Design Guidelines for Step Pool Stormwater Conveyance (SPSC) Systems

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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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Table of Contents

List of Figures

List of Equations

List of Tables

"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.

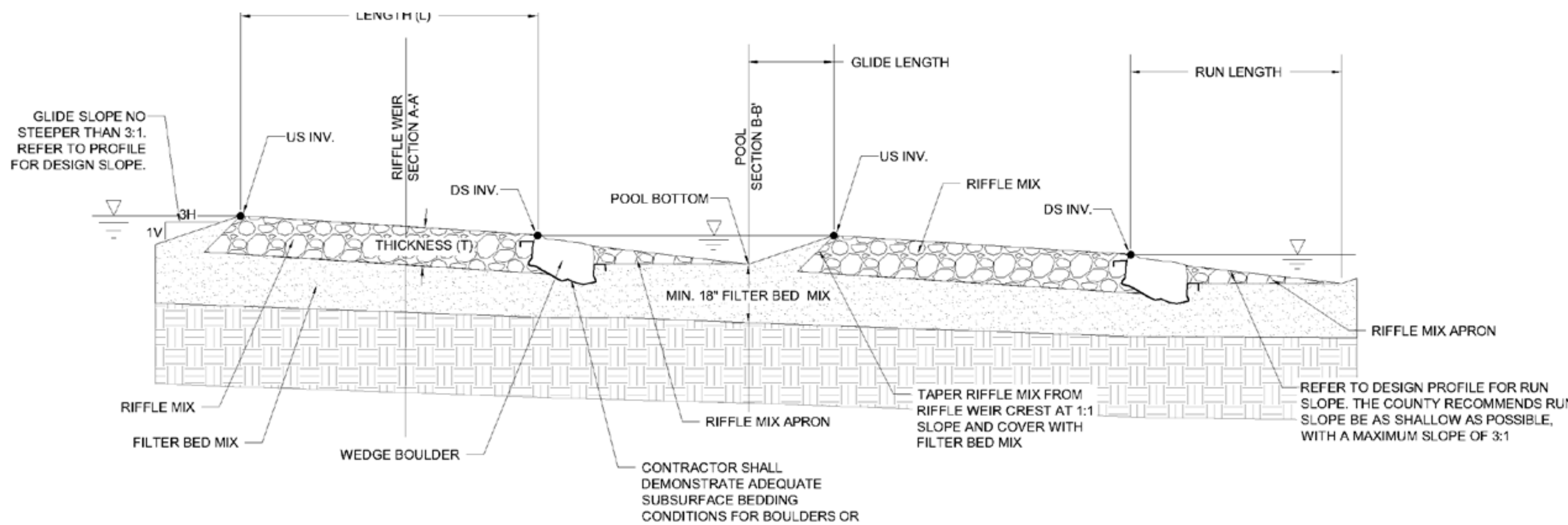

Figure 1: Typical SPSC profile with low flow water surface (riffle weir-pool-riffle weir sequence)

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

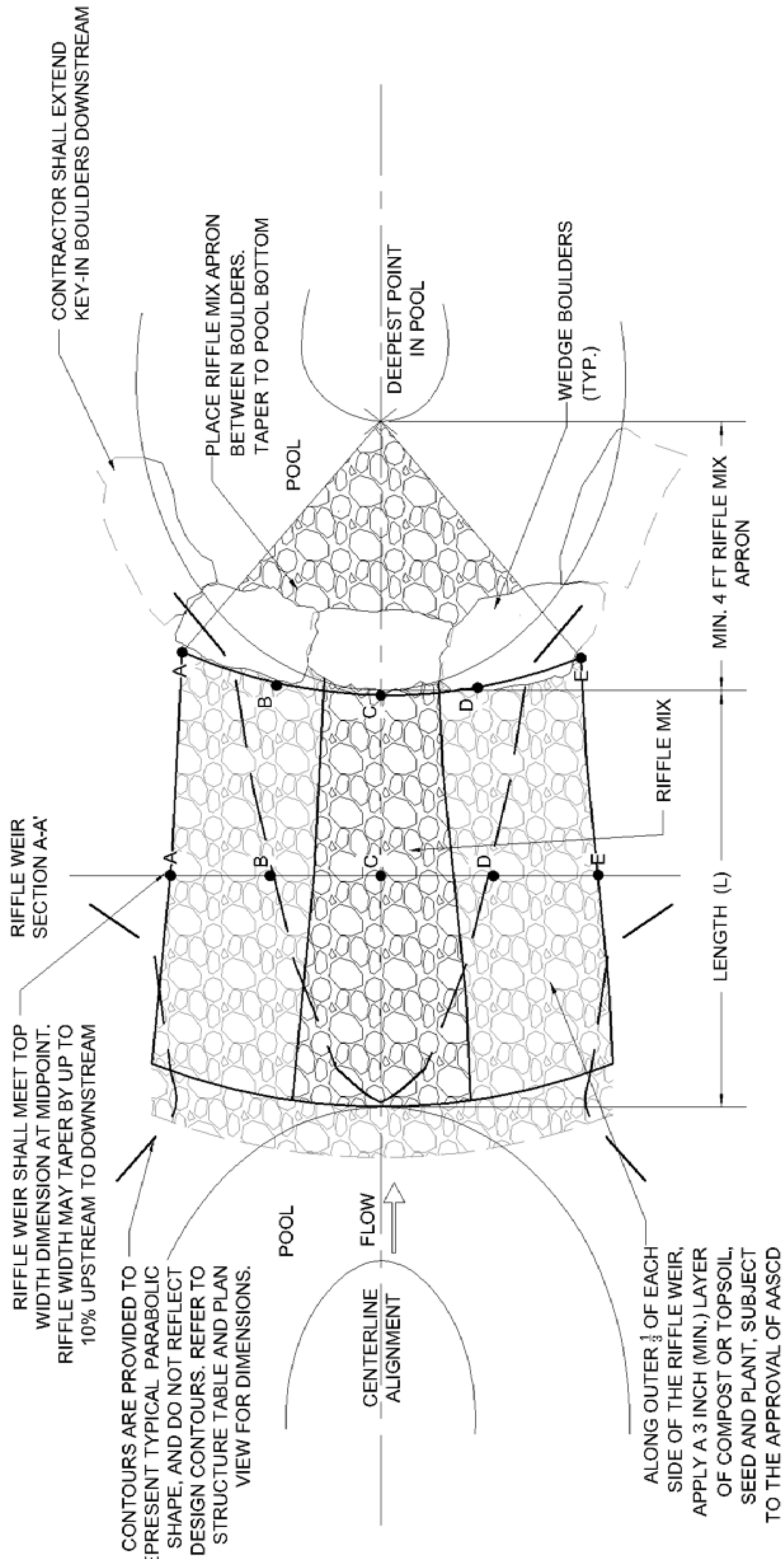

Figure 3: Schematic of a standard riffle weir in plan view

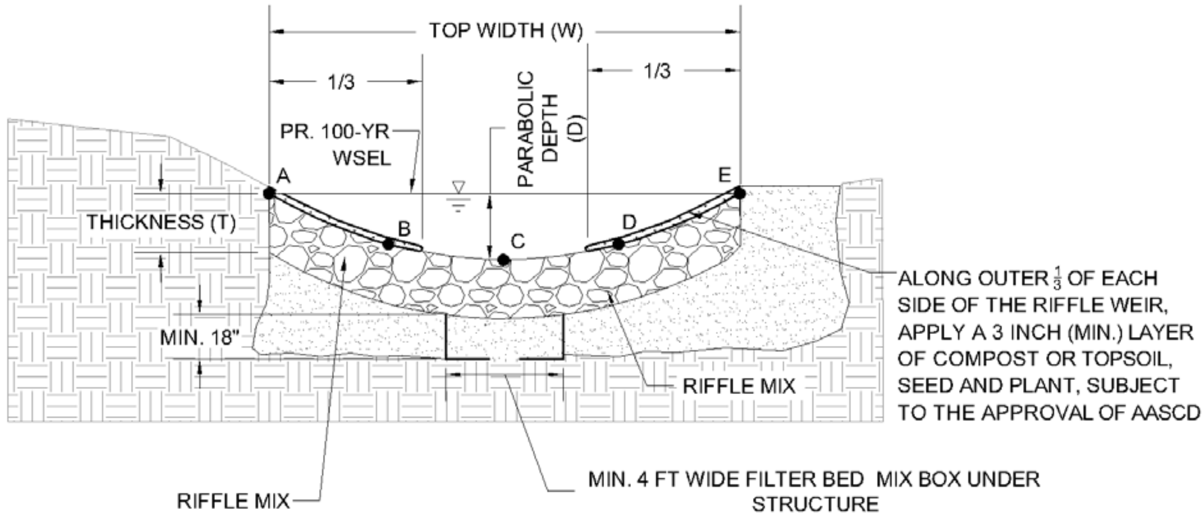

Figure 4: Schematic of a standard riffle weir in cross section (Section A-A' from Figure 10)

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)

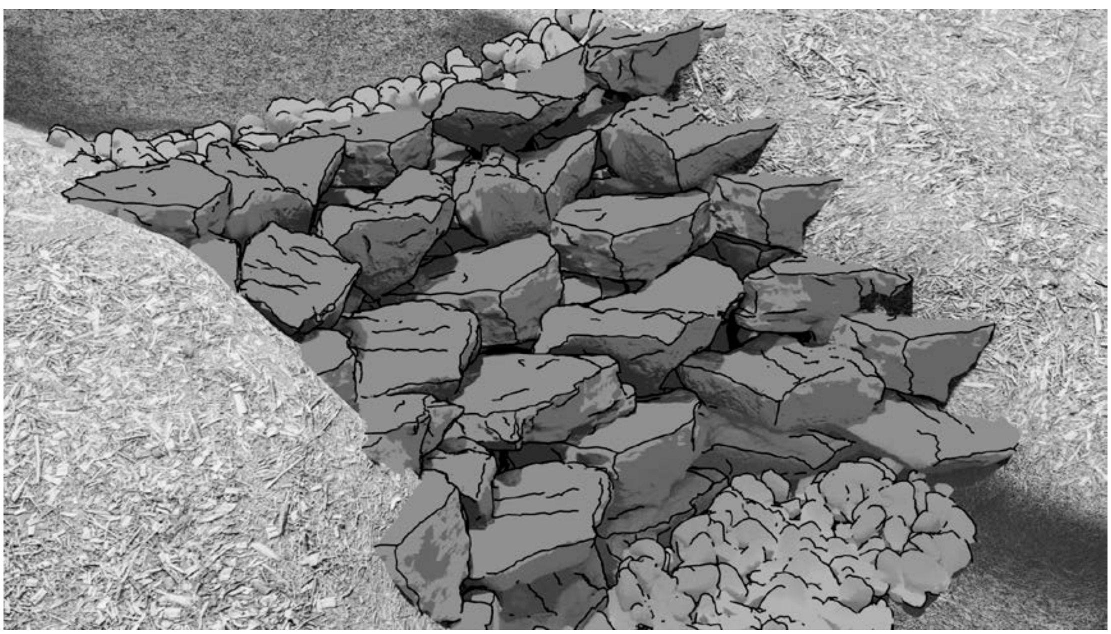

Figure 7: Isometric view of cascade weir (drawn by Phillip Capon)

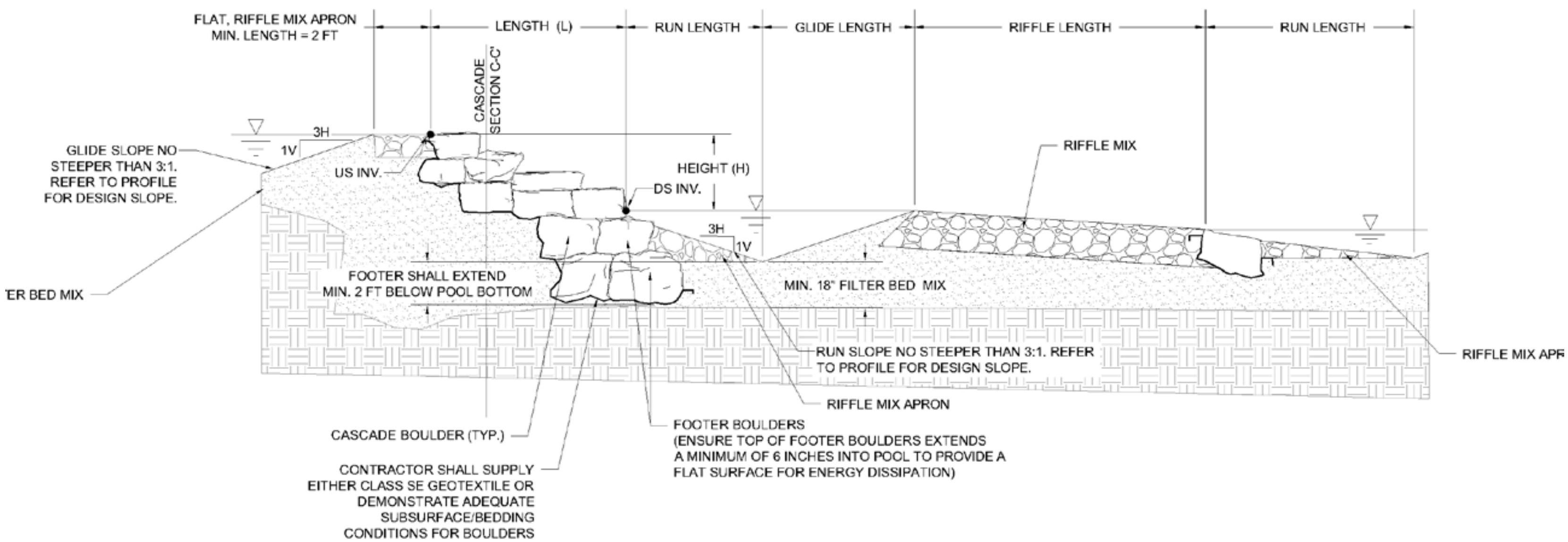

Figure 8: Schematic of cascade weir in profile view

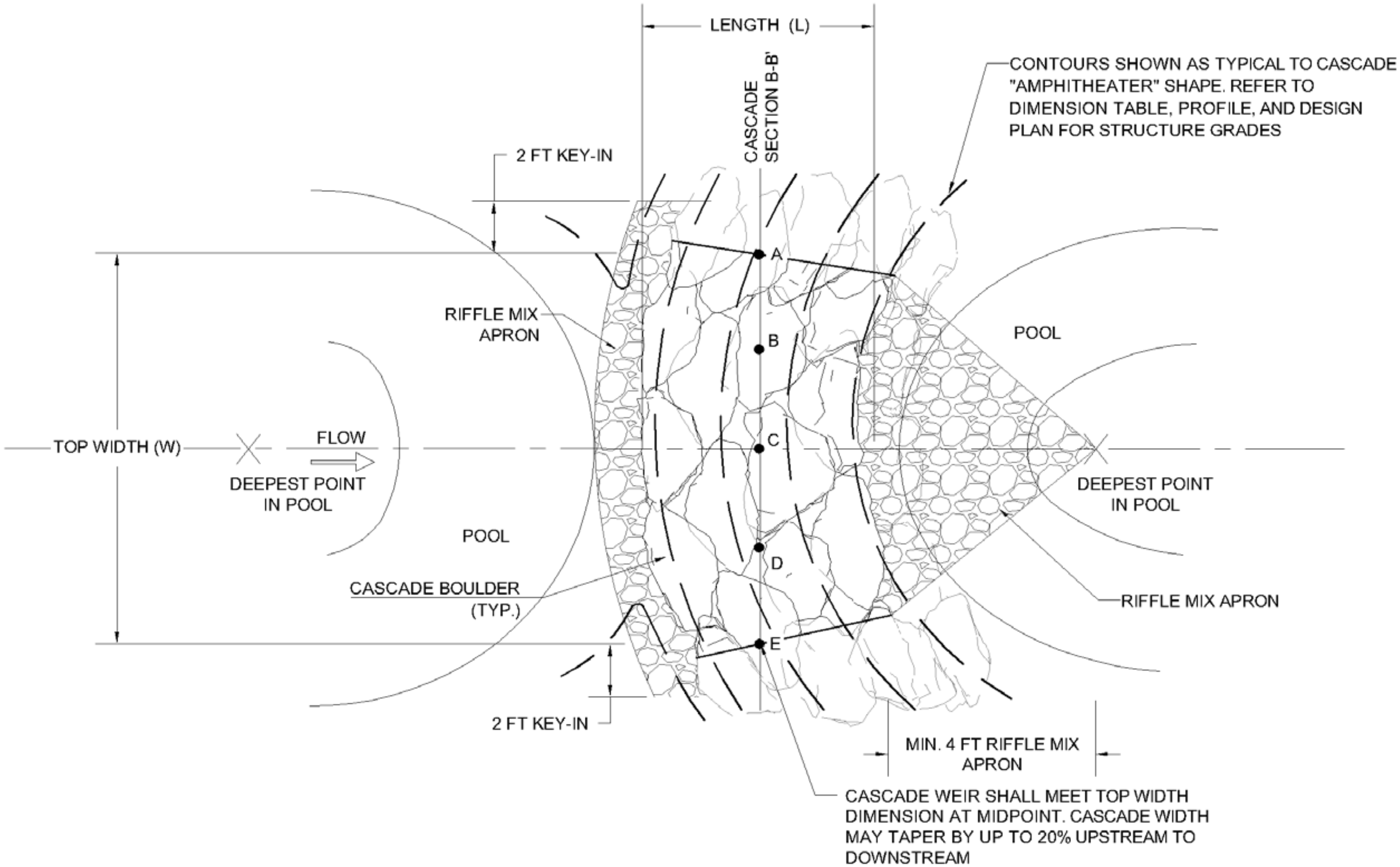

Figure 9: Schematic of cascade weir in plan view

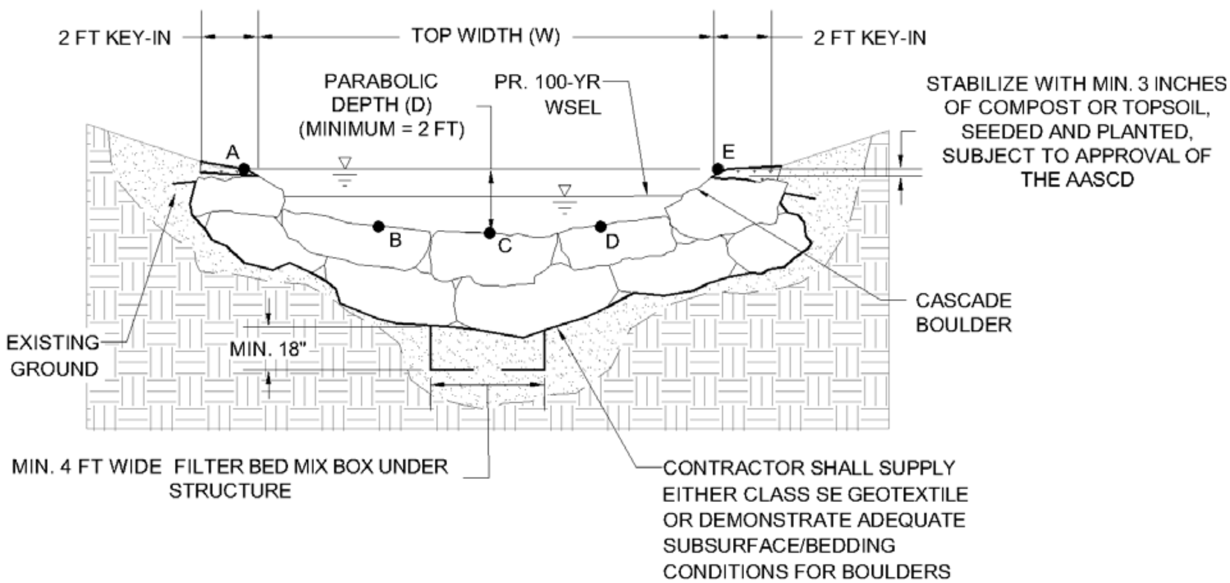

Figure 10: Schematic of cascade weir in cross-section (Section B-B')

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)

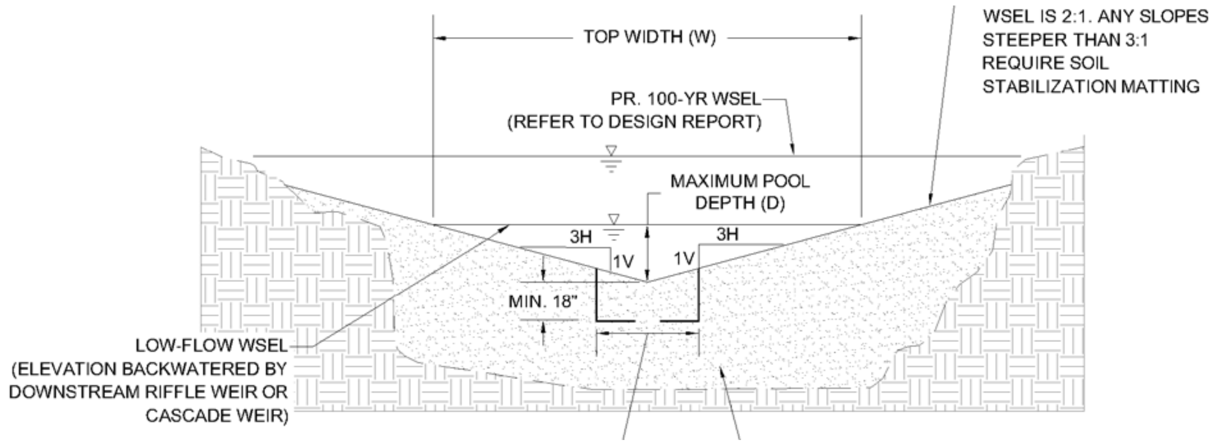

Figure 12: Schematic of pool cross-section at low-flow water surface

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.

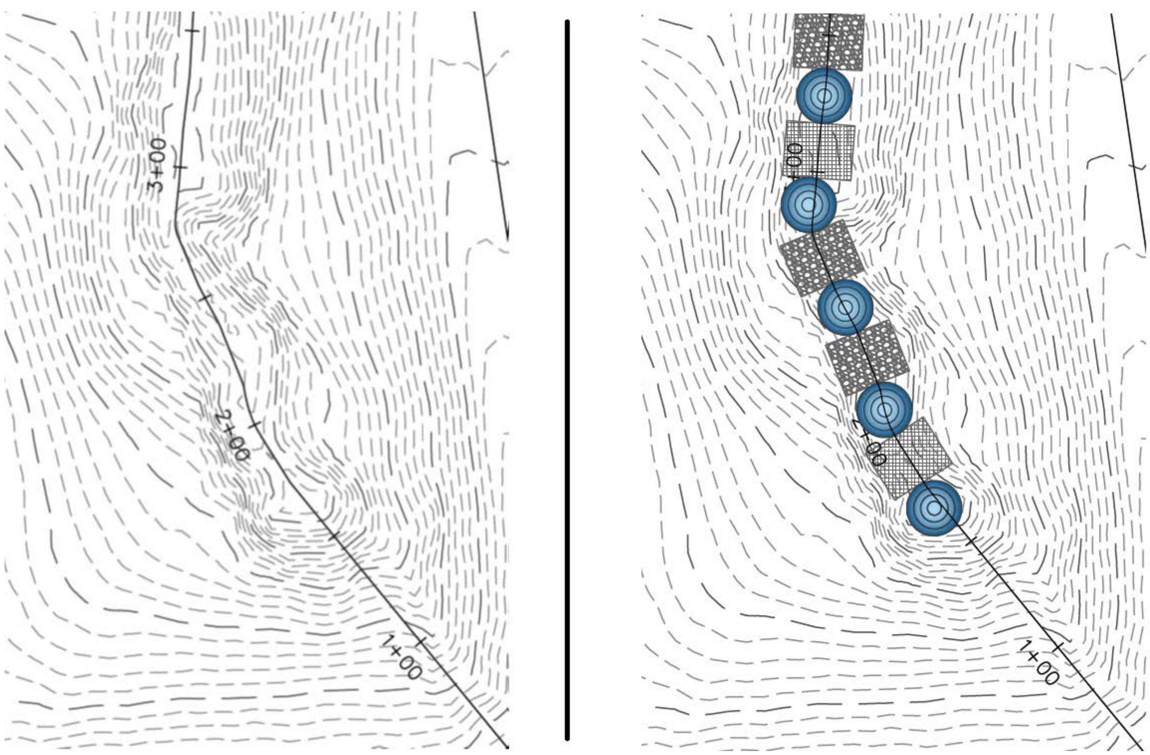

Figure 13: Mapping preliminary alignment

- 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)

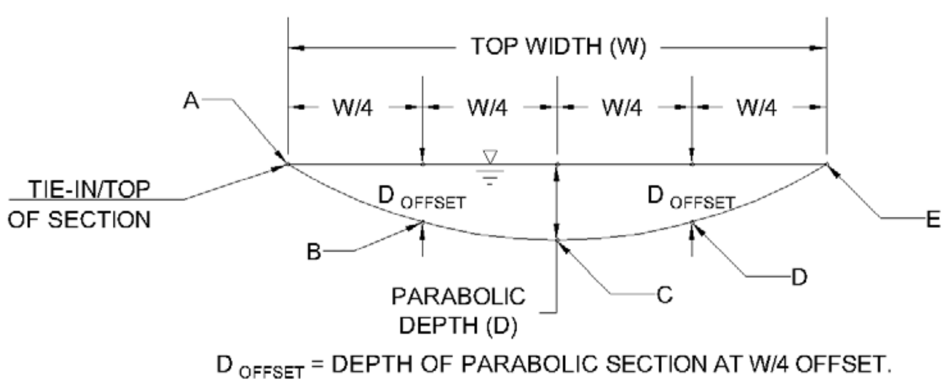

Figure 14: Parabolic section dimensions

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.

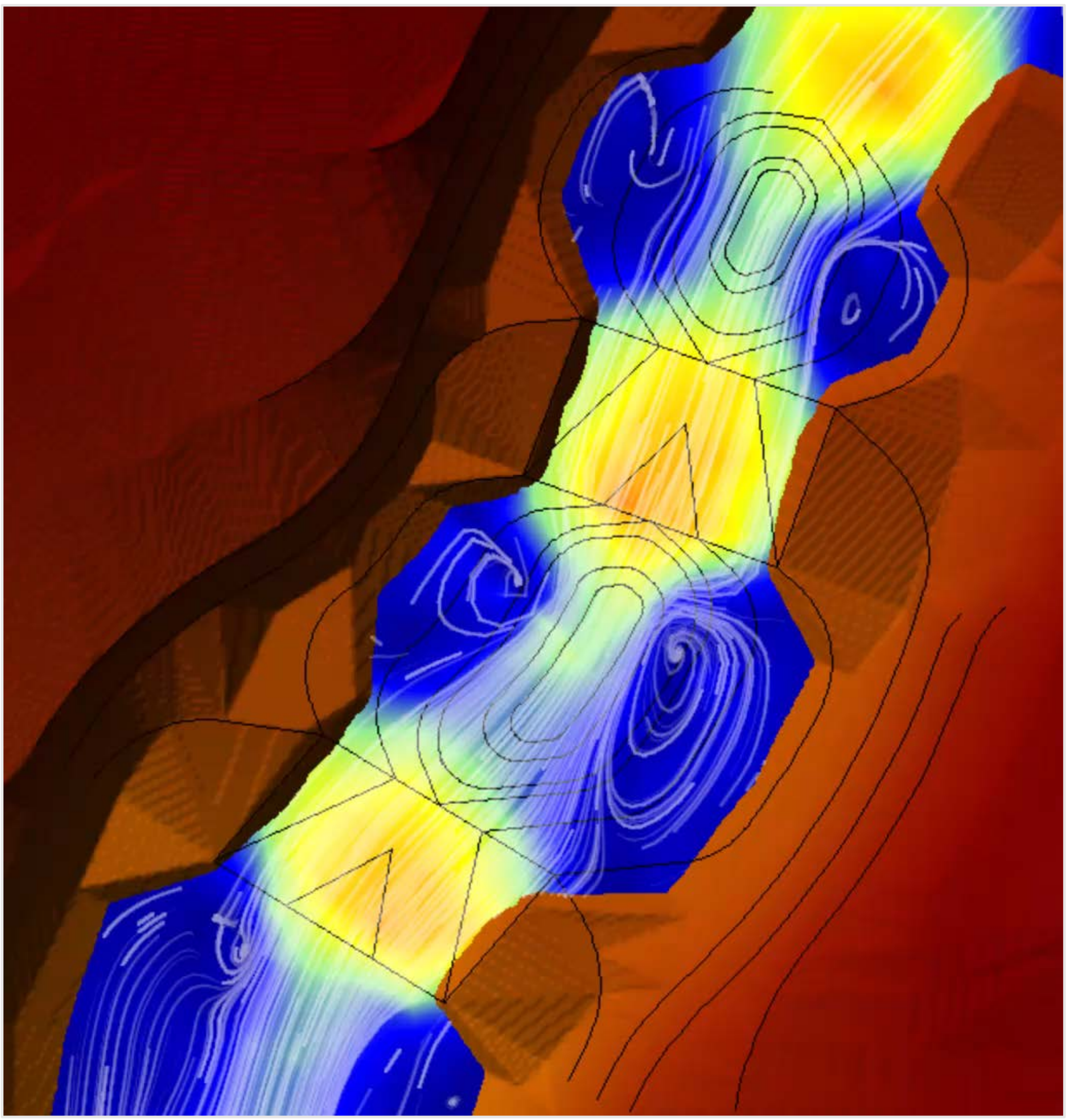

Figure 17: Sample 2-D hydraulic model visualization, showing velocity vectors

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/ft³*			

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.

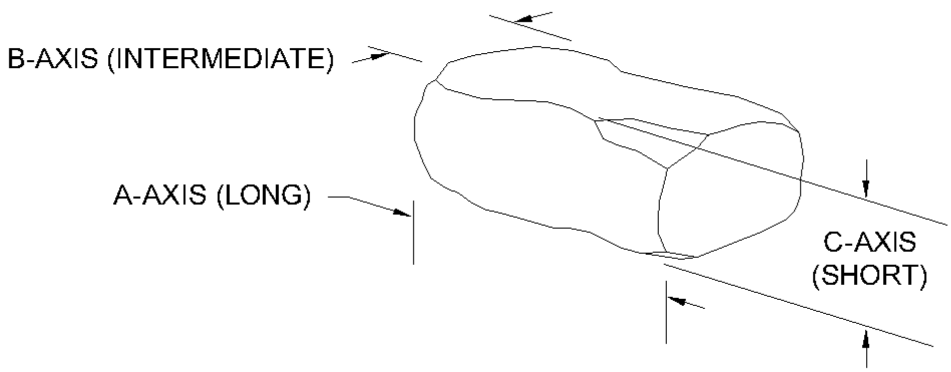

Figure 18: Typical tabular boulder

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. <u>Alternative Best Management Practices:</u> 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

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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, Keith Underwood, and Katie Scott, P.E.; 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*