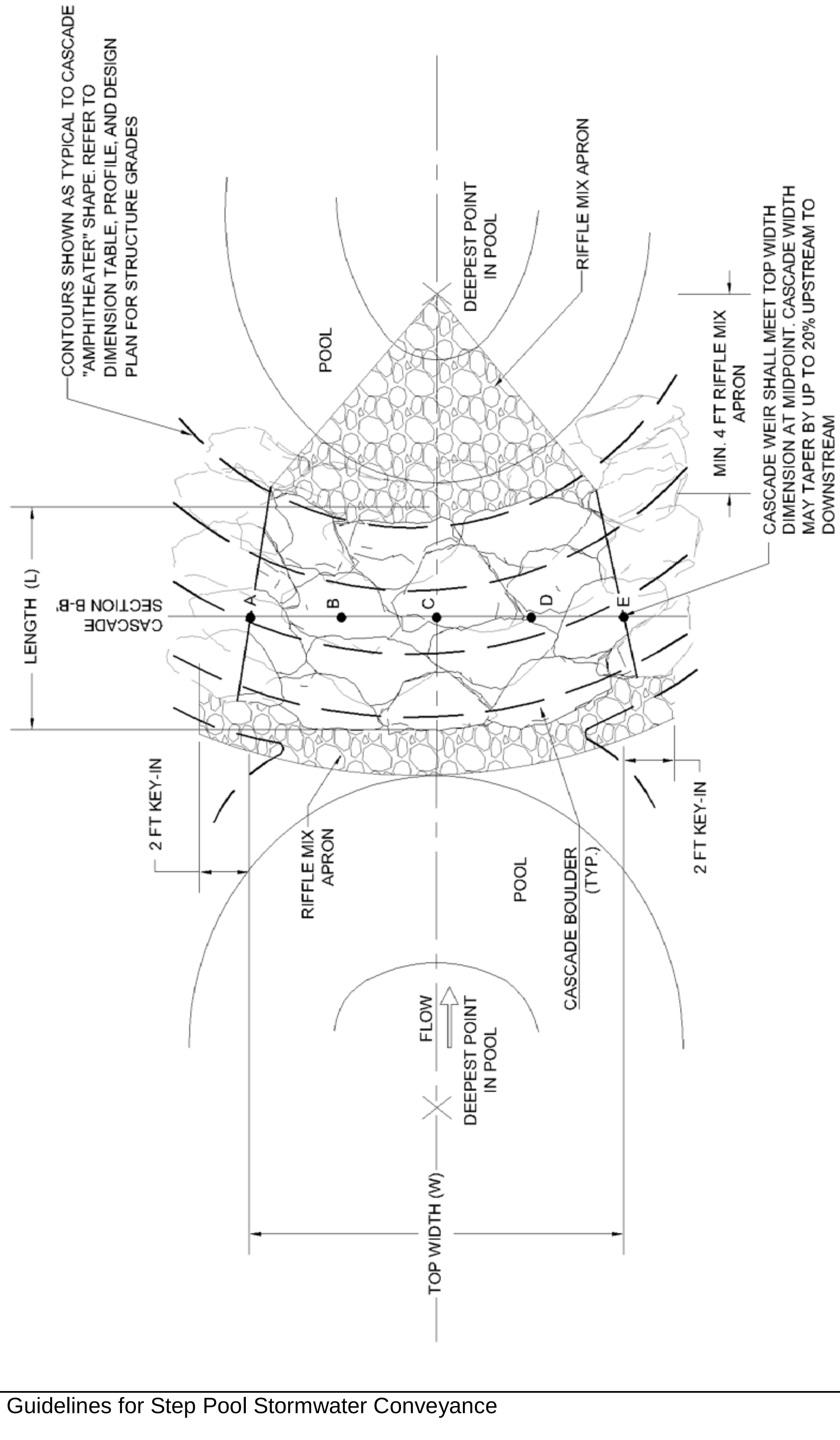

Figure 9: Schematic of cascade weir in plan view

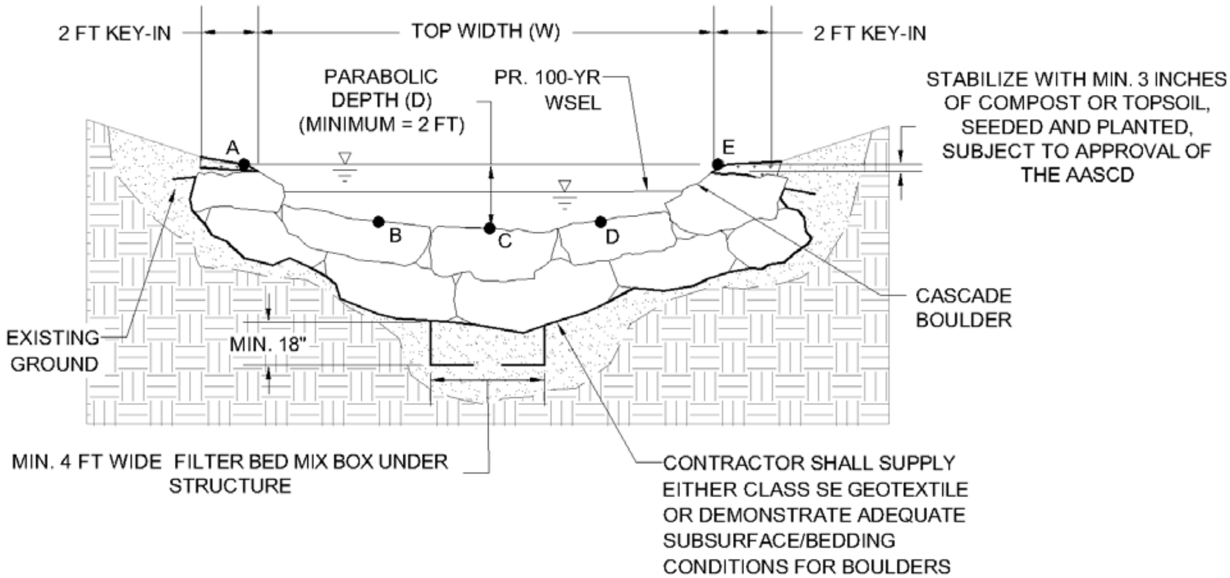

Figure 10: Schematic of cascade weir in cross-section (Section B-B')

Key dimensions and features for cascade weirs include:

- **Apron:** areas along run and glides protected with riffle mix at a minimum depth of 18 inches or 2 x D_{50} (whichever is greater). A flat apron, with a minimum length of 2 feet, is follows the transition from glide to cascade (see Figure 8 and Figure 9). This flat area allows the contractor to pack a sand and riffle mix behind the cobble boulders to encourage surface flow. A riffle mix apron extends along the run slope, tapering horizontally from the downstream cascade invert towards the center of the pool.
- **Berm:** is a raised lateral extension of the cascade weir used to tie the structure into the valley wall. The berm serves several purposes including: facilitates the impoundment of larger flows; helps spread flows over upstream banks (floodplains); and directs flow to the cascade preventing end-around cuts.
- **Boulder size:** the designer shall refer to Section 3.2 Stone Mix, Size, and Particle Distribution for information on boulder sizing.
- **Cascade length:** measured horizontally along the proposed profile from the upstream crest of the cascade weir (upstream invert) to where it meets the design low-flow water surface of the receiving pool (downstream invert) (see Figure 8).
- **Cascade height:** the vertical distance between the upstream and downstream inverts of the cascade weir (see Figure 8). The typical cascade height is between 2 and 5 feet, with whole foot increments preferred to simplify design and constructability, however, the designer may choose a structure specific height. While the preferred maximum allowable height of a cascade weir is 5 feet, cascade weirs with heights more than 5 feet may be permitted on a case-by-case basis with approval from the County.

- **Cascade slope:** the percentage of vertical elevation change along the cascade length. Cascade slope is a function of cascade height divided by cascade length. The maximum allowable slope of a cascade weir structure is 50 percent. As steepness increases beyond 50 percent, it becomes more likely that flow will form a vertical jet, increasing the likelihood of accelerated bed scour downstream of the cascade weir. The 50 percent maximum slope helps ensure that flow will maintain contact with the face of the cascade weir and remain primarily horizontal so that boulders can resist flow.
- **Cascade top width:** the typical width of the parabolic cross-section flowing full (i.e., 100-year WSEL) (see Figure 10). The minimum top width is 8 feet.
- **Footer boulders:** all cascade weir structures are anchored on the downstream end by a series of footer boulders (see Figure 8). A second or third row (as necessary) of footer boulders shall anchor the cascade boulders such that footers extend a minimum of 2 feet below the receiving pool bottom elevation, or to the maximum calculated scour depth (whichever is greater). For additional information on appropriate boulder material and size requirements refer to Section 3.2 Stone Mix, Size, and Particle Distribution.
- **Glide slope:** bed slope measured along the transition from pool to cascade weir (see Figure 8). The recommended glide slope is 3H:1V, but no steeper. Cascade glides include a flat riffle mix apron with minimum length of two feet before entering the steep, boulder section of the cascade weir.
- **Key-in:** distance of buried boulder material embedded into the adjacent bank (see Figure 9 and Figure 10). The key-in distance shall be a minimum of 2 feet.
- **Parabolic depth:** measured as the maximum depth of the cascade weir section flowing full (i.e., 100-year WSEL) (see Figure 10). The cascade weir section maintains a parabolic shape throughout its length, and the maximum depth is measured from the top of bank to the deepest point in the center of the channel. The minimum parabolic depth for cascade weirs is 2 feet.
- **Run slope:** bed slope measured along the transition from cascade weir to pool (see Figure 8). The steepest allowable run slope is 3H:1V, but is preferred to be as shallow as possible while still meeting the desired pool depth.

2.1.3 Pools

Pools lead and follow riffle and cascade weir segments. Their flat slope and wide cross section reduce velocity and promote surface water storage and near-surface groundwater exchange. Importantly, pools are habitat features that support a diversity of vegetation and animal habitat along the newly created edaphic gradients. Despite their typically steep slope, SPSC systems are “pool dominant,” meaning that ratio of riffle to pool (length of riffle and cascade weirs divided by length of pool) should not exceed one (1).

The continuous filter bed promotes both filtration of surface water and near surface groundwater through the pools. Local geology, groundwater patterns, watershed size, the depth of filter media, and the depth of pools all interact to determine the duration that surface water and saturated soils may persist following a storm event. It is the responsibility of the designer to create a planting plan that can be adapted to maximize habitat value within post-construction conditions. Additional information on planting strategy can be found in Section 5.0 Planting Plan.

A photograph of a typical SPSC pool is provided in Figure 11. A Schematic drawing of a cross section of a pool is provided in Figure 12. For a profile view of a pool as part of the SPSC sequence, refer to Figure 1 and Figure 7.

Figure 11: Pool-riffle sequence (Anne Arundel County)

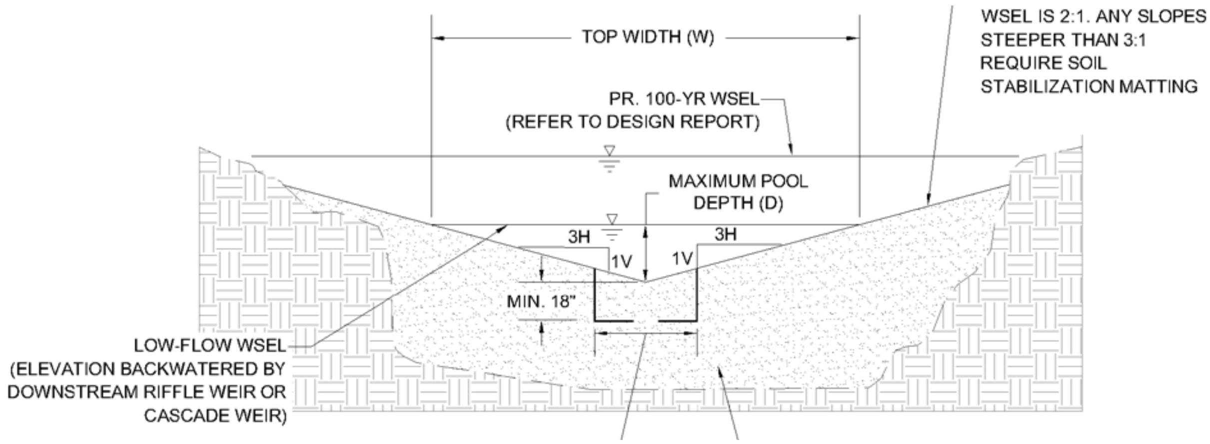

Figure 12: Schematic of pool cross-section at low-flow water surface

Key dimensions and features for pools include:

- **Length:** measured horizontally along the proposed profile along the portion of the low flow water surface that would remain flat at low flow. This typically aligns with the end of the upstream riffle or cascade weir to the crest of the downstream riffle or cascade weir.
  - The minimum pool length should be equal to the length of the preceding riffle weir (e.g., if the upstream riffle weir has a length of 10 feet the receiving pool must be a minimum of 10 feet long). Pools downstream of cascade weirs shall have a minimum length of either 10 feet or the length of a standard one-foot riffle weir, whichever is greater.
  - The first pool in the system is typically downstream of a piped outfall or concentrated discharge. In this situation, the pool length is measured from the outfall invert to the crest of the downstream riffle or cascade weir.

  Note: Pool length is inclusive of run and glide length (see Figure 1 and Figure 8).
- **Pool slope:** the percentage of water surface elevation change along pool length (see Figure 1 and Figure 7). SPSC pools are completely inundated by the downstream riffle or cascade weir at the low flow condition, resulting in a design slope of zero percent.
- **Pool top-width:** the maximum width of the pool measured at the elevation impounded by the crest of the downstream weir (see Figure 12). Pool top width shall be at a minimum equivalent to the design top width of the downstream structure. For example, if the downstream riffle weir has a design top width of 15 feet, the receiving pool shall expand to at least 15 feet wide at the low-flow water stage. Designers shall note that avoiding overly narrow pools helps to reduce potential for scour in transitions from riffle and cascade weirs to pools. Pool width should be maximized as site conditions allow. A typical design goal is to equate pool width with the available valley or gully width.

- **Pool depth:** measured vertically along the proposed profile from the elevation impounded by the invert of the downstream structure (low flow water surface elevation) to the lowest point in the center of the pool (maximum depth) (see Figure 12). The minimum pool depth is one foot. The maximum pool depth is 3 feet. Pools that maintain a water depth greater than 2 feet for more than 24 hours will require a bench or a fence per the Arundel County Stormwater Practices and Procedures Manual (Anne Arundel County, 2017). The designer may vary pool depth freely within that range as desired to optimize site specific storage goals and grading. However, the lowest point in the center of the pool should be a singular point to avoid creating "bathtubs" which may provide large amounts of water storage but little in the way of habitat along the edaphic gradient.
- **Side slopes:** pools should have side slopes of 3H:1V or shallower up to the low flow water surface elevation (see Figure 12). Shallow side slopes promote a gradual transition of soil hydrology from wet to dry, and therefore support a diverse plant community that will help to stabilize the soil. Above the low-flow water surface elevation, the designer should tie-in to existing grade at a stable slope. Slopes steeper than 3H:1V will require soils stabilization matting. Designers shall take care to avoid over steepening of side slopes to maximize potential for vegetation establishment. The County does not allow slopes steeper than 2H:1V. If tie-in slopes steeper than 2H:1V above the low flow water surface are unavoidable, the designer should consider the use of boulder stabilization.

Designers should note that as habitat features, pools offer opportunities to incorporate diversity into each SPSC. Designers may vary pool width, depth, and side slopes provided minimum criteria are met. Habitat value can also be increased by incorporating large woody debris. The choice to incorporate wood is at the discretion of the designer, who should incorporate proper measures to avoid mobilization that may jam or block downstream culverts or riffle and cascade weir openings. In most circumstances, large wood can be safely anchored along the outer edge of pools by way of burying it into the bank.

2.1.4 Filter Bed

All SPSC projects are underlain with a continuous filter bed that is constructed with a mix of sand and woodchips. Specification information for the sand and woodchip mix is included in Section 3.1 Filter Bed Media. The mix provides a free draining filter media, and the woodchips provide an input of carbon to support nutrient adsorption.

SPSC projects are typically fill earthwork projects, achieved by raising the invert elevation of an existing drainage channel at or above the top of the existing channel. The filter bed is typically installed as the underlying fill material. In limited circumstances, an SPSC may have sections of earthwork cut. For example, if the watercourse is relocated or shifted outside the existing channel footprint, or in upland areas where a swale is cut into the landscape.

In all instances, the designer must show on the design plan that a filter bed is continuous throughout the entire project at a depth and width suitable to maintain positive longitudinal subsurface flow that is uninterrupted by cohesive or poorly drained soils.

- **Composition:** The filter bed is composed of sand and woodchips. The designer shall specify that the contractor provide a quantity of woodchips equivalent to 20 percent of the required sand fill volume and mix into the sand fill during installation. For material specifications refer to Section 3.1 Filter Bed Media.
- **Length:** The entire longitudinal length of the project must include a continuous filter bed. This includes all pools, riffle weirs, and cascade weirs.
- **Depth:** The filter bed shall have a minimum vertical thickness of 18 inches under the invert of all SPSC elements, including riffle and cascade weirs, and pool segments. The filter bed must also be deep enough to demonstrate continuous positive drainage within the filter bed across its length. Continuous positive drainage means that infiltrated flow can move through the filter bed downstream via gravity without being obstructed by less pervious soils. The stone construction materials (e.g., boulders and riffle mix) are pervious and may intersect the filter layer.
- **Width:** The minimum cross-sectional width of the filter bed shall equal 4 feet and shall be placed along the entire project length centered along the project centerline.

The dimensions of the filter bed will vary by project and should be adjusted by the designer to improve compliance with site specific project goals (including volume of water treated, volume of water stored, depth of existing channel, and project cost). In a typical configuration, where the project is predominantly in fill, the minimum dimensions can be easily exceeded. However, it is the responsibility of the designer to ensure that the filter bed meets or exceeds the minimum criteria in all instances. In limited instances where the project is constructed on top of native sandy soil, the designer may claim additional volume and filtration credit to account for the underlying soil, provided the in-situ soil conditions are documented to the satisfaction of Anne Arundel County.

2.2 Design Narrative, Goals, and Constraints

The primary goal of a SPSC project is to provide a stable outfall connection between a concentrated upland discharge and the receiving stream valley. Depending on site specific needs, the designer may focus on additional goals and objectives which may include, but are not limited to the following:

- Providing safe open channel conveyance in lieu of storm drains.
- Meeting stormwater quality or quantity goals.
- Providing slope and outfall stabilization.
- Subwatershed retrofits to meet County goals for Chesapeake Bay TMDL Watershed and MS4 impervious acre restoration credit.
- Providing and atheistic feature in the landscape.
- Providing a connective vegetative corridor for wildlife.

The designer should summarize the design goals and outcomes in the design report. As appropriate for the project, the designer should quantify any relevant reporting metrics in a table alongside the narrative. Table components may include, but not limited to, rainfall captured and treated (PE), ESD volume (ESD_V), Retrofit Storage volume (RSv), equivalent impervious acre credits, and total nutrients reduced.

The designer should also perform an analysis of project constraints. This should include, but is not limited to:

- Identification of limits of disturbance.
- Inventory of natural resources including forest, specimen trees, steep slopes, streams and wetlands.
- Screening for and identification of rare, threatened, and endangered species.
- Screening for and identification of historic and cultural resources.
- Location of utilities.
- Property and easement boundaries.
- Floodplain setback requirements (for more information refer to Section 2.9 Design Validation).
- Size and location of existing infrastructure, including underground utilities.
- Understanding of existing soils and local groundwater elevations.

2.3 Hydrology

A site-specific hydrologic analysis is required for SPSC projects using current methods and criteria outlined in the most recent edition of the Anne Arundel County Design Manual (Anne Arundel County, 2001). A summary of current guidance is presented below:

- The designer shall analyze existing site drainage patterns. In new development projects, ESD shall be used to the MEP upstream of the proposed SPSC such as to minimize alterations to the existing drainage patterns for the site.
- Delineate the surface area draining to the points of interest from reliable topographic mapping. The limits of the drainage area shall be field verified, especially drainage areas with existing storm drain systems. The minimum scale for drainage area mapping shall be 1 inch = 200 feet. The drainage area point of interest should be delineated to the outfall point of the SPSC where it meets a connecting channel tie-in location, if applicable. The resulting flow rates should apply to the entirety of the upstream SPSC. The designer may subdivide the drainage area should lateral storm drain input or significant changes in contributing drainage area suggest a flow change location is warranted.
- Analyze land use and soil characteristics to develop a composite runoff curve number (RCN) for the drainage area.

- Delineate the maximum Time of Concentration (Tc) flow path and estimate Tc using the USDA-NRCS TR-55 method.
- Using USDA-NRCS TR-55 or USDA-NRCS TR-20 (as appropriate), determine the 2-, 10-, and 100-year peak discharges for all points of investigations and required land use scenarios. The designer should confirm with the County and apply current rainfall depths and distribution curves.
- For watersheds less than 200 acres, the County may approve use of the Rational Method as a substitution for TR-55 or TR-20.
- The designer should consider both the post-project land use and the “ultimate condition” land use for the SPSC and shall design for the more conservative condition.
- The designer shall include pertinent model input and output hydrology parameters for all points of investigations and required land use scenarios on a separate drainage area sheet in the construction plans.
- In the event there are upstream stormwater management facilities that may influence the volume of water arriving at the proposed SPSC, the designer should incorporate routing of peak flows through those facilities. However, per the County Stormwater Practices and Procedures Manual, if determination of floodplain boundaries is required, the designer should note that no allowance should be made for storage within ponds or other detention structures or behind undersized culverts (Anne Arundel County, 2017).

2.4 Preliminary Alignment and Profile

The SPSC design process is iterative. First, a preliminary alignment and profile is required to establish baseline parameters for sizing of typical weirs and pools. Once the structures are sized, the designer will refine the alignment and profile to compliment the valley and drainage features. This section covers the initial alignment and profile development. The sizing of riffle and cascade weirs, and pools is described in Section 2.5 Typical Section Design. Final refinement of alignment and profile is discussed in Section 2.6 Final Profile and Sequencing.

Before drafting an alignment and profile, the designer should carefully evaluate existing and proposed site conditions, including an accurate topographic survey of the site, to identify the start and end of the proposed SPSC. Typically, a SPSC will begin at an outfall structure or concentrated discharge point, and tie into a stable receiving stream or floodplain at a base-level grade control (refer to 2.7 Stable Tie-in Requirement). Once the start and end points have been identified, the designer should lay out an alignment generally following the existing drainage pathway and connecting the two points while incorporating site constraints (e.g., property lines, utilities, and specimen trees). The suggested step-by-step process to determine the alignment and profile is outlined below.

Step 1. Establish the upstream tie-in point and note its elevation. The upstream control is typically tied to the elevation of the concentrated discharge point. For piped outfalls, the top invert of the riffle weir associated with the entry pool should be set at or, if desired, above the invert of the discharge pipe or culvert. The designer should present justification that any tailwater conditions created by the SPSC will not alter the drainage system performance. The designer should also consider the age and material of the pipe network and whether it can tolerate backwater during storm flows (i.e., Hydraulic Grade Line analysis).

Step 2. Establish the downstream base level control point and note its elevation. Identification of an appropriate downstream control elevation is critical to preventing future headcut erosion through the site. Additional information on base-level control is included in Section 2.7 Stable Tie-in Requirement. The designer should also coordinate with the County to understand whether the receiving valley or waterway is slated for future restoration work, and if so, ensure their design is complementary to the proposed work.

- Draft a preliminary horizontal alignment in plan view on a topographic base map including one-foot contours. Carefully follow the existing flow path. Special attention should be given to the following guidance: Center the proposed alignment between the existing valley walls, rather than attempting to follow the existing thalweg. This will simplify the alignment and offer a realistic estimate of post-project length (see Figure 13). Note that the preliminary alignment does not track small fluctuations to the thalweg. Rather, the alignment is optimized to center the proposed structures within the valley. This is evidenced by the outside edges of the concept structures, which are generally aligned parallel to contours of equivalent elevation along the valley.

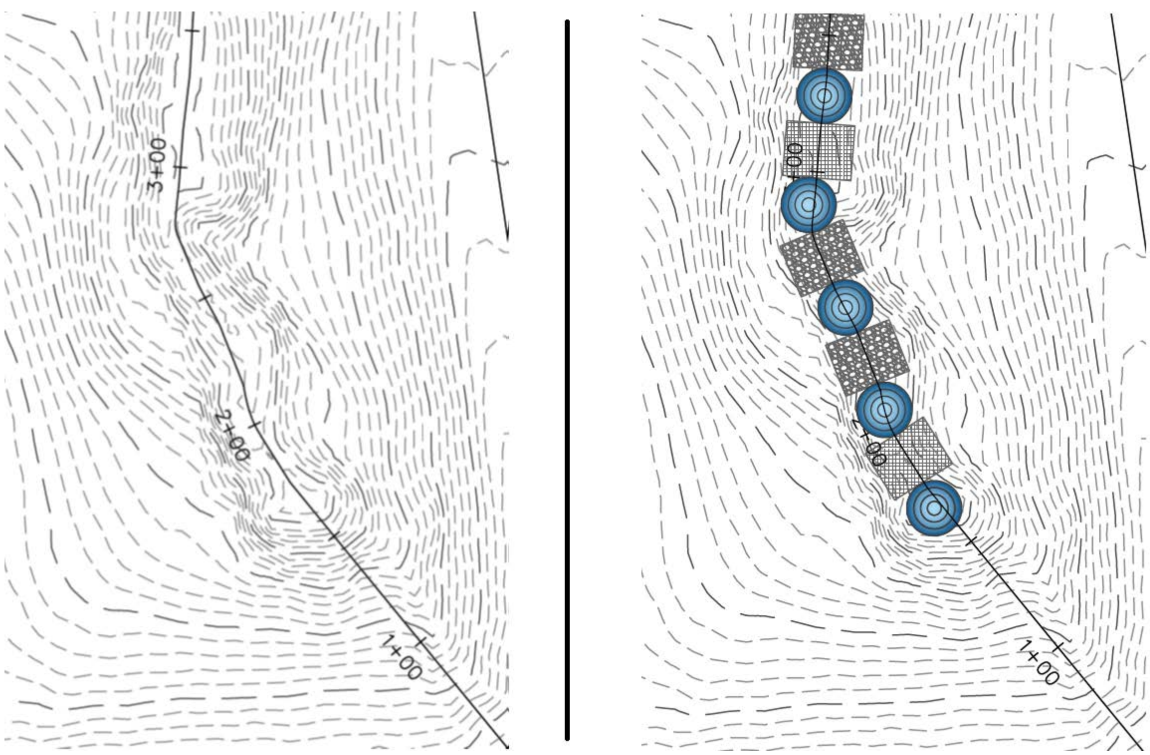

Figure 13: Mapping preliminary alignment

- While the SPSC alignment should generally follow the existing drainage pathway, the designer should use best judgement to create a smooth curvilinear alignment and avoid reinforcing extreme meanders or bends.
- Special attention should be given to minimize impacts to natural features, especially stands of mature forest, specimen trees, and steep slopes. Working within or near the existing drainage pathway, to the extent practicable, is the best technique to minimize impacts.
- The designer should note and embrace opportunities that may create additional lateral storage and habitat area. For example, within a degraded gully it is common for erosion via mass wasting and or channel migration to leave abandoned flow paths or depressions that can be repurposed as a pool area in the proposed SPSC.
- The designer will find it is helpful to focus on the location of structures and corresponding elevations in relation to the local topography. The goal is to backwater as big an area behind each weir as possible without having overly deep pools or requiring excessive grading between structures.

Step 3. The designer should evaluate the plan view and profile to assess the need to divide the alignment into separate design reaches and determine the controlling elevations for each. Analyze the profile for breaks in landscape form and typical valley slope (valley slope is typically more reflective of landscape form than channel slope). Also, analyze the plan view to understand any major changes in valley width or other constraints.

For example, in the event an SPSC alignment extends from a steep gully beyond the valley toe of slope and must traverse a portion of the floodplain or valley bottom to reach a stable tie-in point, the profile will appear steep, with an inflection point where slope becomes shallow along the floodplain. The designer may wish to consider these segments of alignment as individual reaches of SPSC with unique starting and ending elevations to conform more closely to the landscape and avoid a major extrusion of fill emerging from the existing hillslope.

Step 4. Measure the length of each reach along the plan view alignment. This length of an individual reach is described in this manual as L_{design}.

Step 5. Map a preliminary vertical alignment by connecting the proposed starting elevations and ending elevations for each reach. The designer should also consider profiling the top of the existing banks alongside the centerline profile. This approach will help the designer understand how the existing terrace or local landform grade converges and diverges from the existing drainage pathway.

Step 6. Measure the elevation difference (ΔE) between the top and the bottom invert elevations of each reach. For simplicity, round up to the nearest whole foot.

Step 7. Along each reach, compute the average reach slope (Sr), by dividing ΔE by L_{design}.

Step 8. The values for ΔE and L_{design} are used in combination with typical structure sizing to establish the number and configuration of riffle weirs, cascade weirs, and pools. Note the values and proceed to typical section design (Section 2.5 Typical Section Design).

In limited circumstances, the landscape in the uppermost reach of a proposed SPSC may have a very steep slope (i.e., exceeding 25 percent). Designers should attempt to create a workable design using the SPSC process. However, it is understood that there are situations where conforming to the existing infrastructure and landscape may not be practical or feasible. In these instances, the designer may consider a drop-manhole structure or structural alternative along the uppermost reach, with approval and coordination from the County.

Subsurface filtration water quality credit is not allowable on SPSC reaches that exceed 5 percent in longitudinal slope. If water quality credit is a project goal, the designer should consider reach slopes at this stage and determine whether those goals are feasible. Refer to Section 2.6 Final Profile and Sequencing for additional information.

2.5 Typical Section Design

This section introduces relevant design formulae and their inputs, followed by an overview of how to apply these equations as part of an iterative design process.

The designer shall use the calculated hydrology and the one-dimensional hydraulic equations described in this guidance to design typical sections for riffle weirs and, as necessary, cascade weirs. Riffle and cascade weirs should be designed to contain a Design Discharge (Q_{design}) of the 100-year storm within their parabolic section without mobilizing their median sized bed material (D_{50}). The County requires that the designer demonstrate channel stability up to the 100-year storm event. The County selected the 100-year storm event as a design event that is suitably conservative to promote long term stability. It is the responsibility of the designer to consider any site-specific needs for additional factors of safety and freeboard.

The designer may elect to design the SPSC based on a storm event less than the 100-year storm. However, it is incumbent on the designer to outline a site-specific case for a reduced discharge to the satisfaction of the County. Unless otherwise indicated in this guidance, all references to the Q_{design}, may be assumed to refer to the 100-year storm.

Both riffle and cascade weir section dimensions are determined through an iterative process using a combination of one-dimensional geometry and flow equations to evaluate the performance of a given channel section of known parabolic depth, top width, and stone size. The designer will verify that the proposed section adequately contains the design discharge and check the velocity and flow regime against the maximum allowable velocity for a given stone size using the Isbash formula (refer to Section 2.5.1 Hydraulic Equations). Should the designer wish to size typical sections or stone using a different method from that outlined in this guidance, they should document their methods in the design report and seek County approval.

2.5.1 Hydraulic Equations

SPSC structures are sized using a threshold channel design approach. The stone for the proposed channel must be sized to remain immobile in events up to and including the design flow event. The designer shall apply the equations described in this section in series to solve for velocity and depth at the design discharge, and subsequently compare those results against the maximum allowable velocity for the selected stone size.

The SPSC designer should select initial design dimensions and evaluate performance using the hydraulic equations described in this section. It is strongly recommended that a spreadsheet be used to rapidly test changes to design variables. The County maintains a spreadsheet as a companion to this manual to assist with hydraulic sizing of structures available online at https://www.aarivers.org > Restoration > Step Pool Stormwater Conveyance (SPSC).

The SPSC design requires the following parameters to be selected and validated by the designer. Refer to Section 2.1 Typical SPSC Components for more information on how each of these parameters are measured:

- Structure type (riffle or cascade weir)
- L = Length (ft)
- H = Height (ft)
- Top width (ft)
- PD = Parabolic depth (ft)
- D_{50} (ft) = Median stone size
- D = Design depth of flow (ft)

1. **Top width of the water surface in a parabolic section for a given design depth:**

   Equation 1: Flow top width for parabolic section with given depth (derived from, $y=ax^2$)

$$W = T_W * \left(\frac{D}{P_D}\right)^{0.5}$$

Where:

W = Top width at a given depth, ft

T_W = Top width of full section, ft (Given)

P_D = Parabolic depth of full section, ft (Given)

D = Depth of flow, ft (Given)

2. **Use the results of Equation 1 to calculate cross-sectional area for a given design depth:**

   Equation 2: Cross-sectional area for parabolic section

$$A = \frac{2WD}{3}$$

   Where:

   A = Cross sectional area of a parabolic channel, ft^2

   W = Top width at a given depth, ft (Calculated with Equation 1)

   D = Depth of flow, ft (Given)

3. **Use the results Equation 1 to calculate hydraulic radius for a given design depth:**

   Equation 3: Hydraulic radius (Chow, 1959)

$$R_h = \frac{2W^2D}{3W^2 + 8D^2}$$

   Where:

   R_h = Hydraulic Radius, ft

   W = Top Width at a given depth (Calculated with Equation 1)

   D = Depth of flow, ft (Given)

4. **Calculate or estimate Manning's n value for the proposed section**

   Equation 4: Manning's n value (United States Department of Agriculture, 1989)

$$n = D^{1/6} \Big/ \left(21.6 \log\left(\frac{D}{D_{50}}\right) + 14\right)$$

   Where:

   n = Manning's n, use 0.05 for cascade weirs

   D = Depth of flow in the riffle weir section, ft (Given)

   D_{50} = Median coble size, ft (Given)

   This equation for Manning's n value provides an estimate of roughness as a function of the size of stone and the depth of flow. Please note, the results may be unreliable or negative at extremely low or high depths. Designers are advised to use an alternate method for estimating Manning's n should the design depth provide unreasonable results.

The calculation for Manning's n value applies to riffle weir sections only and is not applicable for cascade weir sections. Designers shall apply a standard Manning's n value of 0.05 for all cascade weir sections to standardize the calculation of cascade section flow. This will help facilitate review and to avoid extraordinarily high roughness estimates and therefore underestimation of flow velocity.

For riffle weirs, the designer will select a stone size ranging from 6 to 24 inches (0.5 foot to 2 feet). For cascade weir structures, select a default stone size of 30 inches (2.5 feet). Designers should not increase the D_{50} used for stone sizing calculations for cascade weir structures beyond 30 inches.

Smaller riffle mix is more favorable than larger stone. A structure that is sized to be stable with smaller stone will have lower maximum velocities. Smaller stone is easier to shape and naturalizes more readily with a sand and gravel substrate. However, employing a smaller riffle mix will generally increase the size of structure required to safely convey the same discharge. To ensure that SPSC designs default to a reasonable size of riffle mix for a given discharge, the County has established recommended riffle mix stone sizes as a function of the Q_{100} design discharge. These recommendations are summarized in Table 1. The use of the recommended riffle sizing simplifies the iterative design process by resolving one of the many variables the designer may wish to consider.

Table 1: Recommended riffle mis D_{50}

Recommended riffle mix size for a given Q_{100}	
If Q_{100}, cfs ≤	The recommended D_{50} is:
15	6 in
125	9 in
500	12 in
1,500	18 in

5. **Calculate the proposed riffle or cascade weir slop**

Equation 5: Proposed riffle or cascade weir slop

$$S = \frac{H}{L}$$

Where:

H = Height, ft (Given)

L = Length, ft (Given)

6. **Calculate discharge within the proposed section at the design depth**

Use Manning's equation to calculate the discharge at the design depth. Compare the discharge against the desired discharge (Q_2, Q_{10}, Q_{100}) for adequacy of conveyance.

Equation 6: Manning's open channel discharge

$$Q = \left({}^{1.49}/_{n}\right)(A)(R_h)^{2/3}(S)^{1/2}$$

Where:

Q = Flow within design section, cfs

n = Manning's n (calculated with Equation 4)

A = Cross-section area of a riffle channel, ft^2 (calculated with Equation 2)

R_h = Hydraulic radius, ft (calculated with Equation 3)

S = Riffle or cascade weir slope, ft/ft (calculated with Equation 5)

7. **Solve for average velocity within the proposed section at the design depth**

This is achieved by dividing the results of Equation 6 by the cross-sectional area calculated in Equation 2.

Equation 7: Channel velocity

$$V = {}^{Q}/_{A}$$

Where:

V = Average velocity in the riffle weir section, fps

Q = Flowrate in the riffle weir section, cfs (calculated with Equation 6)

A = Cross sectional area of the riffle weir section, ft^2 (calculated with Equation 2)

8. **Evaluate flow regime**

Use the equation for Froude number to evaluate whether the proposed section is supercritical or subcritical at the design depth. A Froude number exceeding 1 indicates that the flow is supercritical, while a Froude number of less than 1 indicates that the flow is subcritical.

Equation 8: Froude number

$$Fr = \frac{V}{\sqrt{gD}}$$

Where:

Fr = Froude number

V = Channel velocity, ft/s (Calculated with Equation 7)

g = 32.2 ft/s^2, (constant: acceleration due to gravity)

D = Depth of flow, ft (Given)

9. Compare calculated velocity to maximum allowable velocity for bed material

Determine the maximum allowable velocity for the proposed size of bed material using the Isbash Formula and compare that result with the result from Equation 7.

Equation 9: Isbash formula (Isbash, 1936)

$$Maximum\ Allowable\ Velocity = \mathrm{C}\left(2g\,\frac{\gamma_s - \gamma_w}{\gamma_w}\right)^{0.5} (D_{50})^{0.5}$$

Where:

C = 0.86 for supercritical flow or 1.2 for subcritical flow (use the results of Equation 8)

g = 32.2 ft/s^2, (constant: acceleration due to gravity)

γ_s = Stone density*

γ_w = 62.4 lb/ft^3 (water density)

D_{50} = median size of stone diameter, ft

*Note: Riprap and granite typically have a density of 165 lbs/ft^3. However, it is the responsibility of the designer to use a value for density that is consistent with the material specified on the design plan. For example, ferricrete boulders generally have a lower density (approximately 145 lbs/ft^3).

As the results of the Isbash formula are a function of stone size and flow regime alone, the maximum allowable relationship is known and can be consolidated into a table for stones of known density. Generally, as median stone diameter increases, so does maximum allowable velocity. However, a given stone is more easily mobilized under a supercritical flow regime than a subcritical flow regime. For reference, see Table 2.

Table 2: Maximum allowable velocity for given D_{50} (stone density = 165 lbs/ft^3)

Isbash Maximum Allowable Velocity (ft/s) (density = 165 lbs/ft^3)		
D_{50}, inches	Subcritical Flow Regime	Supercritical Flow Regime
6	8.7	6.3
9	10.7	7.7
12	12.3	8.8
18	15.1	10.8
24	17.5	12.5
30	19.5	14.0

10. Finalize parabolic section dimensions

The prior calculations show that conveyance is a function of channel shape. Therefore, ensuring the sections are constructed in conformance with the design is very important. To improve constructability, the designer should provide a typical depth measurement at an offset from the channel centerline. The County recommends that the channel be divided into fourths, to provide three measurements easily checked in the field as shown in Figure 14.

The depth measurement, A, at W/4 can be calculated using Equation 10.

Equation 10: Depth of parabolic section at offset = Tw/4

$$A = \frac{3}{4} * P_D$$

Where:

A = Depth at T_W/4 offset from channel line, ft

P_D = Parabolic depth of full section, ft (Given)

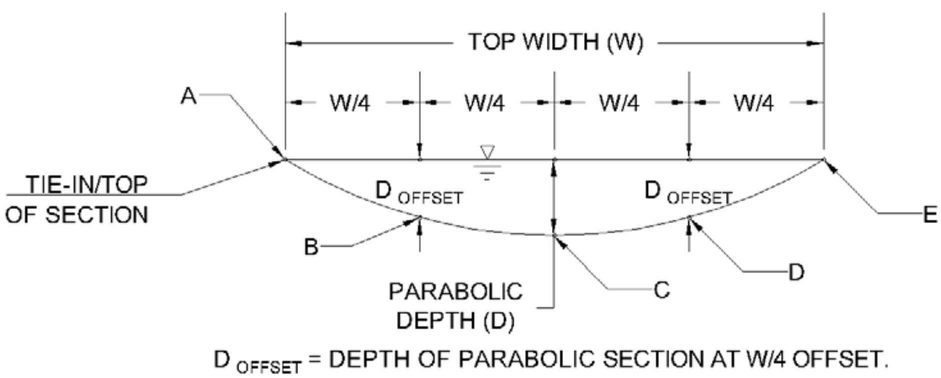

Figure 14: Parabolic section dimensions

2.5.2 Design of Riffle and Cascade Weirs

The hydraulic sizing of riffle and cascade weirs requires an iterative process of evaluation and testing of different design dimensions in search of an optimal balance of size and performance. The process can be challenging as there are multiple viable solutions for a given design discharge. It is difficult to advise the designer of a repeatable process that is ideal for all possible scenarios because the SPSC technique can be adapted to both very small flows and very large flows. The designer must apply their experience, judgement, and knowledge of the existing landscape features to evaluate and select dimensions that are most appropriate for their given site and constraints.

This section includes stepwise workflows that simplify the process of structure sizing and produces repeatable results. The County maintains a spreadsheet tool as a companion to this guidance that is optimized to follow this workflow (available at https://www.aarivers.org). Following this stepwise technique is not a requirement, nor does it absolve the designer from exercising their own judgement.

The designer has control over the following variables as described in Section 2.5.1 Hydraulic Equations:

- L = Length (ft)
- H = Height (ft)
- W = Top width (ft)
- P_D = Parabolic depth (ft)
- D_{50} (ft) = Median stone size
- D = Depth of flow (ft)

Adjusting any one of these variables will impact the flow capacity and velocity of the design section. The following general rules may assist the designer in selecting favorable design variables:

- The most resilient and minimally invasive solution is generally the structure with the smallest footprint that safely conveys the design discharge.
- It is best to focus the initial hydraulic sizing on the maximum design discharge, typically the 100-year storm event. The 2- and 10-year storm events generally will not result in higher velocity or flow depth (unless the project is influenced by backwater during high flows).
- The existing drainage pathway width may be a primary limiting factor on the selection of a riffle weir, cascade weir, or pool top width. While a wider riffle or cascade weir section conveys a higher discharge, if the section is wider than the existing channel it may require overbank cut to install the SPSC, potentially increasing impacts to adjacent natural resources. Combined with a minimum width depth ratio of 10, top width is often constrained to a limited range.

- Parabolic depth is closely related to top width. Upon selecting a design top width, the designer shall select a parabolic depth that meets width depth ratio requirements. For example, if the designer is constrained to a 10-foot top width, the maximum allowable parabolic depth for a riffle weir is one (1) foot to comply with the minimum width depth ratio of 10.
- The designer shall select an appropriate unit weight of stone and specify the unit weight used in the calculations clearly on the design plans.
- Upon selecting length, height, top width, parabolic depth, and median stone size, the designer can easily evaluate a variety of depths of flow to determine the performance of a given structure at different design stages.

2.5.2.1 Riffle Weir Sizing Guidance

This section includes a step-by-step process for sizing a standard one-foot riffle weir (as defined in Section 2.1.1 Riffle Weirs. Anne Arundel County has developed standard design details as a companion to these guidelines. These details are available for download at www.aarivers.org). The 1-foot riffle height is the preferred typical riffle height.

Step 1. Start with an initial riffle top width of 10 feet and riffle length of 10 feet. Set the width depth ratio to 10. To simplify sizing, the County recommends setting the design depth equal to the parabolic depth throughout this process. These initial values are the minimum riffle dimensions.

Step 2. Compare the Q_{100} to the recommended riffle mix table (Table 1). Select the corresponding riffle mix D_{50}.

Step 3. Review the results:

- If the channel exceeds required capacity, reduce the design depth below the parabolic depth until equal to the design flow/Q_{100}.
- If the channel does not have adequate flow capacity, proceed to Step 4.
- If the channel has adequate capacity, but the velocity exceeds the maximum allowable velocity, proceed to Step 5.
- If the channel has adequate capacity, and the velocity is within the allowable range, proceed to Step 6.

Step 4. Increase the channel top width until the channel has adequate flow capacity or the top width constraining factor is reached. If top width is maximized, increase the parabolic depth.

- If the channel has adequate capacity, but the velocity exceeds maximum allowable velocity, proceed to Step 5.
- If the channel has adequate capacity, and the velocity is within the allowable range, proceed to Step 6.

Step 5. If the channel exceeds the allowable velocity, increase the riffle length until velocity is in the allowable range. Typically, this creates a corresponding reduction in channel capacity requiring iterative calibration:

- ○ If the channel does not have adequate flow capacity, return to Step 4.
- ○ If the channel has adequate capacity, and the velocity is within the allowable range, proceed to Step 6.

Step 6. Check the channel performance against the 2- and 10-year discharge by altering the design depth and calibrating the calculated flow to Q_2 and Q_{10}. Note that for these events, the design depth will be less than the parabolic depth.

Step 7. The designer may now make any modifications necessary to ensure the design is acceptable for the site specific 2-, 10-, and 100-year storm flow design goals.

The calculated dimensions are a valid riffle weir solution. The designer should evaluate the proposed dimensions against the site constraints. The designer may further refine and optimize the riffle height, parabolic depth, top width, and riffle length to match site constraints. The designer is encouraged to maintain standard one-foot riffle weir dimensions for all riffle weirs within a specified reach. As needed, the designer may size additional riffle weirs to conform to site conditions.

2.5.2.2 Cascade Weir Sizing Guidance

The designer shall follow a similar design process and use the same set of equations as those used for riffle weir sizing. However, the designer should note the following:

- All cascade weir structures shall use a Manning's n value of 0.05.
- Isbash maximum velocity shall be calculated for a stone size of 2.5 feet (30 inches).
- The maximum cascade weir height is 6.0 feet. Structures higher than 6.0 feet will only be allowed with review and concurrence by the County.
- The designer is encouraged to set cascade top width equal to the standard one-foot riffle weir width calculated in Section 2.5.2.1 Riffle Weir Sizing Guidance to minimize potential for extremely narrow structures and facilitate a smooth grading transition between riffle and cascade weir segments. This also results in freeboard within cascade weir sections which reduces the risk of overtopping. A wider section improves constructability, reduces the average depth of flow within the structure, and reduces scour potential within the receiving pool.
- The County recommends a minimum parabolic depth of 2 feet for cascade weirs. The 2-foot minimum ensures a parabolic section can be constructed from irregular boulders and minimizes potential for flanking around the cascade weir. For structures less than 20 feet wide, the minimum two-foot cascade weir parabolic depth will be deeper than the corresponding standard one-foot riffle weir parabolic depth.

Step 1. The designer should choose initial design dimensions:

- Select a desired cascade height, H.
- Set top width equal to the standard one-foot riffle weir top-width (as calculated Section 2.5.2.1 Riffle Weir Sizing Guidance).
- Set parabolic depth, P_D.
  - Parabolic depth shall be a minimum of two feet.
  - If the calculated standard one-foot riffle weir parabolic depth is greater than two-feet, match cascade weir parabolic depth to the standard one-foot riffle weir parabolic depth.
- The initial cascade length should be set to the minimum length, based on the maximum allowable cascade slope (50 percent) for the selected structure height (e.g., if the designer chooses H of 5 feet, the designer should start with a length of 10 feet).
- Set Manning's n value to 0.05.
- Set D_{50} to 30 inches (2.5 feet).

Step 2. Calibrate the design depth of flow so that calculated flow equals the desired design flow (Q_{100}). Do not modify parabolic depth. Depth of flow will be lower than the section parabolic depth.

Step 3. Review the results:

- If the velocity is within the maximum allowable velocity, proceed to Step 4.
- If the velocity is above the maximum allowable range, increase the length of structure until velocity is below the maximum allowable velocity. Return to Step 2.

Step 4. Check the channel performance against the 2- and 10-year discharge by altering the design depth and calibrating to Q_2 and Q_{10}. The designer should make any modifications as necessary to ensure the design is acceptable for the site specific 2-, 10-, and 100-year storm flow design goals.

The calculated dimensions are a valid cascade weir solution. The designer should evaluate the proposed dimensions against the site constraints. The designer may further refine and optimize the top width, height, parabolic depth, and cascade length to meet the needs unique to their proposed site. The designer may proceed to size additional cascade weirs (of different dimensions) as necessary to complete the proposed design.

2.5.3 Design of Pools

Pools are low energy slope areas designed to impound water and minimize velocity. Standard dimensions for pools are closely related to the dimensions of the upstream riffle or cascade weir structure that discharges into the pool. The designer should note the following:

- Pools should be constructed with minimum side slopes of 3H:1V.
- For pools downstream of riffle weirs, the minimum length of pool shall be equal to the length of the upstream riffle weir.
- The maximum pool depth for pools shall range from 1 to 3 feet (see Section 2.1.3 Pools). The designer may modify depth depending on site specific goals and constraints, or to incorporate diversity of depth.
- Pools immediately downstream of cascade weirs should have a minimum length equal to the greater of (a) the length of the calculated standard one-foot riffle weir, or (b) the length of the cascade weir that precedes it. At low design flow rates and with shorter cascade weir heights, the standard one-foot riffle weir is generally longer due to a comparatively lower slope. However, as cascade height and design flow rate increase, cascade weirs may extend longer than the standard one-foot riffle weir length. This guideline ensures that the length of pool downstream of cascades is conservative in most circumstances.
- The top-width of pool at its widest point shall be equal or greater than the design depth top width of the upstream riffle or cascade weir. The top-width of the pool is measured at the elevation backwatered by the downstream structure invert (low-flow water surface elevation).
- For the first outfall pool (i.e., entrance pool), designers should size a plunge pool using the Maryland Erosion and Sediment Control Guidelines (Maryland Department of the Environment, 2011) and compare the width and length to those of the calculated standard one-foot riffle weir. The designer shall use the more conservative sizing. The minimum depth for the first pool is 1.5 feet.

Designers should note that ensuring pools meet or exceed the requirement for minimum width is critical to reducing velocity and potential for scour. Wider pools increase the available surface storage and reduce the need for imported fill. Should the proposed structures have a top width that is narrower than the existing drainage channel, the designer is advised to maximize pool width within the existing channel footprint, while considering impacts to natural resources.

Downstream of cascade weirs, designers shall evaluate the potential for scour using Equation 11. This equation is a modified version of the Veronese equation to estimate the potential depth of scour.

Equation 11: Veronese equation (United States Department of Argriculture, 2007) modified for SPSC

$$p_d = K * H^{0.225} * \left(\frac{Q}{T_W}\right)^{0.54} - y$$

Where:

p_d = Calculated maximum scour depth, ft

K = 1.32 (coefficient for U.S. units)

H = Height of upstream structure, ft

Q = Design flow, cfs (typically Q_{100})

T_W = Top width of the upstream structure, ft

y = Design flow depth within the downstream structure, ft

The resulting scour depth, p_d, represents depth from the top of pool elevation (low-flow water surface) to the bottom of the conceptual scour hole. Footer boulders for cascade weirs should extend a minimum of 2 feet below the pool bottom and at least one (1) foot below the calculated maximum scour depth elevation. Should the calculated scour depth, p_d, exceed 5 feet, the designer may wish to consider modifying geometry (e.g., reduce height or increase top width) to reduce required depth of footers.

2.6 Final Profile and Sequencing

After calculating typical riffle weir, cascade weir, and pool dimensions the designer may begin the process of designing the final profile sequence. Before beginning the profile design, the designer should revisit their proposed alignment and adjust it, as necessary. As the typical riffle weir width and parabolic depth is now known, adjustments to the project centerline can be incorporated to minimize overbank cut and optimize placement within the valley.

Once the alignment is updated, begin profile design:

Refer to Section 2.4 Preliminary Alignment and Profile, and recall average reach slope (S_r), elevation difference (ΔE), and reach length (L_{design}).

Step 1. Refer to Section 2.5.2 Design of Riffle and Cascade Weirs, and recall the calculated length of the standard one-foot height riffle weir (L_{riffle}).

Step 2. As outlined in Section 0

Step 3. Design of Pools, determine the typical length of pool (L_{pool}).

Step 4. Using the information above, calculate the number of riffle-pool sequences that can fit within the project length. $N_{pools/riffles} = L_{design} / (L_{pool} + L_{riffle})$.

Note: typically, projects start with an entrance pool. The designer may subtract the length of one pool from L_{design}, to account for the loss of length to the entrance pool.

Step 5. Round $N_{pools/riffles}$ down to the nearest whole number.

Step 6. Compare $N_{pools/riffles}$ to ΔE.

- If $N_{pools/riffles} \geq \Delta E$, the project may be constructed with a series of one-foot riffle weirs and cascade weirs are not required. Note: extra length beyond the minimum may be added to pools in the final profile.
- If $N_{pools/riffles} \leq \Delta E$, the project area is not long enough to be constructed with exclusively one-foot riffle weirs. The designer should re-evaluate the project alignment to ensure that length has been maximized. Otherwise, the designer may use cascade weirs to make up the additional grade.

Step 7. Draft a vertical profile with riffle weirs (or cascade weirs) and pools in alternating series. Note the maximum run and glide slopes for riffle weirs is 3H:1V. The entrance pool should be designed to match typical pool length, width, and side slope requirements for pools downstream of riffle weirs. The designer is encouraged to re-visit structure sizing as necessary to meet project goals.

Step 8. Upon completion of the design profile, develop a matching grading plan. Evaluate the grading plan carefully, paying close attention to areas of cut and fill. Make any revisions as necessary to optimize the final alignment, profile, and plan view.

The following guidance may further assist the designer when developing the design profile:

1. The designer should carefully track the bank elevation or elevation of the adjoining landscape and within reason try to conform the proposed profile to the existing top of low bank. It is helpful to note the tie-in elevation of each riffle or cascade weir (tie-in elevation = channel bottom + parabolic depth) to visually evaluate how well each structure will integrate with the existing landscape.

2. As cascade weirs represent a dramatic elevation drop, they should be located thoughtfully within the existing landscape to avoid excessive fill above grade (e.g., berms ≥ 3 feet acting as cross-slope levees), or excessive entrenchment within the existing drainage channel. That being said, situation may arise that do require large fill or mass excavation to make the project fit best into the natural landscape. The designer shall take effort to note natural slope transitions, knick points, or valley pinch points that may be favorable locations for a cascade weir.

3. SPSC projects typically begin with an entrance pool (i.e., at a storm drain outfall or concentrated discharge) and end in a stable outfall pool. Refer to Section 2.7 Stable Tie-in Requirement for guidance on stable-tie in.

4. Structures should be placed along straight (tangent) sections of the centerline alignment and pools may be placed on either tangents or curves. **Designers should avoid curving the baseline through a riffle or cascade weir.** Once the approximate location of

structures and pools are known, the designer should update the alignment to ensure curves are restricted to pool sections.

5. The designer is reminded that pool length can and should be extended beyond the minimum required length and used as a tool to align the locations of structures to best conform to landscape features. For example, if a lateral discharge or drainage channel enters the SPSC in the middle of a reach, careful management of pool length can ensure that the lateral discharge enters a receiving pool segment at the proper elevation.

6. Subsurface filtration water quality credit shall not be allowable on SPSC segments that exceed 5 percent in longitudinal slope. For water quality sizing a "segment" is defined as a riffle-pool sequence. For example, a standard one-foot riffle weir length equal to 10 feet, followed by a pool length equal to 10 feet would have an acceptable segment slope of 5 percent (1-foot drop/20-foot sequence length).

2.7 Stable Tie-in Requirement

The design report for an SPSC must include a site-specific investigation of base-level control along the project reach and must include an analysis demonstrating that the downstream tie-in will not degrade vertically. Vertical headcut propagation originating from downstream of the project area is the primary failure risk for a SPSC.

The following tie-in scenarios are provided as examples. The designer should incorporate site specific engineering judgement and is not limited to these scenarios.

Scenario 1: SPSC extends to receiving stream or tidal water

The designer must investigate the receiving reach and design the SPSC so that it discharges into a pool segment of the receiving stream or to tidal water. For projects that discharge to tidal waters, the SPSC should discharge to mean lower low water to ensure the long-term resiliency of the project during different tidal ranges and storm events (Figure 15).

In the event the SPSC discharges to an incised receiving stream, the designer must provide an analysis justifying that the receiving stream bed will not degrade vertically and that the receiving stream will not laterally migrate away from or into the proposed SPSC. For example, this analysis may include a visual inspection of the receiving reach for signs of headcut propagation and analysis of lateral erosion rates.

If the receiving stream is found to be vertically unstable, the designer is encouraged to extend the project to include receiving stream grade control measures or develop a stream restoration approach for the receiving reach. An in-stream grade control structure may be considered in the receiving reach to promote a backwater pool at the SPSC confluence. Care must be taken, however, to ensure that the structure does not create an impediment to the passage of any migratory or resident fish species present in the receiving stream.

Figure 15: Southdown Shores SPSC tie-in to tidal water (Anne Arundel County)

Scenario 2: SPSC extends to unconfined floodplain

The designer must investigate the receiving floodplain and design the SPSC so that it discharges into either an existing depressional area or design a broad receiving pool in the floodplain to widen flow and promote conversion of concentrated flow to shallow sheet flow when overtopped. The designer may also consider a transitional grade control structure (or structures) to promote a gradual transition from a confined SPSC to a well-connected stream and floodplain. The designer must provide calculations justifying that unconfined overflow from the channel will be of appropriate depth and velocity so as not to degrade the existing floodplain. The designer should anchor the last structure adequately to ensure resiliency against vertical degradation.

Figure 16: Hospital Drive SPSC, novel cascade weir design to navigate breach in former dam (Anne Arundel County)

2.8 Non-conforming Designs

The designer is encouraged to make every reasonable effort to design a SPSC meeting the minimum dimension criteria as outlined in this guidance. However, on a case-by-case basis, the County will entertain exceptions to these criteria, provided the designer can justify the need for an exception and demonstrate that a non-conforming design meets project goals and will remain stable in the design event. Specific examples include, but are not limited to:

- If a given site is constrained by limited length and a conforming riffle weir design cannot be resolved within the available site boundaries, the designer may request an exception from the County's recommended stone size to use a larger stone size to reduce the length of riffle weir.

- If a site is constrained by width due to property access or natural resource impacts, the designer may request an exception from the County to increase the incision of the channel (permit a width- depth ratio less than 10).
- If a site has little risk of receiving flow from the 100-year event across its length, the designer may request an exception to the maximum design storm requirements, provided justification for a lower recurrence event is provided.
- If a site is constrained by an exceptionally steep slope (i.e., greater than 25 percent), the designer may petition the County to use a drop manhole structure.

All the above are subject to the approval of the County and must be justified in the design report with a site-specific analysis that demonstrates that the preferred dimension criteria present an unusual hardship and that the proposed remedy will remain stable and meet design goals.

2.9 Design Validation

Upon successful design of a conceptual profile and grading plan, the designer shall validate the design parameters against the project goals. The designer should refer to Appendix D: Design Checklist throughout this process to ensure the design conforms to project goals.

The designer should check the results of their analysis using a hydraulic model (typically coincident with the 60 percent design development stage). A one-dimensional model such as HEC-RAS is appropriate for data validation. When using HEC-RAS the “mixed-flow” regime is recommended to allow for transition to supercritical flow and to correctly estimate maximum velocity. The designer should evaluate the 2-, 10-, and 100-year peak flow events to ensure that bed material is adequate, and that velocity and water surface elevations are consistent with those calculated using the guidance in Section 2.5 Typical Section Design. Provided the designer has accurate cross-section geometry and uses identical Manning’s n values to the preliminary analysis, the HEC-RAS model should validate the spreadsheet calculation and help to reveal any hot-spots that may require supplementary bed stabilization or re-design.

The designer should take care to closely investigate energy slope for any tailwater or backwater influence throughout the model and verify whether reduced velocities are accurate representations of the proposed condition and not solely the result of averaging between sections. Individual riffle or cascade weirs are typically backwatered to some degree by impounded flow from the downstream pool, but often the water surface remains reflective of the bed slope across at least a portion of the riffle or cascade weir up to and including the 100-year event. This water surface slope transition is often coincident with a hydraulic jump. Should the designer wish to isolate these transitions, multiple sections through riffle and cascade weirs may be required.

If an accurate hydraulic model demonstrates reduced energy slopes and lower velocities from those assumed in the spreadsheet calculations, the designer may re-evaluate and as appropriate reduce stone D_{50}.

Designers may also consider the use of a two-dimensional hydraulic model, particularly to optimize performance and size of pools under design flows. Properly functioning pools dissipate velocity between riffle and cascade weirs, and experience very low velocity along outer edges. Ideally, pools will be long enough and wide enough to demonstrate low velocity, ineffective, circulating flow (see Figure 17).

Along waterways with 100-year floodplain setback requirements, the designer may be required to provide an analysis of post-project floodplain limits. The designer shall coordinate with the County on sites where this is required. If using HEC-RAS, the designer is advised to perform a separate floodplain run using the "subcritical" flow regime to produce a conservative 100-year flood boundary.

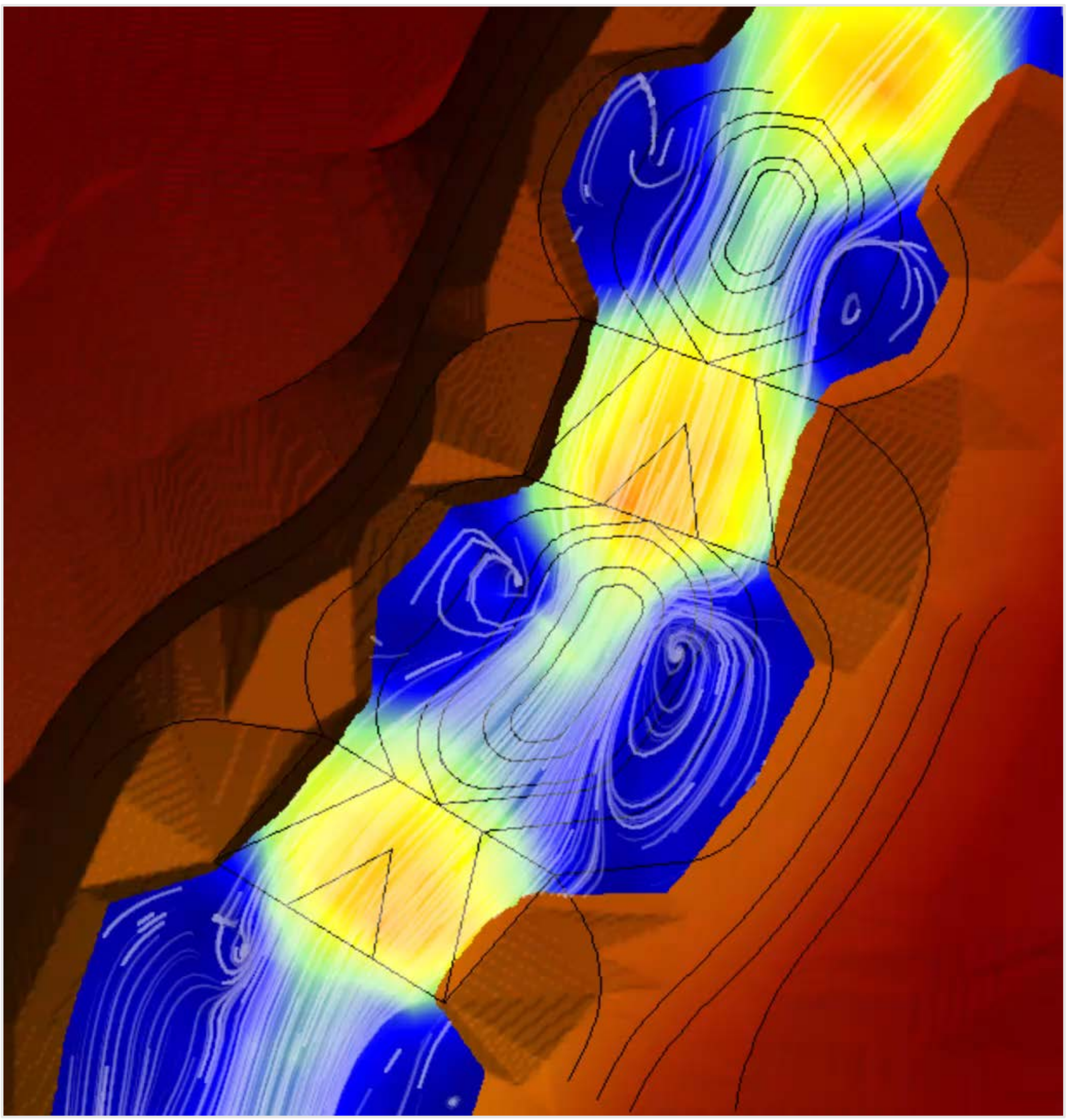

Figure 17: Sample 2-D hydraulic model visualization, showing velocity vectors

2.10 Setback Requirements

For SPSC structures placed along reaches with regulatory floodplain, the designer shall note the following County setback requirements:

- The minimum setback from the 100-year water surface elevation of the system to structures on slabs is 10 feet.
- Systems located uphill of an existing house or structure shall be evaluated for possible adverse effects to the structure.
- The 100-year water surface elevation of a system located uphill of a building or structure that has a basement shall be no closer than 20 feet from the structure or the intersection of the structure foundation footing and the phreatic line associated with the overflow depth of the device, whichever is greater.
- The 100-year water surface elevation of a system located downhill of a building or structure that has a basement shall be no closer than 10 feet from the structure foundation or the intersection of the structure foundation footing and the phreatic line associated with the overflow depth of the device, whichever is greater.
- The 100-year water surface elevation of a system shall be located a minimum of one (1) foot below the structure floor or basement floor. Certification to this effect from a professional engineer shall be shown on the plan.
- The 100-year water surface elevation of a system shall not be located within 25 feet horizontally of an engineered retaining wall or the top of a slope that is 25 percent or greater. In no case shall the phreatic line associated with the overflow depth of the system intersect the existing or final ground surface of the retaining wall or slope. Note, this limitation does not apply to imbricated boulder walls or boulder outcrops installed with the SPSC to minimize excavation and disturbance of existing side slopes.
- The 100-year water surface elevation of a system shall not be located within 50 feet horizontally of any residential water supply well.
- The designer shall consider the proximity of sanitary septic drain fields when locating a new system. These systems can raise the localized groundwater elevation and therefore impact existing septic drain fields. The designer shall ensure that a constructed SPSC system poses no impact to primary and secondary septic drain fields and shall consult the Anne Arundel County Health Department regulations in these instances.
- The 100-year water surface elevation of a system shall not be located within 10 feet horizontally from any public sanitary sewer manhole and clean out structures or house connections. Sewer manholes, clean outs, pump stations, and other surface sewer structures shall be vertically elevated a minimum of 1 foot above the 100-year storm elevation.

2.11 Common Mistakes and Tips for Success

When designed and constructed properly, a SPSC is a resilient, regenerative practice that promotes long term channel stability while supporting habitat along its length. The SPSC design process outlined in this manual is intended to be robust and conservative. However, there are common challenges that may add risk to a given project. The following list outlines some common mistakes and challenges:

- **Proper identification of constraints is critical to establishing the parameters of the design.** Establishing the limits of work, including allowable impacts to property, easement, utilities, and adjacent resources directly influences the proposed plan and profile.
- **Identification of downstream tie-in elevation is critical.** Small differences in downstream grade can create needs for major revision to the SPSC profile. It is especially important to predict and account for both the present and future condition of the receiving reach and consider the possibility of future degradation that may impact the SPSC. Designers should refer to Section 2.7 Stable Tie-in Requirement for additional guidance.
- **Designers should identify distinct reaches along the length of a SPSC.** A thorough understanding of the existing landform is critical to designing an SPSC that integrates with the landscape. This is most obvious along steep sections of the profile. Failing to identify extended lengths of high slope as separate reaches will cause the profile to diverge out from existing valley grade and offer greater opportunity for higher flows to escape the SPSC.
- **Designers should be careful not to set the profile of the SPSC too high.** This is often a byproduct of trying to maximize storage by lifting the channel above its banks to contain more water. The resulting profile requires a series of high berms at each structure. While low profile berms may occasionally be necessary, or even desirable, to tie-in structures or navigate short rapid changes in grade, a repeating series of high berms (i.e., greater than three feet) indicates that the proposed profile has diverged significantly from the existing landscape. Carefully consider the parabolic depth of the proposed structures and how they will tie into the existing grade. Thoughtfully, locate cascade weir structures to navigate sharp drops in elevation. To the extent possible, attempt to match the low flow water surface elevation of the SPSC with the existing low bank or terrace elevation.
- **Avoid overreliance on cascade weirs to meet required grades.** While this guidance does not restrict the ability of the designer to employ a set of cascade weirs in series, the designer should proceed with caution. If a reach requires extremely high cascades in series (e.g., multiple cascade weirs, six feet or greater in height), construction can become very challenging and other methods, such as a drop manhole structure, may merit consideration.
- **Designers should avoid placing structures along curves in the alignment.** This is particularly important if grade lines are generated with an automated CAD template. Curved alignments will result in weir structures that are shorter on the inside of the curve and longer on the outside. If constructed per plan, these structures will not be appropriate

for the site-specific hydraulics. Note: if the entire alignment is semicircular, structures would be set along the curvilinear flow path.

- **Designers should not neglect opportunities for variability.** While SPSC systems intentionally lend themselves to a series of repeating structures of identical dimension, designers should embrace opportunities to create variability and integrate with the existing landscape. Modifying riffle heights, adding small cascades or changing pool length and depth (provided minimum dimensions are met) adds variability to the sequence and can help ensure smooth grading tie-ins to the adjacent landscape.
- **Avoid excessively oversized structures.** While it is the responsibility of the designer to consider any site-specific needs for factors of safety and freeboard, excessively large structures create unnecessary disturbance and add expense to the project.
- **Designers should not introduce additional risk into cascade weir sizing.** Designers are encouraged to use a maximum stone size of 30 inches when applying the Isbash relationship to cascade weirs (as described in this guidance). A common mistake is to continue to increase boulder size beyond 30 inches to provide resistance to higher velocity flow. The 30-inch maximum creates a reasonable threshold for velocity and ensures that cascade weirs are constructible and can be built with available source material.

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3.0 Aggregate and Stone Requirements

To the extent possible, the aggregate, cobble, and boulders used in SPSC systems should be consistent with locally sourced material found in Anne Arundel County. Maintenance of pH levels is an important consideration in maintaining habitat and water quality within SPSC systems. Therefore, the use of limestone or cement-based stone products (including recycled concrete) is prohibited.

3.1 Filter Bed Media

All SPSC projects require a sand and woodchip filter bed regardless of whether the project is presented as a stormwater filtration device for ESD or retrofit credit. The sand shall meet the AASHTO-M-6 or ASTM-C-33 standard, 0.02 inches to 0.04 inches in size. Sand substitutions such as Diabase and Graystone (AASHTO) #10 is not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No “rock dust” can be substituted for sand. The woodchips should be made from hardwood trees, recently chipped (green), and un-composted. Woodchips are typically mixed with the sand on-site, approximately 20 percent by volume, to increase the organic content in support of denitrification. Designer and contractor shall note that due to compaction upon installation, the woodchips are not to be considered as a “fill” material when quantifying volume of material needed to fill the channel. The 20 percent woodchip is considered a separate, supplementary volume.

The minimum depth of the filter bed below the invert of all project features shall be 18 inches with a minimum width of 4 feet as shown in the profile and section views in Section 2.1 Typical SPSC Components.

For projects located in extremely incised or eroded gullies where the depth of fill far exceeds the required filter volume, designers may specify the use of common borrow fill material for subgrade fill, provided a continuous filter bed meeting the volume and minimum depth requirements is installed above.

Note: Sand and woodchips are not mixed prior to installation. The woodchips are installed in layers during construction to provide clean and efficient access. As the site is being worked and graded, the sand and woodchips will become well incorporated. Woodchip hotspots and clean sand areas are desired.

3.2 Stone Mix, Size, and Particle Distribution

3.2.1 Riffle Mix

Riffle mix is a mixture of stone ranging from 6 to 24 inches in median diameter (D_{50}) washed with sand and gravel. Riffle mix is used as the bed material for all riffle weir structures and as an apron stone on run and glide facets leading into and out of pools. The preferred stone for riffle mix is silica stone ranging from rounded to angular in shape. Silica stone is sometimes quarried and sold under the name “river jack,” or “river rock.” The designer shall specify that all rock be of silica composition and free from lime or limestone, cement, or concrete. Granite or broken ferricrete boulders that meet the hydraulic sizing criteria may also be used in lieu of silica stone.

The depth of the riffle mix material shall be placed to a minimum thickness of the greater of 18 inches or 2 x D_{50}.

Designers shall select the riffle mix D_{50} based on the site specific Q_{100} and hydraulic analysis. The corresponding particle distribution for a given D_{50} is outlined in Table 3.

Table 3: Riffle mix particle distribution

Riffle Mix Gradation Table			
D_{50} Median Stone Size (inches)	% of Material Smaller than Typical Stone	Typical Stone Equivalent Diameter (inches)	Typical Stone Weight (pounds)*
6	7 - 100	12	85
	50 - 70	9	35
	35 - 50	6	10
	2 - 10	2	0.4
9	7 - 100	15	160
	50 - 70	12	85
	35 - 50	9	35
	2 - 10	3	1.3
12	7 - 100	21	440
	50 - 70	18	275
	35 - 50	12	85
	2 - 10	4	3
18	7 - 100	30	1280
	50 - 70	24	650
	35 - 50	18	275
	2 - 10	6	10
24	7 - 100	42	3500
	50 - 70	33	1700
	35 - 50	24	650
	2 - 10	9	35
** Assumed unit weight of 165 lbs/ft^3*			

During riffle weir installation, all areas of riffle mix shall be tracked in with heavy machinery and washed in layers with silica gravel and clean sand to form an interlocking matrix capable of supporting plant material. The designer shall specify a volume of wash-in material equal to 20 percent of the total riffle mix (typically 15 percent gravel and 5 percent sand) required on the site. As this material will fill void space within the riffle mix, it should be considered an additional volume (e.g., if the quantity takeoff requires 100 CY of material for riffle mix, the designer shall specify 100 CY of riffle mix and an additional 20 CY of wash-in material). The track-in and wash-in requirements shall be clearly instructed on the detail sheet.

3.2.2 Boulder Stones

The preferred boulder material for use in Anne Arundel County is ferricrete (e.g., bog iron, sandstone). Ferricrete deposits are common to Anne Arundel County. Its porosity, as well as its ability to retain water, allows it to naturalize quickly, providing habitat for ferns, moss, and other organisms that persist in this landscape position. Granite or sandstone may be substituted for native ferricrete if cost or availability is a concern. Designers shall consider the unit weight of the boulder stone in their design calculations and specify minimum density requirements on the plans.

All boulders should be tabular in shape to allow for maximum interlocking (see Figure 18). Boulders should be placed with the C-axis placed vertically and the B-Axis placed parallel to the direction of flow.

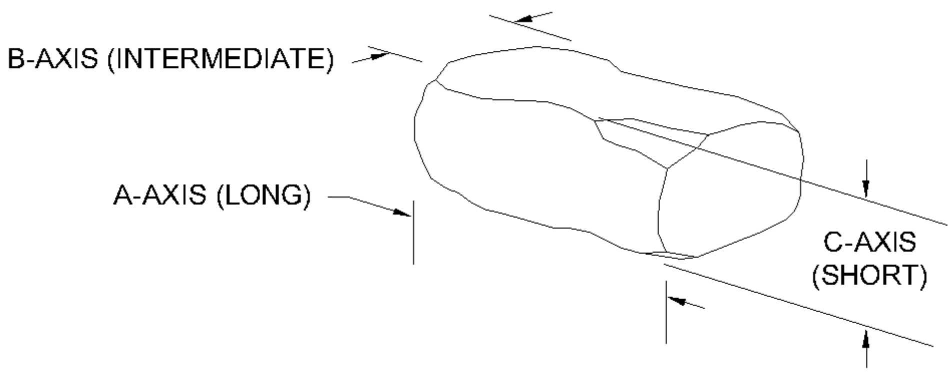

Figure 18: Typical tabular boulder

Boulders shall meet or exceed the dimension requirements for the Maryland Department of Transportation State Highway Administration (MDOT SHA) Class 3 riprap (typical weight ≥ 600 lb). The minimum boulder dimension varies based on use in the project. Top-level boulders used in cascade weirs may be thinner along the C-axis than those used for cascade footers. A wide range of boulder sizes is acceptable and encouraged. The contractor should have flexibility to select stone that can be placed to match the design section, provided the median boulder size is at least 30 inches along the A-axis (consistent with the design stability calculations).

The designer shall note on the plans that the contractor is responsible for selecting boulder material that is appropriately sized to allow for economical construction of structures. While the plans dictate minimum dimensions, excessively large boulder material (i.e., 3.5 feet long or greater) above and beyond the minimum dimensions will not be paid for as a quantity overage.

Recommended boulder dimensions are included in Table 4.

Table 4: Recommended boulder dimensions

Boulder Location	**A-axis (in)**	**B-axis (in)**	**C-axis (in)**
Riffle and cascade weir (surface level)	24-36*	24-36	12-24
Cascade footer boulders (subsurface)	24-36	24-36	12-24
** Median A-axis for each structure must equal a minimum of 30 inches.*			

The designer shall note on the design plans that the edges of the boulders should be placed as tightly against one another as possible, creating a continuous structure. All voids between boulders shall be chinked with cobble or boulder fragments from behind the structure to fill voids and promote surface flow over the boulders.

Filter fabric shall be placed under all layers of boulders in cascade weirs. In riffle weirs, filter fabric is not required under boulders, provided the adequate subsurface bedding conditions are provided and a low profile run is constructed. The recommended fabric is non-woven Class SE Geotextile. Refer to Section 2.1 Typical SPSC Components for placement location. Note: filter fabric shall not be placed under pools or riffle mix.

4.0 Erosion and Sediment Control Plan

Coincident with the 60 percent design development phase, the designer shall present an erosion and sediment control plan suitable for the site. While detailed guidance on SPSC construction is outside the scope of this manual, the County sees the SPSC and the Erosion and Sediment Control (ESC) as one and the same. That is all the tools within SPSC design, including the gravel underdrain, sand/woodchip mix, process of constructing the weirs, all contribute to maintaining a clean site, and is typically far superior to conventional ESC practice and current requirements. Designers and contractors shall note that the Maryland Department of Natural Resources (DNR) maintains a construction manual for RSC projects on their website (Maryland Department of Natural Resources, 2018, 11):

https://dnr.maryland.gov/ccs/Documents/RSC_Training/RSC-Guidance.pdf

While RSC and SPSC projects are defined differently (refer to Section 1.0 Introduction), the DNR manual includes guidance on construction sequencing and best practice that designers may find applicable to both the SPSC and RSC configuration.

General guidance on ESC strategy for SPSC installation:

- The Anne Arundel County Soil Conservation District (AASCD) maintains a plan checklist for SPSC projects, including guidance on plan view, sequence of construction, details on plans, and plan notes. This guidance is available on the AASCD website: http://www.aascd.org.
- The designer and contractor shall consider a temporary slotted pipe underdrain, with supplemental sump pumps, to assist with site dewatering during construction. The pipe may be removed, crushed in place, and or choked in-place depending on site conditions and design goals. Additional detail can be found in the DNR construction manual (Maryland Department of Natural Resources, 2018, 11).
- All access roads shall be constructed with a minimum six-inch layer of woodchips and replenished, throughout the duration of construction. The designer should be knowledgeable of site-specific conditions and consider timber matting, as necessary.
- On most sites, but particularly those with adjacent to mature forest or other high-quality resources, the County recommends that designers specify the use of the existing channel as the primary access road to minimize disturbance. There are other co-benefits to using the existing channel as the access road including beneficial use of sand fill for access during construction that will remain in place as the filter bed and affording the delivery of construction materials directly to their installed position.

  The designer should further note the following when using the channel for access:

  - When feasible, construction is typically sequenced with channel fill occurring from upstream to downstream, and subsequent completion of riffle or cascade weirs, and pools occurring from downstream to upstream. Note: within this sequence, it is recommended that structure materials (i.e., riffle mix and boulders) be placed directly within the channel access path, so it can be tracked in repeatedly by construction equipment before the structures are sculpted to their final shape. Experience has shown that this provides for a more robust, well integrated system that is less prone to movement and piping.

  - When feasible, the designer shall include a six-foot access path along the overbank area to afford maintenance access during and after construction.

- All projects should include specification of a standard pump around practice with a filtration device to ensure the site remains dewatered during construction.
- The designer shall include tree protection for specimen trees to be saved during construction and show protection on the ESC Plan.
- It is common practice for delivery of SPSC materials to occur directly in-place and within the channel. The designer shall provide accessibility to the channel by trucks and other equipment when choosing site entrance and access paths. Maximum slope of ramps and access roads is 10 percent.
- The designer shall note that the contractor may operate freely within the limit of disturbance (LOD) to receive and place material and complete project grading. The designer may also note that the contractor is given a larger than necessary LOD within to operate and should avoid unnecessary impacts to resources within the LOD when possible.
- While typical SPSC side slopes may not require the use of erosion control matting, the designer shall review the site including cut slopes and ensure that appropriate permanent stabilization measures are in place. Any matting used on SPSC sites must be biodegradable. No “biodegradable” plastic mesh matting is allowed.

For sites in which a SPSC is installed as part of a development or re-development project:

- Under no circumstance can the SPSC system be used as a sediment control device during construction unless approved by AASCD. All water should be treated by an approved ESC practice before reaching the SPSC. Upstream controls such as diversion pipes and pump-arounds are required during construction so as not to contaminate the SPSC system.
- The designer should evaluate the condition of the proposed outfall channel when phasing construction. When practical, the designer should consider installation of the SPSC prior to site wide construction (provided upstream ESC has been provided). By installing the SPSC in advance, the channel bed and banks will be prepared to accept the post-development discharge. Otherwise, releasing concentrated discharge to an unstable outfall channel may accelerate degradation during construction and generate additional erosion.

5.0 Planting Plan

The designer should work with a plant ecologist or natural resources specialist to prepare a planting plan suitable for the entire LOD. A selection of approved trees, shrubs, and herbaceous materials, in addition to planting densities and planting zones should be provided in the construction plan set. The planting plan and proposed species must be reviewed and approved by the County project manager or reviewer prior to installation. Additionally, any plant substitutions must be approved by the project manager or reviewer before the substitute species are installed.

Figure 19: Vegetated SPSC during low flow discharge event

The designer should pay attention to the use of native plants, diversity, and dense placement of plant material within appropriate hydrologic and geographic zones throughout the site. The designer should also consider post-project sunlight exposure and shade tolerance. SPSCs with a small disturbance footprint may maintain significant overstory shade by avoiding impacts to mature trees.

While it is not possible to predict the exact level of soil moisture or whether pools will hold water for extended periods, it is the responsibility of the planting plan designer to create a planting plan that can be adapted to post construction conditions. SPSC systems are often ephemeral and do not maintain perennial or intermittent water surface base flow. However, SPSC systems may intercept groundwater and, in some instances, maintain perennial pools. The design should include options for both aquatic plants (for pools that hold water) and emergent and scrub shrub plants (for pools that are predominantly dry).

The designer should consult the Natural Communities of Maryland (Harrison, 2016) to appropriately characterize naturally occurring forest assemblages found in the County. General guidance on planting by typical SPSC components is provided in the following sections. Refer to Appendix E: Abbreviated List of Native Plants and Plant Communities for a list of representative plant communities found in Anne Arundel County and the key indicator species within those communities.

5.1 Planting Riffle Weirs

Riffle weirs and their attendant berms should support plantings. As part of riffle construction, the interstitial spaces between cobbles shall be washed in with sand and gravel. The outer one-third of each riffle weir shall be covered with a 3-inch layer of either sand or topsoil (preferably salvaged) to promote a soil matrix that is readily planted (colonized) and stabilized by vegetation. Incorporation of compost or other organic matter into the soil mix would be dependent on the nutrient status of the placed soil and other factors based at the discretion of the designer.

Riffle weirs are best planted with wet-tolerant, rhizomatous plants such as sedges, rushes, and switchgrass which can be planted as plugs. As appropriate, a native wetland seed mix may also be spread on all riffle weirs as a supplement to plug planting.

5.2 Planting Cascade Weirs

Despite the preponderance of large boulders that are used to construct cascade weirs, these structures can readily accept planting in the sandy/soil matrix of the aprons and berms similar to the riffle weirs described above. Cascade weirs, particularly those constructed with ferricrete boulders, can also be planted within the interstitial spaces between boulders with native ferns.

5.3 Planting Pools

Due to the diverse hydrologic conditions typically established in SPSC pools, a broad variety of native plant communities can potentially be supported. Soils within pool bottoms generally remain moist to wet, with enough frequency to support facultative-wet to obligate plant species. When pools regularly hold water, aquatic plants may be specified within pools (e.g., water lily and golden club). The fringe of pools should be planted with wet-tolerant shrubs and emergent herbaceous species. This fringe area is also suitable for wetland mix seeding. With increased upslope distance from the pools, soils become drier and support mesic and dry upland forest communities.

5.4 Planting Berms and Valley Side Slopes

In the event a project includes berms, they should be planted with a variety of species adapted to conditions along a steep edaphic gradient. Berms and valley side slopes will likely present a variety of potential hydrologic conditions, ranging from very dry on steep upper slopes to constant saturation along toe-of-slopes and the upstream side of the berm. The planting plan should recognize this diversity and include community types that reflect these conditions.

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6.0 Monitoring Plan

Many of these projects will require some sort of performance monitoring, but the duration, intensity, and parameters evaluated depend upon the nature of SPSC, where it is installed in the landscape, the expected performance of the project as it relates to goals and objectives associated with doing the project to begin with, and the regulatory environment under which the project is permitted, and the official Water Quality benefits expected from the project.

Structural stability and plant survivability are the two most pertinent components to monitor for private or developer-built projects. These components shall be monitored as established in the plan review process. Enforcement of the monitoring conditions shall be tied to the as-built approval process and release of the stormwater management bond, if applicable.

Typical monitoring plan requirements are suggested below:

1. Prior to release of certification of completion, County inspectors must ensure that adequate permanent stabilization has occurred in compliance with AASCD guidance. If sediment accumulation from upstream construction (or other sources) is found to interfere with the function of the SPSC, it must be restored to design condition.
2. The monitoring plan shall include an annual vegetation survey and, as necessary, replanting, to document that planted species maintain 80 percent survivability.
3. The monitoring plan shall include a structural stability review, identifying any areas of vertical or lateral erosion. Erosive areas must be restored to functioning condition.
4. The monitoring plan shall include all monitoring required as a condition of project permits.
5. A recorded maintenance agreement is required for all privately-owned SPSC systems.
6. The recommended maintenance plan shall be included on the design plans. For privately-owned structures, the maintenance agreement shall be officially recorded, and the recordation number shall be included on the approved grading plan sheets.

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7.0 Use of SPSCs as a Stormwater BMP and MS4 Retrofit

The SPSC approach is an approved tool for satisfying a variety of stormwater and water quality criteria under several different State of Maryland regulatory frameworks. This section briefly describes the current state of compliance and directs the designer to current regulatory guidance for more information. The approved methods and regulations on crediting are subject to change. It is therefore the designer's responsibility to confirm current guidance with County and State officials during the design process. This document does not describe or dictate means and methods for calculating treatment quantities or stormwater credit as those methods are regulated and described by other guidance.

Generally, SPSC practices are installed by one of two parties seeking to meet different objectives:

1. Developers who may be using the SPSC practice to fulfill a portion of stormwater quality or quantity and stable outfall requirements.
2. County managers and or restoration practitioners who may be using the SPSC practice to secure impervious acre or TMDL credit as part of MS4 compliance.

7.1 Guidance for Developers

The SPSC may be used as an ESD practice when the project conforms to the criteria found in Chapter 5 of the 2000 Maryland Stormwater Design Manual, Volumes I and II (Maryland Department of the Environment, 2000) for microbioretention or bio-swale and the general configuration conforms to the principles of ESD: using small-scale practices distributed uniformly around the site to capture runoff close to the source. SPSCs may be used for runoff reduction or steep slope stability treatment and are considered structural Stormwater BMPs if they are sized to accommodate the volume control requirements specified in Chapter 2 of the Stormwater Design Manual.

Surface storage in pools may be credited as ESD volume stored across the entire SPSC. Additional volume can be claimed for subsurface storage in the filter bed, akin to a microbioretention or bioretention. However, use of SPSC as a structural stormwater BMP is only allowable after meeting ESD criteria to the maximum extent practicable. The designer may potentially increase ESD volume by increasing the depth of pools, width of the filter bed, or length of the facility to increase storage capacity. However, pool depth and storage should not be increased at the expense of project stability. Designers should consult the appropriate State Manual for additional guidance on the calculation of filter sizing and volume.

While SPSC systems can be implemented on steep slopes, under no circumstance can subsurface ESD volume be claimed for SPSC segments with a longitudinal profile slope that exceeds five percent. A "segment" is defined as a riffle-pool sequence. For example, a standard one-foot riffle weir with a 10-foot length, followed by a pool with 10-foot length would have an acceptable segment slope of 5 percent (i.e., 1-foot drop/20-foot sequence length).

In situations where the existing soil underlying the proposed SPSC is confirmed through geotechnical borings to be highly infiltrative the designer may use the State Manual's water quality sizing criteria for an infiltration basin in lieu of filtration. This is prescribed so the designer is not forced, under certain circumstances, to replace highly infiltrative in-situ soil with filter bed material. To claim water quality credit, the design ponding depth (e.g., head, h_f), intended to drive the seepage through the filter, should be entirely above the seasonal high groundwater elevation.

A proposed SPSC will satisfy volume requirements if two conditions are met:

1. Adequate storage volume within the pools and filter bed shall be provided to meet or exceed the required storage volume and quantity management requirements for the drainage area. The designer shall provide calculations comparing provided storage to require volumes.
2. It must be demonstrated that the design discharges to a stable connection to the receiving waterway.

Developers are encouraged to coordinate early with the County to review SPSC placement and the condition of the receiving channel. In some instances, the County may be able to claim additionally MS4 credit for prevention of future bed and bank erosion along the outfall channel. If this is the case, the County will coordinate with the developer and collect additional pre-project monitoring data and documentation as needed.

7.2 Guidance for Restoration Practitioners

SPSC may be used as a retrofit practice as part of Anne Arundel County's MS4 Program goals towards impervious acre restoration. The Chesapeake Bay Program publishes guidelines for the calculation of sediment and nutrient removal efficiency for BMPs within the Chesapeake Bay Watershed. The State of Maryland has adopted the Bay Program efficiencies and interpreted their equivalency to impervious acre restoration credit in a document entitled "Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated, Guidance for National Pollutant Discharge Elimination System Stormwater Permits" (Maryland Department of the Environment, 2021, 11). SPSC projects can provide both TMDL nutrient reduction credit (Nitrogen, Phosphorous, Total Suspended Sediment) and MS4 impervious acre restoration credit as described in MDE's guidance document. The mechanisms for credit as they apply to SPSCs are described briefly here:

1. <u>Pollutant Load Reductions for Upland BMPs:</u> A SPSC may claim credit for Retrofit Storage Volume for stormwater captured and treated. Generally, the same design criteria and restrictions (including restrictions on slope) apply to both ESD and stormwater retrofit projects as described in Section 7.1 Guidance for Developers. The 2021 MS4 guidance states "a dry channel regenerative step pool stormwater conveyance system is considered a stormwater retrofit by the CBP Stream Restoration Expert Panel. This practice may use the BMP code SPSD and use the same pollutant load reductions as a filtering practice. The impervious area draining to these practices may be considered treated in accordance with the design rainfall depth treated (P_E) for crediting purposes." Stormwater volume treated by SPSCs may be directly translated to impervious acreage treatment credit as outlined in the 2021 Guidance. Nutrient volumes are calculated as a function of BMP treatment efficiency.

2. Alternative Best Management Practices: Alternative best management practices do not directly treat stormwater. However, they qualify for equivalent impervious acre credit for nutrients and sediment reduced through other means. SPSCs are categorized as a “stream restoration” practice by MDE when implemented as an alternative BMP. Per the 2021 MS4 guidance (Maryland Department of the Environment, 2021, 11), stream restoration practices can quantify nutrient and sediment reduction by following protocols, basic qualifying conditions, and reporting requirements outlined in the Chesapeake Bay Program “Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects” (Chesapeake Bay Program Urban Stormwater Work Group, 2014, 09 08) and subsequent supplements and updates.

The 2014 guidance includes four general protocols to define pollutant load reductions associated with individual stream restoration projects. The 2014 guidance defines SPSC projects under Protocol 4 as “Dry Channel RSC” projects and classifies the approach as a stormwater retrofit practice, rather than a stream restoration practice (with calculation as described in item 1 of this section). However, in 2019, a fifth protocol was approved for outfall and gully stabilization projects, described in a separate document “Recommendations for Crediting Outfall and Gully Stabilization Projects in the Chesapeake Bay Watershed (Chesapeake Bay Program Urban Storwmater Work Group, 2019, 10 05). This guidance updates the classification of Dry-channel RSC practices (SPSC) to allow credit both as a stormwater retrofit (Protocol 4) and an Outfall Gully Stabilization Practice (OGSP, Protocol 5). This 2019 Bay Program guidance outlines methods to quantify nutrient and sediment reductions as a function of prevented sediment loss through vertical bed stabilization of the outfall channel. MDE’s 2021 MS4 guidance includes instructions on how to convert this reduction to an equivalent impervious acre credit.

In 2021, the Bay Program published a “unified guide” outlining crediting for stream restoration projects in the Chesapeake Bay watershed (Wood, Schueler, & Stack, 2021, 09 17). This document consolidates key changes and updates to expert panel protocols between 2014 and 2021 and is the current guidance at the time of this document’s publication.

Depending on site conditions and qualifying criteria a SPSC water quality retrofit project may claim MS4 TMDL nutrient and Impervious Acre credit as:

- As a standalone stormwater treatment device.
- As an OGSP alternative BMP.
- As a combination stormwater treatment and OGSP (credit may stack).

The designer should familiarize themselves with the applicable credit protocols and as necessary, collect pre-project monitoring data required to justify the proposed credit. Calculations of credit under each protocol and impervious acre equivalency should be provided in the design report.

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8.0 References

Anne Arundel County. (2001). *Design Manual.* Retrieved from https://www.aacounty.org/departments/public-works/engineering/design-manual/

Anne Arundel County. (2017). *Anne Arundel County Stormwater Management Practices and Procedures Manual.* Retrieved from https://www.aacounty.org/departments/planning-and-zoning/development/forms-and-publications/Practices_Procedures_Manual.pdf

Chesapeake Bay Program Urban Stormwater Work Group. (2014, 09 08). *Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects.* Chesapeake Stormwater Network. Retrieved from http://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2013/10/stream-restoration-short-version.pdf

Chesapeake Bay Program Urban Storwmater Work Group. (2019, 10 05). *Recommendations for Crediting Outfall and Gully Stabilization Projects in the Chesapeake Bay Watershed.* Chesapeake Stormwater Network. Retrieved from https://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2019/10/FINAL-APPROVED-OUTFALL-RESTORATION-MEMO-101519.pdf

Chow, V. T. (1959). *Open Channel Hydraulics.* McGraw-Hill.

Donovan, M., Miller, A., Baker, A., & Gellis, A. (2015). Sediment contributions from floodplains and legacy sediments to Piedmont streams of Baltimore County, MD. *Geomorphology, 235*, pp. 88-105.

Harrison, J. W. (2016). *The Natural Communities of Maryland: 2016 Natural Community Classification Framework.* Wildlife and Heritage Service, Natural Heritage Program, Maryland Department of Natural Resources. Annapolis, Maryland: Unpublished report.

Isbash, S. (1936). Construction of Dams by Depositing Rock in Running Water. *International Congress on Large Dams, 14*.

Maryland Department of Natural Resources. (2018, 11). *Regenerative Stream Conveyance: Construction Guidance* (1st ed.). (A. L. Donna An, Ed.) Annapolis, Maryland: DNR Chesapeake and Coastal Service 14-091418-95.

Maryland Department of the Environment. (2000). *Stormwater Design Manual, Volumes I & II.* Ellicott City, Maryland.

Maryland Department of the Environment. (2011). *2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control.* Baltimore, Maryland.

Maryland Department of the Environment. (2021, 11). *Accounting for Stormwater Wasteload Allocations and Impervious Acres Treated.* Retrieved from https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/Documents/Final%20Determination%20Dox%20N5%202021/MS4%20Accounting%20Guidance%20FINAL%2011%2005%202021.pdf

NatureServe. (2022). *NatureServe Explorer, web application.* Arlington, Virginia: NatureServe. Retrieved 04 02, 2022, from https://explorer.natureserve.org/

Rosgen, D. L. (1996). *Applied River Morphology.* Pagosa Springs, Colorado: Wildland Hydrology.

United States Department of Agriculture. (1989). *Loose Riprap Protection, Minnesota Technical Note 3.* St. Paul, Minnesota: USDA Soil Conservation Service.

United States Department of Argriculture. (2007). National Engineering Handbook. In *Technical Supplement 14B, Scour Calculations, Part 654.* United States Department of Argriculture Natural Resources Conservation Service.

Wood, D., Schueler, T., & Stack, B. (2021, 09 17). *A Unified Guide for Crediting Stream and Floodplain Restoration Projects in the Chesapeake Bay Watershed.* Chesapeake Stormwater Network. Retrieved from https://chesapeakestormwater.net/wp-content/uploads/dlm_uploads/2021/10/Unified-Stream-Restoration-Guide_FINAL_9.17.21.pdf

Appendix A: Prior Version Acknowledgements

This document represents a refresh of the 2012 Anne Arundel County Design Guidelines for Step Pool Storm Conveyance, first published in June 2009. The 2012 document text remains the core of this document, and the authors and original technical review committee are acknowledged here.

The original document was prepared by Hala Flores, P.E., Dennis McMonigle, and Keith Underwood; and updated by Ken Pensyl with subsequent updates and revisions supported by a technical review committee with membership (and their affiliations as of 2012) as follows:

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Appendix B: Site Photos

This appendix contains photos of an assortment of SPSC projects completed within Anne Arundel County. The SPSC systems depicted in these photos demonstrate wide variability in age of installation, size, shape, and configuration, but each is designed to meet site specific needs and goals, based on the principles outlined in this guidance. Many of the photographs depict SPSC sites during or recently after storm events with water present. Designers should review the photographs with particular focus on how projects are blended into the natural landscape, with minimal disturbance, and well colonized with native vegetation.

Figure B-1: Barrensdale Outfall Restoration – Magothy River Watershed (Anne Arundel County)

Figure B-2: Barrensdale Outfall Restoration – Magothy River Watershed (Anne Arundel County)

Figure B-3: Cape St. Claire Park SPSC – Magothy River Watershed (Anne Arundel County)

Figure B-4: Cape St. Claire Park SPSC – Magothy River Watershed (Anne Arundel County)

Figure B-5: Rupert's Ravine, Patapsco Tidal Watershed (Anne Arundel County)

Figure B-6: Rupert's Ravine, Patapsco Tidal Watershed (Anne Arundel County)

Figure B-7: Riffle weir sequence at Winchester SPSC (Anne Arundel County)

Figure B-8: Woody debris placement in a pool at Winchester SPSC (Anne Arundel County)

Figure B-9: Killarney House and Neighbors, Beards Creek Community BMPs – South River Watershed (Anne Arundel County)

Figure B-10: Southdown Shores Outfall – South River Watershed (Anne Arundel County)

Figure B-11: Dairy Farm Road Outfall – Towser's Branch Watershed (Anne Arundel County)

Figure B-12: Dairy Farm Road Outfall – Towser's Branch Watershed (Anne Arundel County)

Figure B-13: Four Seasons Outfall Restoration – Little Patuxent Watershed (Anne Arundel County)

Figure B-14: St. Luke's (Anne Arundel County)

Figure B-15: St. Luke's (Anne Arundel County)

Figure B-16: Pond 1330 Retrofit (Anne Arundel County)

Figure B-17: Buttonwood (Anne Arundel County)

Appendix C: Minimum and Maximum Design Dimensions

These tables are provided to assist the designer in understanding minimum and maximum dimension constraints. These tables are only a broad outline of constraints applicable to all SPSCs and are not a replacement for site specific sizing of features. The designer shall consider site specific hydrology and hydraulics in establishing all dimensions. Any deviations from these criteria should be justified in the design report.

Table C-1: Riffle Weirs

Dimension	Minimum	Maximum	Basis of Design
Length	10 feet	--	This is the minimum constructible length offering adequate size to install riffle mix at the design elevation. Constraining length at a reasonable minimum helps avoid excessively steep, short, structures. Length should be calculated as a function of site-specific hydrology and hydraulics.
Top width	10 feet	--	This is the minimum constructible top width using typical materials and construction equipment. Top width should be calculated as a function of site-specific hydrology and hydraulics.
Height	--	1.5 feet	The recommended riffle weir height is one foot (standard one-foot riffle weir). However, riffle weir heights may be designed between 0 and 1.5 feet to meet site specific needs. Designers should use cascade weirs to navigate heights greater than 1.5 feet.
Width depth ratio	10	--	This ratio was selected to minimize overly deep, incised sections and ensure that riffle weirs maintain broad, shallow, flow. The ratio is calculated by dividing top width by parabolic depth.
Parabolic depth	1 foot	--	Derived from minimum width of 10 feet with minimum width depth ratio. Parabolic depth should be developed with site-specific hydraulics.
D_{50}	6 inches	24 inches	Chosen based on available stone gradations readily available to incorporate into riffle mix and sensitivity analysis across range of flow rates. The designer should choose D_{50} based on site specific hydraulics. The County has provided recommended sizing as a function of flow rate to simplify the selection of D_{50}.
Thickness	18 inches OR $2xD_{50}$ when D_{50}> 9 inches	48 inches	Minimum depth was chosen to apply a factor of safety of 1.5 beyond 2x the minimum D_{50} size. Maximum depth is based on 2x the maximum D_{50} size.

Table C-2: Cascade Weirs

Dimension	Minimum	Maximum	Basis of Design
Top width	10 feet	--	This is the minimum constructable width accounting for the size of boulder material. Top width should be calculated as a function of site-specific hydrology and hydraulics. Cascade weir top width should be set to match the top width of the standard one-foot riffle weir. Matching width facilitates a smooth grading transition between riffle and cascade weir segments and typically results in freeboard within cascade weir sections which reduces the risk of overtopping.
Height	>1.5 feet	5 feet	Set as safe maximum constructable height. Cascade weirs higher than 5 feet are a strong indication of a uniquely challenging landscape.
Slope	--	50%	The purpose of cascade weirs is to make up grade quickly, and to this end, cascade weirs slopes up to 50% offer an ideal balance of height and length. As steepness increases beyond 50%, it becomes more likely that flow will form a jet, increasing the likelihood of accelerated bed scour downstream of the cascade weir. The 50% maximum slope helps ensure that flow will maintain contact with the face of the cascade weir and remain primarily horizontal so that boulders can resist flow.
Parabolic depth	2 feet or standard one-foot riffle weir parabolic depth (whichever is greater)	--	Set as minimum to improve constructability with large boulder material, and ensure structures are not overly shallow to prevent flanking.
Thickness	2 feet	4 feet	Based on a double slayer of boulders, each with minimum thickness of 12 inches and maximum thickness of 24 inches.
Key-in	2 feet	--	Based on project experience and size of typical boulder material.

Table C-3: Pools

Dimension	Minimum	Maximum	Basis of Design
Length	10 feet	1:1 ratio of riffle to pool	SPSC systems are pool dominant and when possible, should have a greater length of pool than length of riffle weirs. The minimum pool length is equal to the length of the preceding riffle weir. Pools downstream of cascade weirs shall have a minimum length of either the length of the preceding cascade weir or the length of a standard one-foot riffle weir, whichever is greater.
Slope		zero	SPSC pools are fully inundated by the downstream riffle or cascade weir resulting in a low flow water surface slope of zero percent.
Pool Depth	1 feet	3 feet	SPSCs can accommodate a variety of depths and the designer may incorporate variability to meet site specific goals. The one foot minimum ensures pools have adequate depth to promote storage and infiltration.
Side slopes	--	3H:1V	Selected to maximize side slope stability and promote a gradual transition of soil hydrology from wet to dry. Above the low-flow water surface elevation, the designer should tie-in to the existing grade at a stable slope. If tie-in slopes are steeper than 2H:1V above the low flow water surface, the designer should consider the use of boulder stabilization.

Table C-4: Pools

Dimension	Minimum	Maximum	Basis of Design
Run Slope	--	3H:1V	The County recommends that designers minimize run slope. The maximum allowable slope is 3H:1V, understanding that run slopes are often constrained by length and site-specific goals.
Glide Slope	--	3H:1V	If run slope is minimized, most glide slopes will be 3:1. When site conditions allow for a longer pool, the designer should consider shallower glide slope.

Table C-5: Filter Bed

Dimension	Minimum	Maximum	Basis of Design
Thickness	18 inches	--	When filling an existing channel, minimum dimensions are easily exceeded. A minimum depth of 18 inches below the surface of the SPSC ensures positive horizontal drainage will be maintained. The minimum is generally only applicable in limited sections of cut to ensure subsurface conditions are adequate to promote filtration.
Width	4 feet	--	When filling an existing channel, minimum dimensions are easily exceeded. A minimum width of 4 feet ensures a minimally adequate cross-sectional area will be available and unlikely to be contaminated during construction. The 4-foot width corresponds closely with standard excavator bucket width to promote constructability. The minimum is generally only applicable in limited sections of cut to ensure subsurface conditions are adequate to promote filtration.

Appendix D: Design Checklist

The checklist table provides the designer and reviewers a broad outline of the major design considerations and design steps in preparing minimum design elements of an SPSC system. The reviewer should be thoroughly familiar with SPSC design before conduction design review. Be aware that this checklist is not all-inclusive of all potential review items.

Table D-1: Design Checklist

SPSC Item		Check	Yes/No	Reviewer Comments
Design Narrative		Narrative has been provided outlining specific SPSC goals and constraints.		
Hydrology		Drainage area map provided showing watershed boundaries, landcover, Tc paths, and soils to the most downstream point of the SPSC system.		
		TR55/TR20 model (or approved equivalent) provided with summary of ultimate condition peak discharges.		
		For SPSCs providing stormwater management and/or water quality treatment: Provide summary of storage requirements.		
Hydraulic section design		AACO SPSC Spreadsheet completed for all riffle and cascade weirs. If alternate means to size structures were used, explanation/documentation provided.		
		Do the proposed sections provide adequate conveyance of the design storm over the riffle and cascade weirs?		
		Do the proposed sections meet requirements for maximum allowable velocity and stone size?		
		Provided footer depth calculation for cascade weirs.		
Riffle weirs		Are all riffle weirs a minimum length of 10 feet?		

SPSC Item		Check	Yes/No	Reviewer Comments
		Do all riffle weirs have a minimum top width of 10 feet?		
		Is the proposed D_{50} appropriate for the design flow?		
		Do all riffle weirs meet or exceed a width depth ratio of 10?		
		Is the minimum riffle mix thickness 18 inches or $2xD_{50}$ when D_{50}>9 inches?		
Cascade weirs		Are all cascade weirs no steeper than 50 percent slope?		
		Do all cascade weirs have a minimum top width of 10 feet?		
		Do all cascade weirs have a maximum height of 6 feet?		
		Do all cascade weirs have a minimum parabolic depth of 2.0 feet?		
		Is footer stone depth the greater of: 2 feet below the receiving pool bottom or one foot below the max scour depth?		
Pools		Do the side slopes for the pool (From all unarmored segments) exceed 3H:1V?		
Typical sections		Have typical sections and details been provided for the weirs and pools where needed to accurately represent construction on the plan and profile?		
Alignment and profile		Does the alignment follow the natural drainage path and efforts are made to avoid impacts to natural and/or sensitive resources?		
		Has justification been provided documenting the SPSC extends to a stable base-level control point?		
		Does the proposed profile generally conform to the existing landscape?		

SPSC Item		Check	Yes/No	Reviewer Comments
		Is the typical ratio of riffle to pool less than or equal to one?		
		Are riffle and cascade weirs placed along straight segments of the alignment?		
		Are run slopes a maximum steepness of 2H:1V and glide slopes a maximum steepness of 3H:1V?		
		For projects seeking subsurface water quality credit, is proposed credit limited to segments that are 5 percent slope or less?		
		Have pool segments been placed with a flat low flow water surface slope?		
		Is the depth of pool following weirs between 1 and 3 feet?		
		Are there sections of the design that do not conform to the guidance in this document? If so, has justification been provided?		
		Have the limits of the sand/woodchip filter bed been defined?		
		Does the sand/woodchip filter bed maintain a minimum depth of 18 inches and a minimum width of 4 feet along the project centerline?		
Plan view		Has proposed grading been provided, and are minimum/maximum dimensioning requirements met?		
		Has the 100-year water surface boundary been delineated on the plan?		
		Is the 100-year water surface elevation sufficiently contained within allowable property and easements and is below all habitable structures?		

SPSC Item		Check	Yes/No	Reviewer Comments
Erosion and sediment Control		Has an erosion and sediment control plan approvable by AASCD been provided?		
		For sites with upstream development, have all upstream flows been treated by approved E&S devices prior to entering the SPSC?		
Planting		Does the plan include a permanent stabilization and vegetation/landscaping plan and schedule?		
		Has the designer specified native planting appropriate for this site, with suitable diversity and density?		
		Does the planting plan appropriately consider soil and wet conditions throughout the site?		
Maintenance		Has a maintenance plan and agreement been provided for the SPSC project?		
Monitoring plan		Has a monitoring/maintenance plan been developed for County-owned systems as prescribed in this guidance? Is the plan clearly shown on the plan sheet?		

Appendix E: Abbreviated List of Native Plants and Plant Communities

Step Pool Storm Conveyances are designed with the intention that they will mimic natural processes. Vegetation plays an important role in these processes. It is highly encouraged on all projects and required on those in Anne Arundel County to use native vegetation appropriate for the conditions of the site.

The following is a sample, abbreviated list of native plants that may be used on SPSC structures within the airport zone. The list has been cross-checked for consistency with the Maryland Aviation Administration (MAA) approved plant list. This list may be subject to expansion to accommodate other native plant species and future updates to the MAA guidelines. It is the responsibility of the designer to check and propose native plant species that are consistent with MAA regulations for projects within the airport zone.

Table E-1: Abbreviated MAA Plant List

Common Name	Scientific Name	Comments
Holly species	*Ilex spp.*	(Male Only)
Sweetbay Magnolia	*Magnolia virginiana*	
American Sycamore	*Plantanus occidentalis*	
American Hophornbeam	*Ostrya virginiana*	
Sourwood	*Oxydendrum arboreum*	
Black Willow	*Salix nigra*	
Red Maple	*Acer rubrum*	
River Birch	*Betula nigra*	
Eastern Redbud	*Cercis canadensis*	
Shortleaf Pine	*Pinus echinata*	
Virginia Pine	*Pinus virginiana*	
Northern Bayberry	*Morella pensylvanica*	
Spicebush	*Lindera benzoin*	(Male Only)
Virginia Sweetspire	*Itea virginica*	
Summersweet	*Clethra alnifolia*	
Blue Flag Iris	*Iris versicolor*	
Christmas Ferns	*Polystichum acrostichoides*	
Cinnamon Fern	*Osmunda cinnamomea*	
Little Bluestem	*Schizachyrium scoparium*	
Tussock Sedge	*Carex stricta*	
Joe-Pye Weed	*Eupatorium maculatum*	

The current full MAA approved list can be accessed at:

https://marylandaviation.com/wp-content/uploads/2020/07/MAA-Approved-Plantings-List.pdf

An outline of the most common natural plant community assemblages found in Anne Arundel County that are likely to occur in the physical environments of SCPC projects are provide below.

These natural plant communities follow the community classification system described by J. Harrison in “The Natural Communities of Maryland” (Harrison, 2016). The National Vegetation Classification code and attendant key indicator species are also provided. For additional community classification information and a more extensive community description, the designer should consult The Natural Communities of Maryland (Harrison, 2016) and the NatureServe Explorer website (NatureServe, 2022).

Table E-2: Common Natural Plant Community Assemblages in Anne Arundel County

Community Type	**Northern Coastal Plain Mesic Mixed Hardwood Forest**
Classification Code	**CEGL006075**

Key Indicator Species

Common Name	***Scientific Name***
American Beech	*Fagus grandifolia*
White Oak	*Quercus alba*
Northern Red Oak	*Quercus rubra*
Tulip Poplar	*Liriodendron tulipifera*
American Holly	*Ilex opaca*
American Hornbeam	*Carpinus caroliniana*
Pawpaw	*Asimina triloba*
Mapleleaf Viburnum	*Vaccinium acerfolium*
Christmas Fern	*Polystichum acrostichoides*

Community Type	**Northeastern Coastal Plain-Piedmont-Oak-Beech / Heath Forest**
Classification Code	**CEGL006919**

Key Indicator Species

Common Name	***Scientific Name***
American Beech	*Fagus grandifolia*
Chestnut Oak	*Quercus montana*
Black Oak	*Quercus velutina*
White Oak	*Quercus alba*
Pignut Hickory	*Carya glabra*
Mockernut Hickory	*Carya tomentosa*
American Holly	*Ilex opaca*
Sassafras	*Sassafras albidum*
Mountain Laurel	*Kalmia latifolia*
Common Serviceberry	*Amelanchier arborea*
Black Huckleberry	*Gaylussacia baccata*

Community Type	**Inland Dune Ridge Forest**
Classification Code	**CEGL006354**

Key Indicator Species

Common Name	***Scientific Name***
American Beech	*Fagus grandifolia*
Chestnut Oak	*Quercus montana*
Black Oak	*Quercus velutina*
White Oak	*Quercus alba*
Pignut Hickory	*Carya glabra*
Mockernut Hickory	*Carya tomentosa*
American Holly	*Ilex opaca*
Sassafras	*Sassafras albidum*
Mountain Laurel	*Kalmia latifolia*
Common Serviceberry	*Amelanchier arborea*
Black Huckleberry	*Gaylussacia baccata*

Community Type	**Coastal Plain Streamside Forest**
Classification Code	**CEGL006603**

Key Indicator Species

Common Name	***Scientific Name***
American Sycamore	*Platanus occidentalis*
American Sweetgum	*Liquidambar styraciflua*
Swamp Chestnut Oak	*Quercus michauxii*
Willow Oak	*Quercus phellos*
Tulip Poplar	*Liriodendron tulipifera*
Red Maple	*Acer rubrum*
American Hornbeam	*Carpinus caroliniana*
River Birch	*Betula nigra*
Pawpaw	*Asimina triloba*
Northern Spicebush	*Lindera benzoin*
Smallspike False Nettle	*Boehmeria cylindrica*
Jack-in-the-Pulpit	*Arisaema triphyllum*

Community Type	**Coastal Plain Atlantic White Cedar - Red Maple Swamp Forest**
Classification Code	**CEGL006078**

Key Indicator Species

Common Name	***Scientific Name***
Atlantic White Cedar	*Chamaecyparis thyoides*
Red Maple	*Acer rubrum*
Sweetbay Magnolia	*Magnolia virginiana*
Swamp tupelo	*Nyssa biflora*
Blackgum	*Nyssa sylvatica*
Pumpkin Ash	*Fraxinus profunda*
Inkberry	*Ilex glabra*
Swamp Bay	*Persea palustris*
Blue Huckleberry	*Gaylussacia frondosa*
Sweet Pepperbush	*Clethra alnifolia*
Swamp Azalea	*Rhododendron viscosum*
Cinnamon Fern	*Osmunda cinamomea*
Virginia Chain Fern	*Woodwardia virginica*

Appendix F
SPSC Riffle Sizing Spreadsheet
(Based on Anne Arundel County SPSC Guidelines, 2022)

Designer must select/input
Calculated value/Designer shall not change
Default values provided. Advanced designer may change to customize to site specific design

Riffle Weir Sizing			
	Q_{100}	Q_{10}	Q_2
Design Flow (cfs)	0.0	0.0	0.0
Width (ft)	10.0	10.0	10.0
L, Length (ft)	10.0	10.0	10.0
H, Height (ft)	1.0	1.0	1.0
Design Depth of flow (ft)	1.00	1.00	1.00
D50 (in)	6	6	6
P_D, Parabolic Depth (ft)	1.00	1.00	1.00
Width Depth Ratio (W/P_D)	10.0	10.0	10.0
Manning's n Value	0.049	0.049	0.049
Slope (ft/ft)	10.00%	10.00%	10.00%
Rock Unit Weight (lbs/cf)	165.0	165.0	165.0
Top Width at Depth	10.0	10.0	10.0
Flow area (sf)	6.7	6.7	6.7
Hydraulic Radius	0.65	0.65	0.65
Froude	1.28	1.28	1.28
Isbash Maximum Velocity (ft/s)	6.26	6.26	6.26
Depth ("A") at TW/4 offset from centerline	0.75	0.75	0.75
Calculated Flow at Design Depth (cfs)	48.3	48.3	48.3
Calculated Velocity (ft/s)	7.24	7.24	7.24
Does the proposed section provide adequate conveyance?	YES	YES	YES
Is the proposed velocity less than the maximum allowable velocity?	NO	NO	NO

Maximum allowable riffle stone size for a given Q100	
Q100, cfs ≤	Max D50, inches
15	6
125	9
500	12
1500	18
2000	24

Riffle Sizing Guidance (refer to SPSC Guidelines for full details)

This section includes a step-by-step process for sizing a standard one-foot riffle weir (as defined in *Section 3.1.1 Riffle* Weirs). The 1-foot riffle height is the preferred typical riffle height.

1. Start with an initial riffle top width of 10 feet and riffle length of 10 feet. Set the width depth ratio to 10. To simplify sizing, the County recommends setting the design depth equal to the parabolic depth throughout this process. These initial values are the minimum riffle dimensions.
2. Compare the Q_{100} to the recommended riffle mix table (Table 1). Select the corresponding riffle mix D_{50}.
3. Review the results:
    a. If the channel exceeds required capacity, reduce the design depth below the parabolic depth until equal to the design flow/Q_{100}.
    b. If the channel does not have adequate flow capacity, proceed to Step 4.
    c. if the channel has adequate capacity, but velocity exceeds the maximum allowable velocity, proceed to Step 5.
    d. If the channel has adequate capacity, and velocity is within the allowable range, proceed to Step 6.
4. Increase the channel top width until the channel has adequate flow capacity.
    a. if the channel has adequate capacity, but velocity exceeds maximum allowable velocity, proceed to Step 5.
    b. If the channel has adequate capacity, and velocity is within the allowable range, proceed to Step 6.
5. If the channel exceeds the allowable velocity, increase the riffle length until velocity is in the allowable range. Typically, this creates a corresponding reduction in channel capacity requiring iterative calibration:
    a. If the channel does not have adequate flow capacity, return to Step 4.
    b. If the channel has adequate capacity, and velocity is within the allowable range, proceed to Step 6.
6. Check the channel performance against the 2- and 10-year discharge by altering the design depth and calibrating the calculated flow to Q_2 and Q_{10}. Note that for these events, the design depth will be less than the parabolic depth.
7. The designer may now make any modifications necessary to ensure the design is acceptable for the site specific 2-, 10- and 100-year goals.

The calculated dimensions are a valid riffle weir solution. The designer should evaluate the proposed dimensions against the site constraints. The designer may further refine and optimize the riffle height, parabolic depth, top width, and riffle length to match site constraints. The designer is encouraged to maintain standard one-foot riffle weir dimensions for all riffle weirs within a specified reach. As needed, the designer may size additional riffle weirs to conform to site conditions.

Appendix F
SPSC Cascade Sizing Spreadsheet
(Based on Anne Arundel County SPSC Guidelines, 2022)

Designer must select/input
Calculated value/Designer shall not change
Default values provided. Advanced designer may change to customize to site specific design

Cascade Weir Sizing			
	Q_{100}	Q_{10}	Q_2
Design Flow (cfs)	0.0	0.0	0.0
Width (ft)	10.0	10.0	10.0
L, Length (ft)	6.0	6.0	6.0
H, Height (ft)	3.0	3.0	3.0
Design Depth of flow (ft)	0.80	0.80	0.80
D50 (in)	30	30	30
P_D, Parabolic Depth (ft)	2.00	2.00	2.00
Manning's n Value	0.050	0.050	0.050
Slope (ft/ft)	50.00%	50.00%	50.00%
Rock Unit Weight (lbs/cf)	165.0	165.0	165.0
Top Width at Depth	6.3	6.3	6.3
Flow area (sf)	3.4	3.4	3.4
Hydraulic Radius	0.51	0.51	0.51
Froude	2.66	2.66	2.66
Isbash Maximum Velocity (ft/s)	13.99	13.99	13.99
Depth ("A") at TW/4 offset from centerline	1.50	1.50	1.50
Calculated Flow at Design Depth (cfs)	45.5	45.5	45.5
Calculated Velocity (ft/s)	13.5	13.5	13.5
Does the proposed section provide adequate conveyance?	YES	YES	YES
Is the proposed velocity less than the maximum allowable velocity?	YES	YES	YES
Does the proposed cascade have a slope of <= 0.5 ft/ft?	YES		

Scour Depth - pools downstream of cascades	
Q_{100}, cfs	0.0
Pool Max Depth, ft	1.5
H, Height of upstream grade control structure, ft	3.0
TW, Top width of the upstream grade control structure, ft	10.0
y, depth of Q_{100} in downstream/receiving structure	0
K, coefficient	1.32

p_d, Calculated scour depth, ft	0.0
Potential depth of scour below design pool bottom, ft	-1.5
Minimum footer boulder depth below pool bottom, ft	2.0

<u>Cascade Weir Sizing Guidance (refer to SPSC Guidelines for full details)</u>

1. The designer should choose initial design dimensions:
    a. Select a desired cascade height, H.
    b. Set top width equal to the standard one-foot riffle weir top-width (as calculated *in Section 3.5.2.1*).
    c. Set parabolic depth, P_D.
        i. Parabolic depth shall be a minimum of two feet.
        ii. If the calculated standard one-foot riffle weir parabolic depth is greater than two-feet, match cascade weir parabolic depth to the standard one-foot riffle weir parabolic depth.
    d. The initial cascade length should be set to the minimum length, based on the maximum allowable cascade slope (50 percent) for the selected structure height (e.g., if the designer chooses a H of 5.0 feet, the designer should start with a length of 10.0 feet).
    e. Set Manning's n value to 0.05.
    f. Set D_{50} to 30 inches (2.5 feet).
2. Calibrate the design depth of flow so that calculated flow equals the desired design flow (Q_{100}). Do not modify parabolic depth. Depth of flow will be lower than the section parabolic depth.
3. Review the results:
    a. If velocity is within the maximum allowable velocity, proceed to Step 4.
    b. If velocity is above the maximum allowable range, increase the length of structure until velocity is below the maximum allowable velocity. Return to Step 2.
4. Check the channel performance against the 2- and 10-year discharge by altering the design depth and calibrating to Q_2 and Q_{10}. The designer should make any modifications as necessary to ensure the design is acceptable for the site specific 2-, 10- and 100-year goals.

The calculated dimensions are a valid cascade weir solution. The designer should evaluate the proposed dimensions against the site constraints. The designer may further refine and optimize the top width, height, parabolic depth, and cascade length to meet the needs unique to their proposed site. The designer may proceed to size additional cascade weirs (of different dimensions) as necessary to complete the proposed design.