Step Pool Storm Conveyance (SPSC) – aka Regenerative Storm Conveyance/Coastal Plain Outfalls (RSC/CPO)

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Important Note:

This document features design guidelines and procedural steps to aid design engineers in sizing a Step Pool Storm Conveyance (SPSC) system. It is the responsibility of the design engineer to check the feasibility and acceptability for using these systems at their project site. SPSC can be used in lieu of stormdrains as roadside conveyance systems, and in that case are considered non structural BMPs. SPSC, when used for peak flow management or steep slope stability treatment, are considered structural BMPs. SPSC may be used 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 Practical (MEP) and as dictated in the State of Maryland SWM manual. While SPSC systems can be implemented on steep slopes, in no circumstance can water quality credit be claimed for SPSC segments with a longitudinal profile slope that exceeds 5 percent. Additionally for storm conveyance segments that exceed 5 % in longitudinal slope, it is imperative that a registered geotechnical engineer be enlisted to check the proposed design and its adequacy for use as a steep slope treatment measure.

Introduction:

SPSC are open-channel conveyance structures that convert, through attenuation ponds and a sand seepage filter, surface storm flow to shallow groundwater flow. These systems safely convey, attenuate, and treat the quality of storm flow. These structures utilize a series of constructed shallow aquatic pools, riffle grade control, native vegetation, and an underlying sand/woodchip mix filter bed media. The physical characteristics of the SPSC channel are best characterized by the Rosgen A or B stream classification types, where “bedform occurs as a step/pool, cascading channel which often stores large amounts of sediment in the pools associated with debris dams” (Rosgen, 1996). The pretreatment, recharge, and water quality sizing criteria presented in these guidelines follow closely the State of Maryland’s criteria for a typical stormwater filtering device. These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles.

SPSC structures can be designed to provide energy dissipation and extreme flood conveyance/attenuation functions, as well as recharge and water quality treatment in excess of ESD. The inherent energy dissipation achieved in the step pool design is directly linked through hydraulic design computations to reduced stream power and bank shear stresses in the receiving streams, thus satisfying more directly and effectively the State of Maryland’s channel protection requirement and additional local requirements for flood attenuation. The reduced energy and velocity at the downstream end of these structures result in reduced channel erosion impacts commonly seen between conventional stormwater practice outfalls and ultimate receiving waters.

SPSC structures are generally best suited in natural ravines and are the preferred method of storm water conveyance throughout the water train. ESD techniques such as alternative pavement, greenroofs, rooftop disconnections, vegetated swales, etc., should be considered and utilized to the MEP in the upstream area of a proposed SPSC system.

A secondary benefit provided by the pools and plant material is to reduce flow velocity and enhance the removal of suspended particles and their associated nutrients and/or pollutants. Additionally, uptake of dissolved nutrients and adsorption of oils and greases by the plant material yield secondary water quality benefits above and beyond the benefits achieved through the primary water quality sand/woodchip mix filter.

The design material and plant list featured within this document has been adapted to the Anne Arundel County coastal plain environment. The materials used within the SPSC, to the extent possible, are taken from the coastal plain. The sand media is quarried throughout the region and can be readily obtained. The boulders found in these systems are sandstone (e.g., bog iron, iron stone, ferracrete). Sandstone's 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 these systems. While sandstone is the preferred material for use as boulders within these systems, granite may be substituted if sandstone availability is demonstrated to be of a concern. The use of other alternative boulder material must be approved by the Anne Arundel County reviewer and/or project manager. Under no circumstance is limestone or concrete permitted in the construction of SPSC systems.

Construction specifications for the SPSC can be found in the Anne Arundel County Design Manual, Standard Specifications and Details for Construction document.

General Design Situations

SPSC structures consist of an open channel conveyance with alternating riffles and pools. These systems are best suited for ditches, outfalls, ephemeral and intermittent channels with longitudinal profile slopes that are less than 10%. However, the design can be easily adapted for sites where the slope exceeds 10 percent. For these sites, the size and quantity of the cobbles and rows of boulders inherent in the design computations are increased to mitigate for the stability issues associated with steep slopes. It is noted that the utilization of two or more rows of boulders typically will result in a water cascade. In extreme slope situations (>50%), the designer may elect to use impricated riprap, gabion baskets, retaining walls, drop stormdrain structures or other structural/geotechnical slope treatment methods to safely traverse the grade.

In order to preserve the integrity and habitat functions of non-tidal wetlands and streams, the designer is encouraged to minimize to the extent possible changes to the drainage pattern. This is achieved by placing proposed SPSC systems within the site following the native drainage paths. While this may result in temporary construction impacts, in the long run it will preserve the hydraulic input which is crucial to the survivability of habitat functions within non tidal streams and wetlands. It should be noted though that the computations presented in this document do not address water budget or sediment transport/competency issues that are generally encountered in perennial streams and wetlands. Due to this, it is imperative that designers additionally check these issues for SPSC systems proposed within perennial streams and/or wetlands.

"The current condition of single gravel-bedded channels with high, fine grained banks and relatively dry valley-flat surfaces disconnected from groundwater is in stark contrast to the pre-settlement condition of swampy meadows (shrub-scrub) and shallow anabranching streams." (Walter, R., & Merritts, D. 2008). Current stormwater management regulations require that proposed development plans include appropriate mitigation measures and be contingent on the presence of a stable outfall. According to the Anne Arundel County Watershed Master Plans, problem area inventories such as erosion, buffer deficiencies, headcuts, infrastructure impacts, and suboptimal habitats are notable in varying degrees in more than 90 percent of the surveyed stream segments. For projects that drain to stream channels with active incisions, it is imperative that proper tie-in design be established between the SPSC system and the connecting downstream channel. This could be accomplished by installing an in-stream weir at the proper elevation to promote upstream flooplain connection and prevent headcut erosion from unraveling the proposed SPSC systems. An example design solution for tying the SPSC systems with downstream incised perennial channel is presented in this document. It is noted that each case should be evaluated carefully and that design engineers propose appropriate solutions based on the individual circumstance surrounding each case. Additionally, the designer engineer is responsible for notifying and obtaining all required approvals from the Local, State and Federal authorities.

It is important to acknowledge that each site has unique and defining features that require site-specific design and analysis. The guidance provided below is intended to provide the fundamentals for sizing the facility to meet the regulatory requirements but is not intended to substitute engineering judgment regarding the validity and feasibility associated with site-specific implementation. Designers need to 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 and stream restoration plantings with respect to developing appropriate planting plans and habitat improvement features.

Hydraulic Design of SPSC Systems

SPSC systems can be used to achieve a zero surface water discharge. This is accomplished by converting the 100-year surface discharge to subsurface flow/spring head seep. The design of the SPSC should be based on specific established restoration goals for the project. The sand/woodchip mix filter media is specifically required for retrofit projects with water quality restoration goals. The depth and quantity of the pool structures is linked to water quality, energy dissipation, and flow attenuation/peak management requirements. Additionally the SPSC design parameters maybe determined based on the specific needs to retrofit an existing eroded channel outfall for instance. The dimensions of the riffle and pool segments are designed in a manner to ensure adequate and safe conveyance of the design flow. The downstream tie-in to the receiving channel aims to correct existing downstream deficiency, such as incision and erosion, and promote long-term stable outfall conditions. This is a requirement for all proposed developments. The downstream tie-in design may result in additional water quality benefit for the contributory drainage area, however, this may not be claimed as water quality mitigation for new development related impacts, rather this benefit may be claimed for select redevelopment projects and will be evaluated by the Anne Arundel County Department of Public Works for consideration as credits toward the County's National Pollution Discharge Elimination System (NPDES) permit. The construction cost of these systems makes it imperative for the design engineer to carefully target the specific restoration goals prior to providing a design solution. The following steps have been formulated to aid the designer engineer in preparing the minimum design elements for the SPSC.

1. <u>Develop the hydrologic design parameters for the project</u>
    - The drainage area should be delineated to the outfall point of the SPSC and the connecting channel tie-in location if applicable. In new development projects, ESD shall be used to the MEP such as to minimize alterations to the existing drainage patterns for the site.
    - Using TR55, determine the flow path, time of concentration, and weighted runoff curve numbers for all points of investigations and required landuse scenarios.
    - Using TR20, determine the 1, 10, and 100 year peak discharges for all points of investigations and required landuse scenarios.
    - Include pertinent hydrology parameters and results pertaining to all points of investigations and required landuse scenarios on the construction plans.

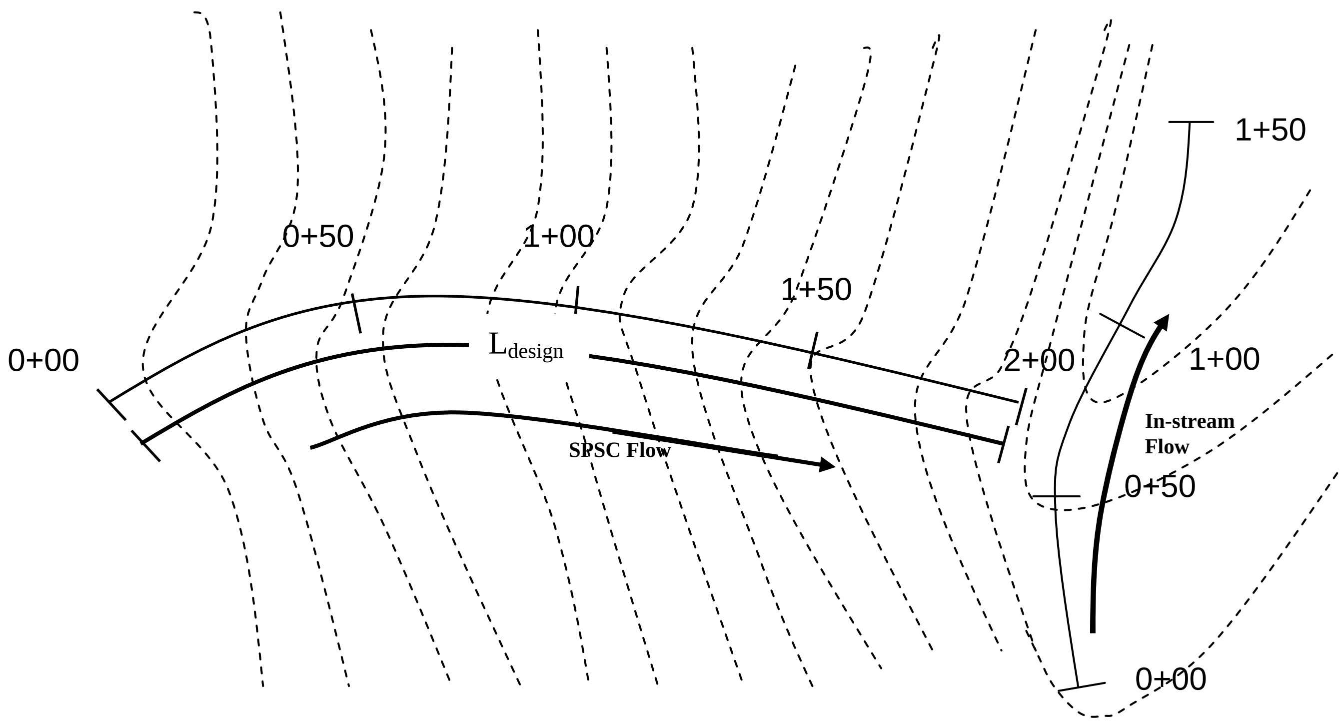
2. <u>Establish and quantify the restoration goals for the project</u>
    - Establish the goals for the SPSC. The goals may include, but are not limited, to the following:

        □ Providing safe open channel surface conveyance in lieu of stormdrains.
        □ Providing structural water quality mitigation in excess of ESD to the MEP.
        □ Providing slope and outfall stabilization
        □ Subwatershed retrofit to meet specific NPDES and/or TMDL requirements.

    - Quantify the required pretreatment, recharge, and water quality volumes for the proposed development. The required volumes should be computed per the current Anne Arundel County's current stormwater management regulations.

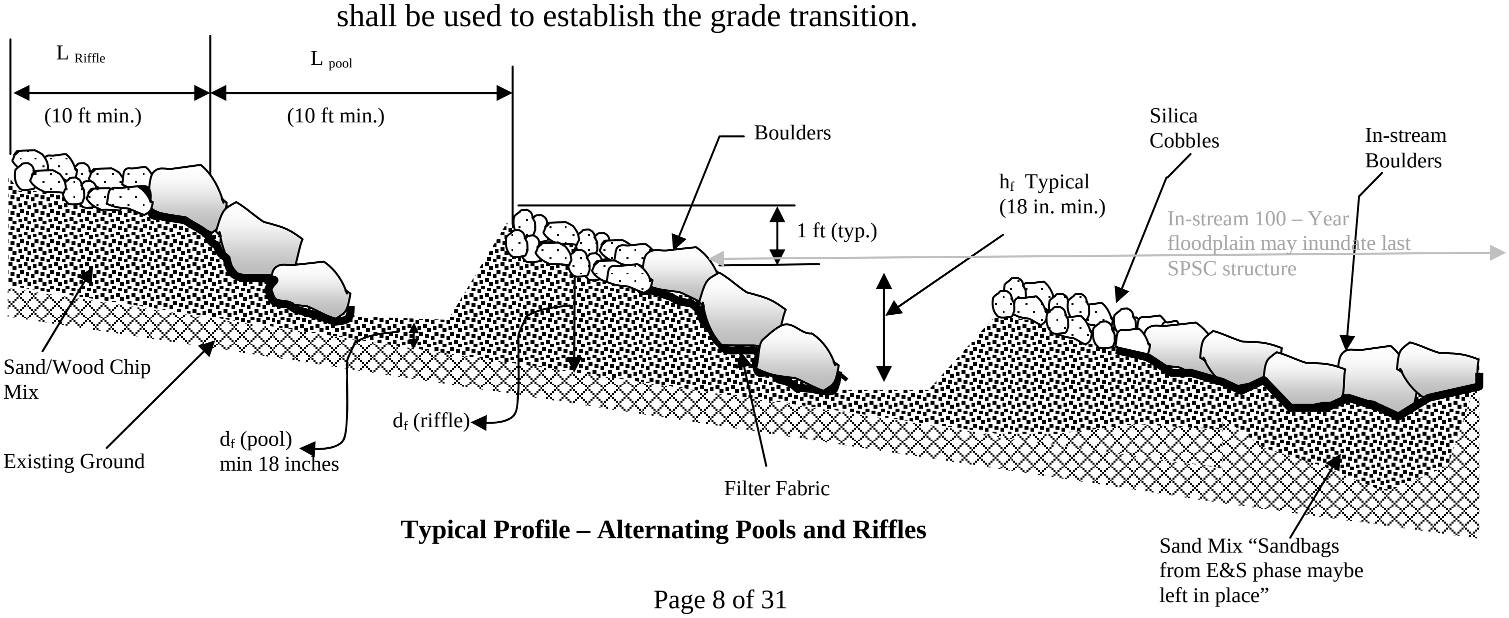
- The restoration goal for the project and the provided quantities of water quality treatment shall be listed on the construction plans.

3. Map the horizontal alignment for the project
   - Develop a geometric plan sheet showing the SPSC alignment with stations and tabulated coordinates. The SPSC will be placed in the landscape following a curvilinear flow path whenever possible that generally follows the shape of the ravine or localized drainage path.
   - Special attention should be followed to minimize impacts to natural features. This could be accomplished through innovative/adaptive construction phasing and tree protection plans.
   - Measure the length of the reach along the plan view alignment from its input to the discharge location. This length shall be described in the design formulas as L_{design}. The discharge location shall be at the receiving channel. In the event that the receiving channel is incised/disconnected from the floodplain, an in-stream weir amy be utilized to connect the receiving channel with the floodplain. A horizontal alignment shall be established for the in-stream work. Design guidelines for the in-stream weir tie-in are included in this document.

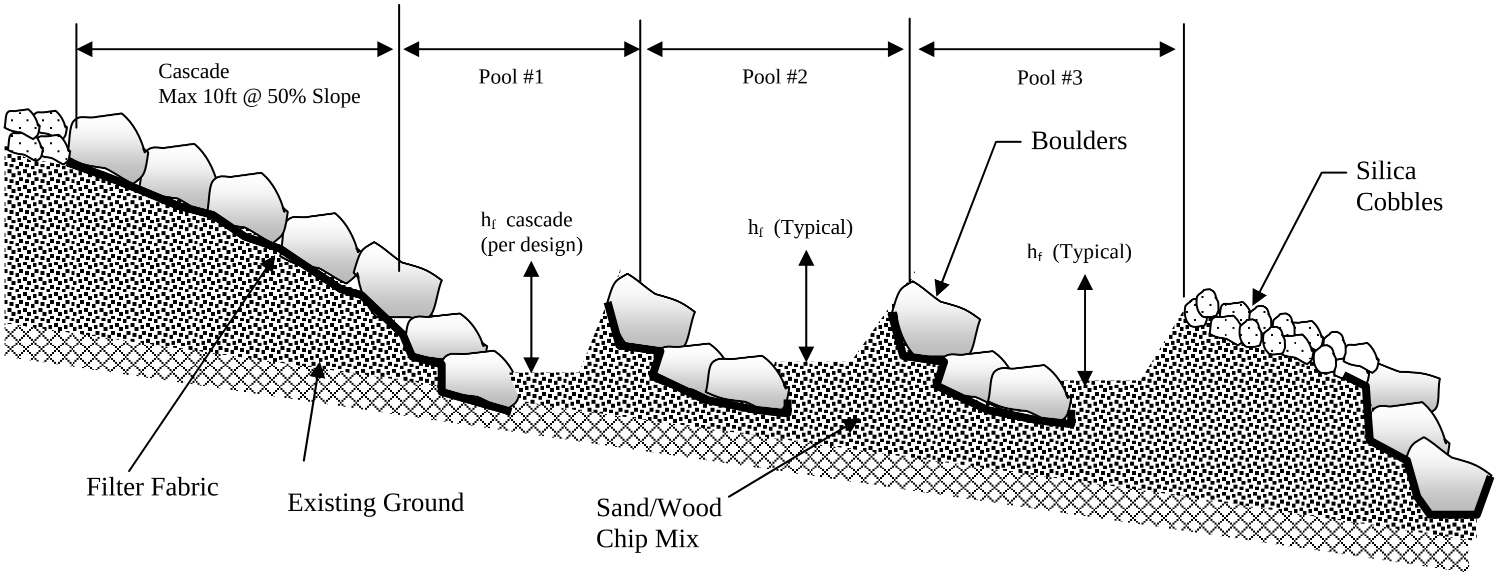


4. Map a preliminary vertical alignment for the project

- Measure the elevation difference "ΔE" between the top and the bottom of the proposed SPSC. In the event that the proposed SPSC connects to an incised downstream channel, the elevation of the floodplain terrace shall be used as the downstream elevation. An in-stream weir design with a top of weir elevation set at the floodplain terrace is required at the tie-in location.
- Compute the average outfall slope, S, by dividing ΔE by $L_{design.}$
- SPSC segments utilized for water quality shall not exceed 5% in longitudinal slope. If the overall slope exceeds 5%, estimate the length of boulder cascade to use for traversing the grade. Boulder cascades maybe placed at 2H:1V or 50% slope. A maximum 5 ft of vertical drop shall be permitted at any single cascade location. Multiple cascades maybe required along the length of the project to traverse steeper grades. The location of the cascade shall be selected to minimize site disturbances and environmental impacts.
- Assume that the length of the pools is equal to the length of the riffles at 10ft. The minimum length of pools and riffles shall not be less than 10 ft.
- Assume a fixed one foot drop along the length of the riffle.
- Assume a minimum 18 inch fixed pool depth.
- Assume no elevation drop along the length of the pool to allow for dead storage ponding and promote filtration/infiltration.
- Alternate pool and riffle channels using an even length distribution along the horizontal alignment. Three consecutive pools separated by cobble riffle grade control structures shall be used following a cascade.
- Using assumptions above, $\Delta E - \Delta E_{cascade}$ in feet will equal the number of riffle channels and associated pools.
- Boulders shall be used in-stream to transition the in-stream weir with the downstream bed elevation. A maximum 5% longitudinal profile slope shall be used to establish the grade transition.



Typical Profile – Alternating Pools and Riffles

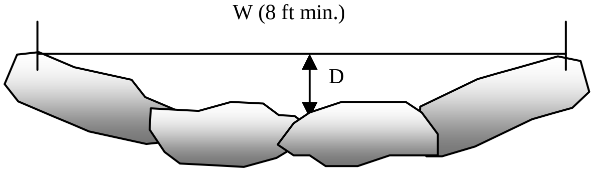


Cascade Profile – Three Pools following Cascade

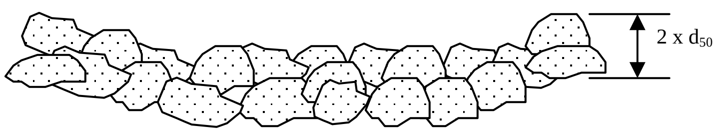
5. Design the typical cross-section for the riffle/cascade and pool channel segments
   - The riffle/cascade and pool channels shall be parabolic in shape.
   - Design the riffle/cascade and pool channels to carry the Q_{design} for the unmanaged 100-year storm flow in a parabolic shape. The area and hydraulic radius of a parabola are computed as follows:

$$Area = \frac{2WD}{3} \qquad \textit{Mathematical Solution}$$

$$Hydraulic \quad Radius = \frac{2W^2D}{3W^2 + 8D^2} \qquad \textit{Chow}, 1959$$



Riffle Section through Boulder



Riffle Section through Cobble

- The minimum freeboard for lined waterways or outlets shall be 0.25 ft above design high water in areas where erosion-resistant vegetation cannot be grown and maintained. No freeboard is required if vegetation can be grown and maintained. (USDA, 2006.)
- Select a trial constructed riffle channel width (W). The width is the dimension perpendicular to the flow.
- Select a trial constructed riffle channel depth (D). The Width/Depth ratio shall not be less than 2.
- The dead storage depth within the pool shall not be considered when checking for adequacy of conveyance
- Design using a trial cobble with a d_{50} of 6 inches. The density of the stone shall be specified. The depth of the cobble material is equal to 2 x d_{50} (MDSHA, Highway Drainage Manual, 1981). Boulders shall be used to line cascade segments.
- Calculate the Manning's n roughness coefficient based on the constructed depth, D, associated with the 100-year ultimate flow conditions and the cobble size:

$$n = D^{1/6} / (21.6 \log (D/d50)+14), \qquad \text{(USDA, 2006).}$$

Where:

n = Manning's n, use 0.05 for cascades.
D = depth of water in the riffle channel associated with unmanaged 100-year Q_{design}, ft.,
d_{50} = cobble size, ft

- Use the Manning formula to calculate the flow and velocity associated with the trial parameters D, W, and d_{50}. The design flow shall meet or exceed the 100-year ultimate flow conditions.

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

Where:

Q = 100 year ultimate flow (cfs)
1.49 = conversion factor
n = Manning's n, determined by USDA, 2006 equation
A = cross-section area of a riffle channel, which for a parabola = 2/3(W)(D), where W is top constructed width (ft) and D is the constructed depth (ft)
R_h = hydraulic radius (ft), calculated using Chow 1959 relationship for parabolas
S = average slope over entire length of project (ft/ft)
V = velocity in the riffle channel (ft/sec), V = Q/A

- Using small incremental depths (0.1 ft), develop a hydraulic rating curve/table for the channel to ensure that subcritical flow conditions prevail to the greatest extent possible. This is achieved by calculating the Froude Number, Fr. A Froude number exceeding 1 indicates that the flow is supercritical. A Froude number of less than 1 indicates that the flow is subcritical in nature. The Isbash coefficient for high turbulence should be used when sizing the cobble stones to accommodate supercritical conditions. Increasing the cobble size or the width depth ratio of the riffle channel can increase roughness and reduce velocity. This can further assist in meeting subcritical flow conditions. Refer to the design example at the end of this document for an example of a hydraulic rating curve table.

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

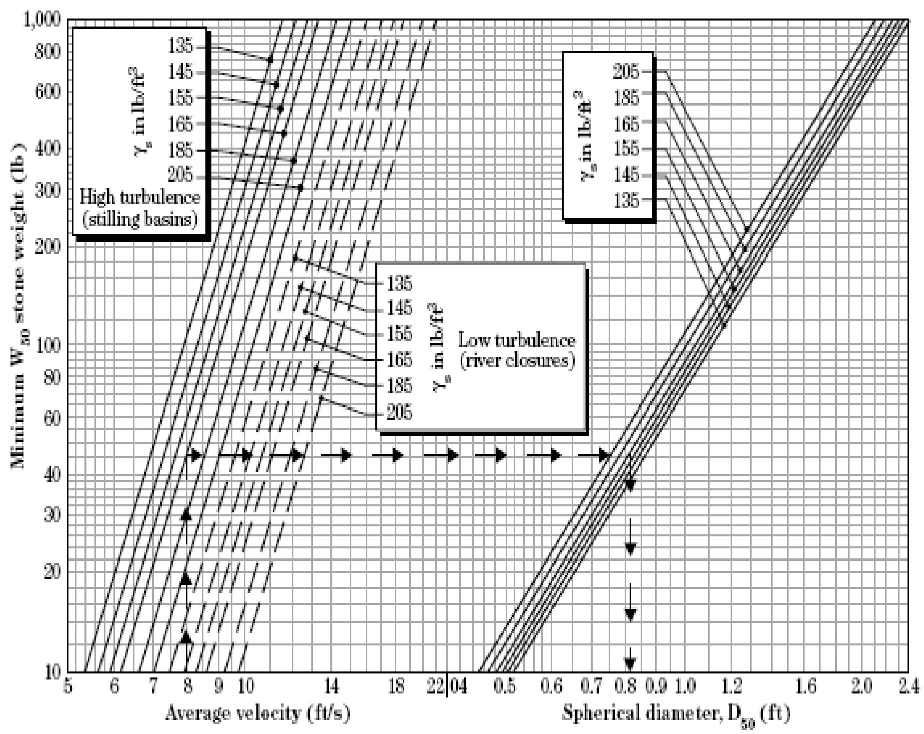
- The design velocity shall be checked to ensure that it is below the maximum allowable velocity estimated from the Isbash formula below (NRCS, 2007). A graphical solution of the Isbash formula is also shown. This will be an iterative design process. Spreadsheets can be used to streamline the calculations.

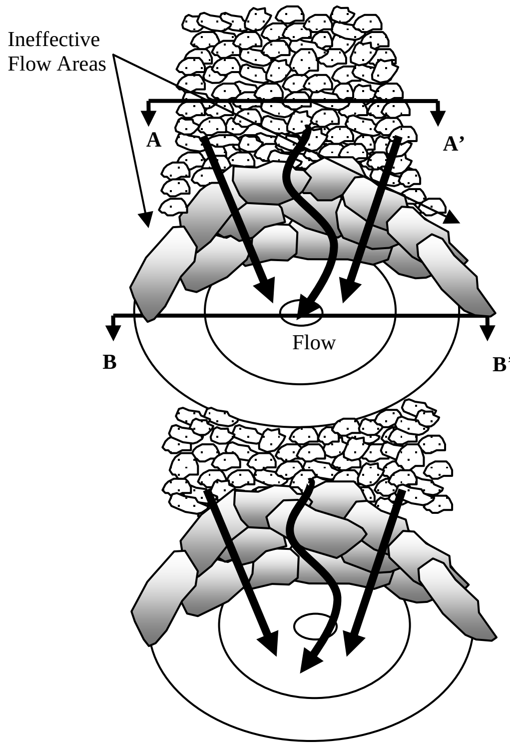
$$Maximum\ Allowable\ Velocity = C \times \left(2 \times g \times \frac{\gamma_s - \gamma_w}{\gamma_w}\right)^{0.5} \times (D_{50})^{0.5} \qquad Isbash\ Formula$$

Where:

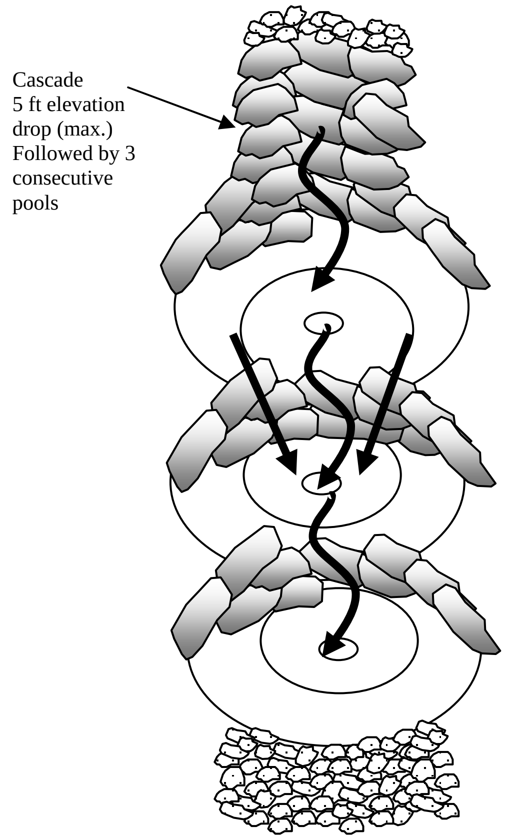
C	= 0.86 for prevailing supercritical flow and 1.2 for prevailing subcritical flow
g	= 32.2 ft/sec2
γ_s	= stone density (lb/ft3)
γ_w	= water density (lb/ft3)
d_{50}	= cobble stone diameter (ft)

Graphical Solution for Isbash technique
Figure TS14C-6, (210-VI-NEH, August 2007, TS14C-4

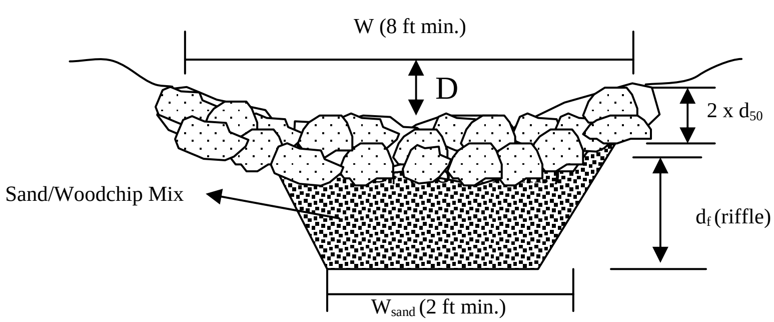




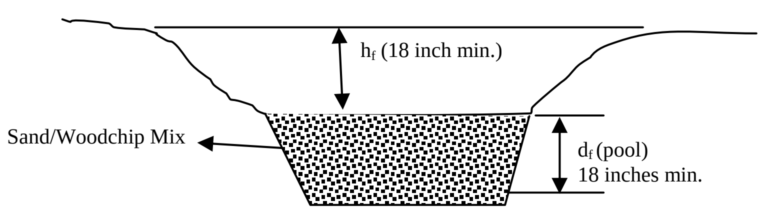
Riffle – Pool Sequence (Typical)



Cascade Sequence



Section A-A'
Riffle Weir Cross Section through Cobble



Section B-B'
Pool Cross Section

- The constructed depth of the typical pools (h_f) and the pool directly following a cascade ($h_{f\ cascade}$) shall not be less than 18 inches and shall not exceed 4 ft. This will result in a pool geometric design with less than 4 ft of embankment and will meet the exemption criteria for the Soil Conservation District small pond approval. The minimum design depth of the pools shall be estimated based on the use of the solved form of the Bernoulli conservation of energy equation shown below. The Bernoulli equation was solved to achieve a pool channel velocity of 4 ft/sec. D and V correspond to the riffle/cascade channel design depth and velocity respectively.

$$h_f \text{ or } h_{f\ cascade} = D + \frac{V^2}{2g} - 0.25$$

- To ensure stability, the pools shall be constructed with a minimum side slope of 3H:1V.

- **The sand/wood chip filter media shall meet the MDE ESD specifications for sand. Sand shall conform to AASHTO-M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. No "rock dust" can be used for sand. The woodchips are added to the sand mix, approximately 20% by volume, to increase the organic content and promote plant growth and sustainability.**

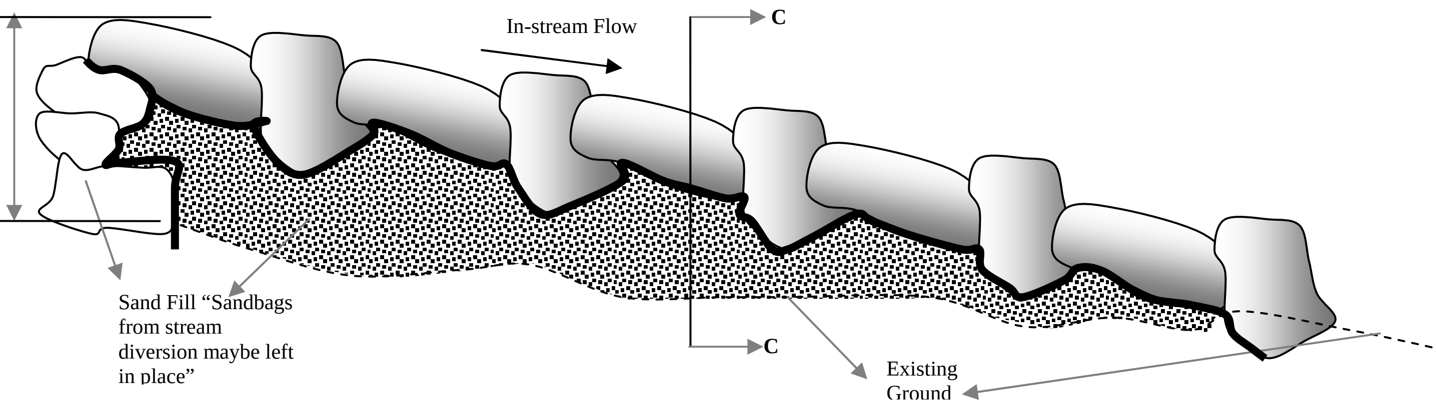
- The minimum depth of the sand/woodchip mix filter media, d_f, below the invert of the pools, shall be 18 inches.

- Filter fabric shall be placed under all boulders. Refer to design figures for placement location. To prevent undercutting, a continuous sheet of filter fabric shall be used along the cross-section.

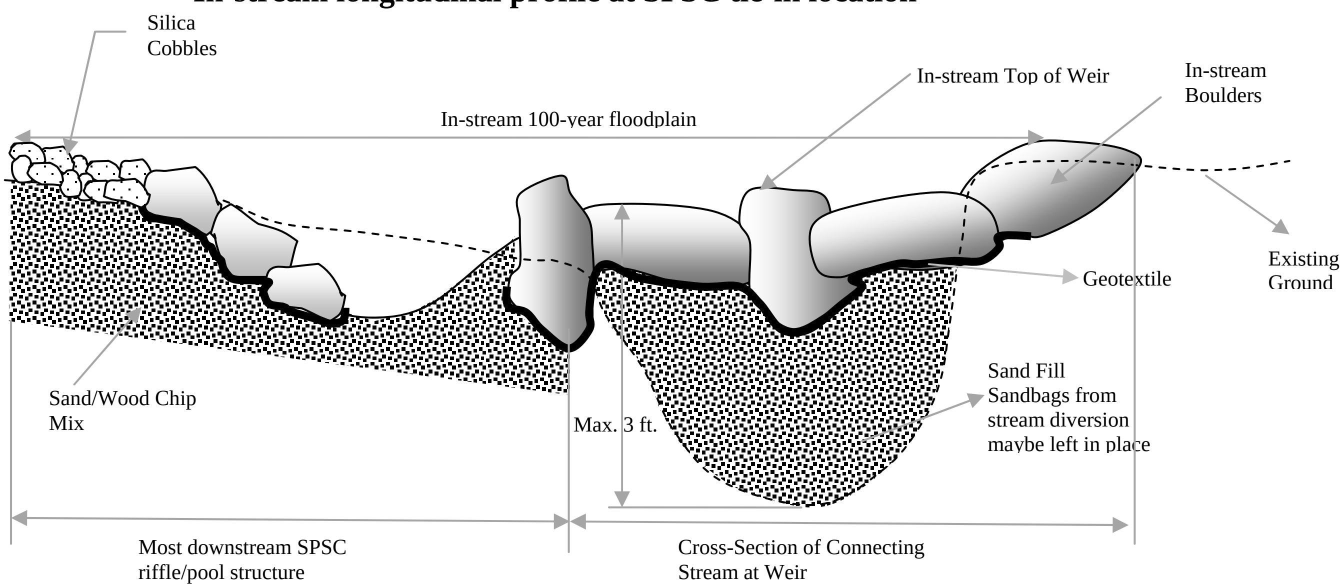
- The sandstone boulders serve as the weir component of the riffle grade control structure. The boulders should be arranged in a curved manner as shown on the riffle pool sequence schematic and the sandstone weir elevation view. This arrangement is intended to encourage flow deflection to the center of the pool and the creation of ineffective flow areas near the channel banks. To achieve this, the sandstone boulders shall be arranged horizontally in the center of the channel and the arms on either side of the channel shall be extended parabolically/ approximately 20 degree angle longitudinally to the center of the pool. The sandstone boulders should be sized by the engineer to be at least 3 to 4 times heavier than the riffle channel cobble. Typically, the diameter of sandstone boulders shall not be less than 2 ft. in length. The typical boulder size shall be designed and specified on the plans by the engineer to best fit the channel shape. i.e., smaller cross-sections will require smaller boulders, while larger channel cross-sections may require larger boulders. The sandstone boulders should be tabular in shape to allow for maximum interlocking.

- The footer rocks provide added stability to the sandstone boulder in the event that excessive erosion is experienced in the energy dissipation pools. The footer rocks may not be necessary in the event that the utilized sandstone boulders size is adequately anchored (six inches below the lowest elevation point in the pool). The footer rocks shall be equivalent in size to the sandstone boulders and should be tabular in shape to allow for maximum interlocking. Footer rocks shall be anchored 6 inches below the lowest elevation point within the pool.

6. <u>Design the in-stream weir tie-in structure (If applicable)</u>
    - The in-stream weir shall be set approximately 30 ft downstream of the tie-in location. The top elevation of the weir shall be set at the desired/historic flooplain elevation as determined appropriate by the engineer and approval authority. This is intended such as to impede headcut through the SPSC and inundate the floodplain for all flows above the base-flow conditions, thus enhance the water quality conditions. To avoid the creation of a high hazard dam condition, the maximum height of the weir shall not exceed 3 ft. Multiple weirs, not to exceed 3 ft in height, maybe required upstream to traverse the grade gradually and connect incised channels to the floodplain.
    - The in-stream weir shall be connected longitudinally to the downstream existing grade through a maximum 5% slope boulder channel. This will ensure that flow velocities do not impede the fish passage.
    - Sand shall be used for filling the stream bed to the desired elevation. Sand bags utilized as part of the erosion and sediment control plan for creating instream diversion maybe left in place. Geotextile shall be used to separate the sand fill and the overlay boulders that line the channel. The boulders shall extend in cross-section to the 100-year floodplain elevation.
    - The in-stream boulders shall be sized such as to remain in place under the 100-year velocity and shear stress, and shall be placed in a manner such as to create maximum hydraulic friction.
    - The last one or two structures within the SPSC system may be inundated by the in-stream 100-year flood elevations.
    - HEC-RAS shall be used to estimate the in-stream 100-year water surface elevation. The HEC-RAS sections shall be extended upstream to the point where the existing and proposed 100-year floodplains converge. The proposed in-stream design shall not result in additional flooding "above and beyond the historic FEMA floodplain" within private property or degradation to the hydraulic adequacy of upstream public facilities.



In-stream longitudinal profile at SPSC tie-in location



Section C-C
Instream Cross-section at Weir

7. Check and adjust the design parameters based on the project goals
   - After implementing ESD to the MEP, determine if the remaining Water Quality Treatment Volume (WQv) is met by comparing the provided sand/woodchip mix filter bed area, $A_{provided}$ to the required filter bed area. The provided sand/woodchip mix filter bed area can be computed by multiplying the average width of the sand/woodchip mix media, where the provided sand/woodchip mix depth is at least 18 inches (MDE, 2000), by the length of the sand/woodship mix media, L_{sand}, in the direction of the flow.

$$A_f = \frac{WQ_v \ x \ d_f}{K\,(h_f + d_f)\,t_f}, \qquad \textit{Filtering Sizing Criteria MDE } 2000$$

Where,

A_f	=	required sand/woodchip mix filter bed area (ft^2)
$A_{provided}$	=	provided sand/woodchip mix filter bed area (ft^2)
W_{sand}	=	width of sand/woodchip mix filter bed (ft), minimum = 4 ft.
L_{sand}	=	length (ft) along the project (L_{pre})
WQ_v	=	prescribed Water Quality Volume (ft^3)
d_f	=	sand/woodchip mix filter bed depth (ft), use minimum 24 inches (Average of d_f (pool) and d_f (riffle).
K	=	coefficient of permeability of filter media (ft/day), use K = 3.5 for sand/woodchip mix.
h_f	=	Depth of Pool (ft), minimum 18 inches.
t_f	=	design filter bed drain time (days), use 1.67 days as recommended by MDE for sand mix filters.

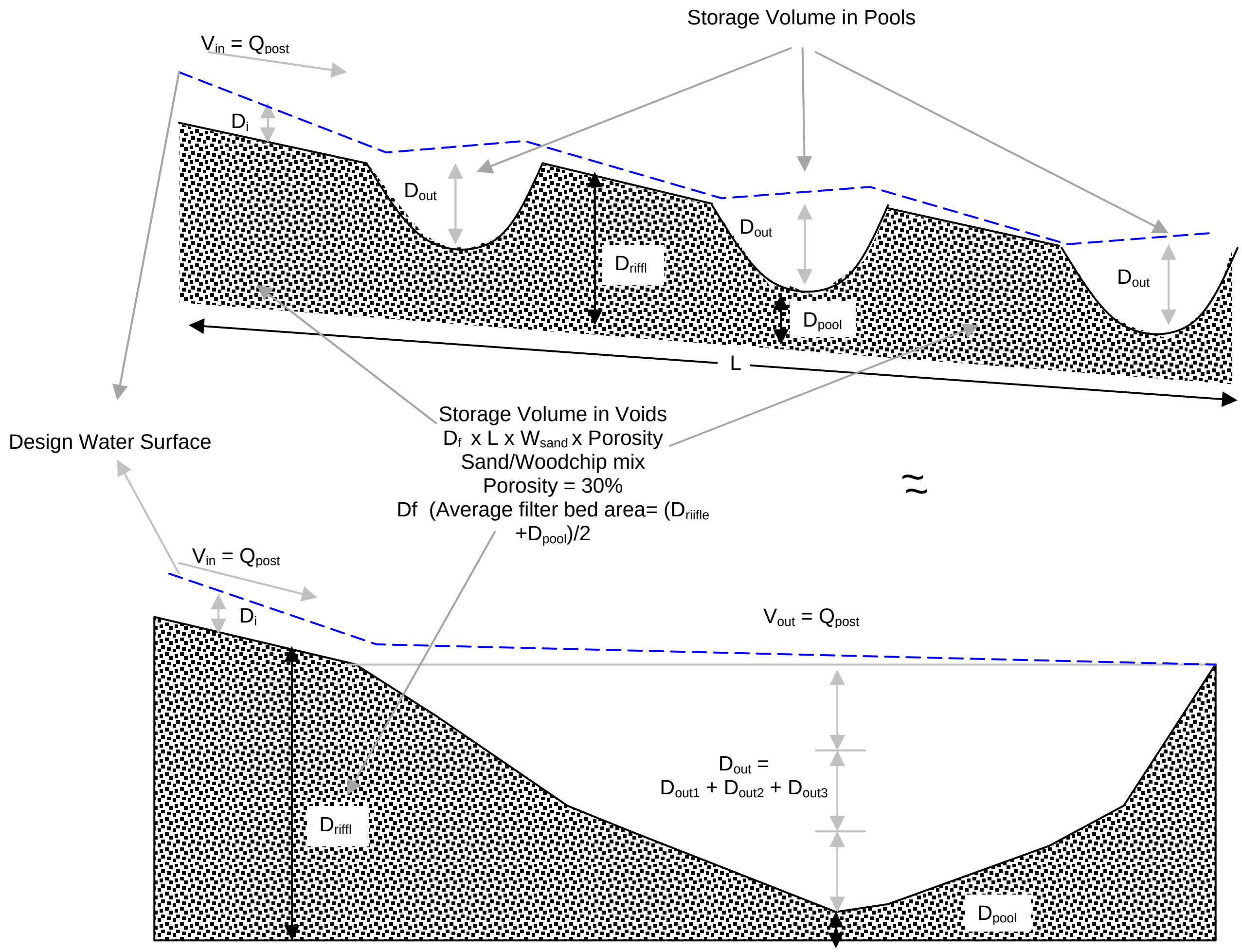
- If the required WQ_v and Re_v are not met by the proposed SPSC design, then increase the filtration capacity by adjusting the depth of pools, width of sand/woodchip mix filter, or length of the facility. If these adjustments are not feasible, utilize other BMP measures to provide the remaining water quality volume.

- In situations where the existing soil, underlying the proposed SPSC, is confirmed through "borings" to be highly infiltratable, the designer may utilize the MDE water quality sizing criteria for an infiltration basin in lieu of filtration. This is prescribed so the designer engineer is not forced, under certain circumstances, to replace highly infiltratable native soil with non-native filter bed material.

- The proposed SPSC will satisfy peak management flow requirements if two conditions are met:

  - □ First, adequate storage volume within the pools and sand/woodchip voids shall be provided to meet the required storage volume/quantity management for the project
  - □ Second, it must be demonstrated that the design renders the hydraulic power equivalent to the predevelopment/desired hydraulic power through the proposed energy dissipation pools.

- To achieve the conditions above, the designer must compare the required peak management storage volume with the combined volume within the pools and the volume in the voids within the sand/woodchip mix. A 30% porosity shall be used for the sand/woodchip mix to calculate the volume within the voids. The total provided storage shall exceed the required storage volume for the design peak management storm. Second, the selected design for the SPSC must be checked using the conservation of energy principles to ensure that the hydraulic power is adequately reduced to design/predevelopment levels. This is achieved by equating the predevelopment or reference condition hydraulic power to the post development hydraulic power and solving for the equivalent added stream length/volume of storage needed to render this power to the desired condition. The conservation of energy principles are then utilized to convert the energy loss within this horizontal length to an equivalent vertical drop. The vertical drop is then converted to multiple drops that are distributed along the system in a manner that result in the least site disturbances. The provided quantity/volume of pools is then compared with the calculated quantity/volume of pools. If the provided pool storage is less than the computed/required pool storage, then additional SPSC design measures or additional upland management strategies must be taken to reduce the inflow and in turn the hydraulic power. Refer to the figure below for a demonstration of the SPSC-provided volume of storage and input parameters for the conservation of energy computations. It should be noted that equating the geometric configuration of a multiple pool system to one pool with an area equal to the cumulative areas within the individual pools is a conservative measure and is used to simplify the hydraulic power routing computations. It is expected that cumulative roughness and headloss within the multiple pool configuration to be much higher than the individual pool configuration.



- The following steps should be followed in checking the before/after hydraulic power:
  - Compute the predevelopment/design and post development hydraulic powers by substituting the predevelopment and post development discharges in terms of Q in the hydraulic power equation. The hydraulic power is expressed in the units of lb/sec.
    Hydraulic Power = γ x Q x S, where
    γ is the unit weight of water = 62.4 lb/ft^3
    Q corresponds to the MDE 2000 CPV discharge
    S is the slope of the outfall channel in percent
  - Equate the predevelopment/design and post development hydraulic powers and solve for the needed added stream length.
  - $\gamma \times Q_{pre} \times (\Delta E/L_{pre}) = \gamma \times Q_{post} \times (\Delta E/L_{post})$
  - The elevation difference between the top and bottom of the project and the unit weight of water will remain constant, therefore, the channel protection requirement could be expressed in terms of a required additional stream channel length L_{add}, needed to render the post development hydraulic power equivalent to the predevelopment hydraulic power.
    - $L_{add} = L_{pre} \times (Q_{Post}/Q_{Pre}) - L_{pre}$
  - The required headloss due to friction through the Step Pool Storm Conveyance system can be calculated using the Darcy-Weisbach equation. By substituting L_{add} for L, this headloss becomes equivalent to the energy loss within an added stream channel of length L_{add}. The friction factor can be calculated using established relationships between Darcy-Weisbach friction factor and the Manning friction coefficient listed in Chow, 1959. The Darcy –Weisbach headloss equation is as follows:

$$Friction\ head\ loss = \frac{f L_{add} V_{out}^{2}}{2 D_{out} g}$$

  - By substituting the required headloss term in the Bernoulli conservation of energy equation, the total combined design depth in ft of all proposed pools shall be at least equal to the "D_{out}" term embedded in the Bernoulli conservation of energy equation depicted below. If the total combined depth in ft of all proposed pools is less than the calculated "D_{out}" term, then additional pools are required or alternatively the pools could be made deeper. Solve for the "D_{out}" term using trial and error techniques or available commercial solver functions/calculators, (i.e., Microsoft Excel). The general and solved forms of the Bernoulli conservation of energy equation are shown below.

General Form of the Bernoulli Equation

(Potential + Kinetic + Static) Energies $_{\text{SPSC entrance}}$ = (Potential + Kinetic + Static) Energies $_{\text{SPSC outlet}}$ + Head loss $_{\text{within SPSCsystem}}$

Solved form of the Bernoulli Equation

$$D_{in} + \frac{9Q^2}{4gD_{in}{}^2W_{in}{}^2} + \Delta E = D_{out} + \frac{9Q^2}{4gD_{out}{}^2W_{out}{}^2} + \frac{9\,fL_{add}Q^2}{4gD_{out}{}^3W_{out}{}^2}$$

Where,

f = Darcy-Weisbach friction factor, the Chow 1959 equations below maybe used to relate the friction factor to a manning roughness:

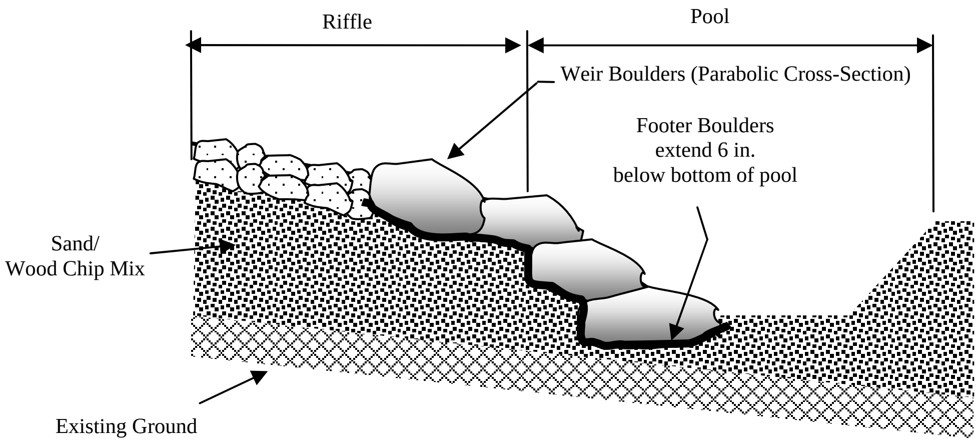
$$f = 8gRh^{-1/3}n^2 \qquad Chow, 1959$$

http://www.water.tkk.fi/wr/kurssit/Yhd-12.121/www_book/runoff_6.htm

L_{add} = additional channel length (ft) required to render the post development power to predevelopment conditions
V_{in} = Design velocity at entrance riffle = V
D_{in} = Design depth at entrance riffle = D
W_{in} = Design width of riffle = W
W_{out} = Width of the pool (ft)
V_{out} = typical velocity of flow (ft/sec) in the pool, this term is unknown in the Bernoulli equation. Using flow continuity principals, this term could be expressed in terms of the CP_V design discharge, D_{out}, and W_{out}.
g = acceleration due to gravity = 32.174 ft/sec^2
D_{out} = Solve for combined depth of flow in all pools (ft) and compare to the total provided pool depth

8. Finalize the cross-section and profile design for the project
   - Develop a grading plan based on the preliminary profile and cross-section typical design.
   - Adjust the preliminary profile dimensions to accommodate site specific concerns/impacts. Minimum design parameters for hydraulic, water quality, and quantity management criteria should be rechecked based on adjustments to the riffle/pool channels to ensure that safe and adequate conveyance is still maintained.
   - The sand/woodchip mix filter bed shall have a minimum depth of 18 inches under the riffle channel and a minimum width of 4 ft and shall be placed as the substrate drainage material along the entire project length. The actual dimensions of the sand/woodchip mix filter bed will be determined based on the required water quality volume.

- Typically, construction of the SPSC system shall begin at the downstream end and proceed upstream to the project outfall. The outlet pool is designed to be placed at the lowest point in the project reach. This is often in the receiving wetland or stream/ floodplain, but can also be located in upland settings where the SPSC system discharges to another stormwater BMP or adequate storm conveyance system.
- Footer boulders shall be placed at the interface of the pools and riffles as shown below. Additional boulders shall be placed on top of the footer bolders at the weir elevation upstream of the footer boulders to form the riffle channel parabolic shape.



- Continue the process of alternating pools and riffles up through the system to the entry pool. If the entry pool ties to an existing pipe outfall, additional armoring of the pool maybe needed to address the pipe exit velocities associated with supercritical hydraulic conditions. The designer may elect to use a larger size pool at the project entry to dissipate the outfall velocity and/or to address pretreatment concerns.
- If the SPSC is proposed below a pipe system, it is desirable that the top invert of the weir associated with the entry pool is set at or above the invert of the discharge pipe or culvert. It is the responsibility of the design engineer to check the adequacy of the upstream drainage system
- Course woodchips and compost should be used throughout the limit of disturbance for site stabilization. All areas should be hydro-seeded.
- It is advisable that excess materials, i.e., cobbles and boulders, be placed at the edge of the cross-section for use during the maintenance phase to correct any physical instability.

9. Draft a planting plan

- The planting plan and proposed species must be reviewed and approved by the County project manager/reviewer prior to installation. Additionally, any plant substitutions must be approved by the project manager/reviewer before the substitute species are installed.
- For projects within the airport zone, a sample list of MAA approved native plants is attached at the end of this document. A selection of approved trees with approved understory of shrubs and herbaceous materials should be provided.
- Pay special attention to use of native material, diversity, and dense placement of plant material within appropriate wetness zones throughout the site (MDE, 2000).
- Spray down a minimum 3 inch layer of compost throughout the site.
- Seed the entire site with Chewing Red Fescue.
- Existing trees to be protected shall be marked clearly on the project plan view and planting plan.
- The designer shall prescribe the use of course woody debris, ie. Inverted root wads, in the pool areas to enhance the soil porosity and create habitat for the biological community.

10. Prepare the operation and maintenance detail and schedule

- Routine/biannual maintenance of County-owned SPSC systems is prescribed for a period of five years. This includes, but is not limited to, mulching of devoid areas, diseased plant replacement and replanting if necessary, removal of excessive debris and invasive species. This is done to ensure plant survivability, and to monitor and ensure the structural integrity of the construction project by performing any routine structural maintenance necessary.
- In the event that sediment accumulation exceed six inches in the first year, the contractor shall spray down an additional layer of compost and replant the pool bottoms.
- Unless encountered with natural groundwater perch, the filtering capacity shall be physically checked. If the filtering capacity diminishes substantially (e.g. water ponds in the pools for more than 72 hours), the top few inches of discolored material within the pools shall be removed and shall be replaced with fresh material. The removed sediments should be disposed in an acceptable manner (e.g. landfill).
- Direct maintenance access shall be provided to the pools and filter bed.
- A recorded maintenance agreement is required for all privately owned SPSC systems.
- The operation and maintenance design detail and schedule shall be shown on the asbuilt plan. For privately owned structures, the maintenance

agreement shall be officially recorded and the recordation number shall be included on the approved grading plans.

- At a minimum, a maintenance plan shall include removal of exotic, invasive, and/or non-native plant species identified in the annual vegetation survey using methods approved by the County and by the Maryland Department of Agriculture.

11. Prepare a monitoring plan and schedule of completion
    - A monitoring plan must be prepared to address the specific restoration goals for the project. Structural stability and plants survivability are the two most pertinent components to monitor for private/developer built projects. These components shall be monitored for 3 years or as established in the plan review process. Enforcement of the monitoring conditions shall be tied to the asbuilt approval process and release of SWM bond.
    - The monitoring plan for SPSC shall include annual vegetation survey to document that planted species have 80% survivability and a biannual physical stability assessment. At the discretion of the project manager, annual benthic macro invertebrate monitoring using the Anne Arundel County approved protocols and storm event chemical monitoring for nutrients and sediments may be required. The monitoring plan shall also address all permit required project monitoring.

References:

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Maryland Department of Transportation, State highway Administration, December 1981, Highway Drainage manual, December 1981.

United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), (210-VI-NEH, August 2007), Stone Sizing Criteria,

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Walter, R., & Merritts, D. (2008). Natural Streams and the Legacy of Water-Powered Mills, Science, 319, 299-304.

Design Example

A Step Pool Storm Conveyance system is proposed as a retrofit solution for 25 acres of land with a contributory impervious cover of 10 acres. The TR20 peak discharges for the project are as follows:

Upstream Landuse Scenario	Peak Discharge (cfs) – Tc = 20 minutes			
	1- year	2-year	10-year	100-year
Desired/Reference Conditions	2	5	12	20
Ultimate Conditions	3	8	16	31

The outfall invert elevation is 100ft, and is connected to an incised stream under existing condition via 430 ft long eroded gully. The longitudinal slope for the connecting stream is 2%. The stream bed is incised by 6 ft below the historic floodplain terrace located at elevation 70 ft.

Calculate the SPSC geometric design parameters needed to safely convey the 100-year post development discharge, provide quantity management for the 10 year storm, and provide water quality treatment for the first inch of runoff. Estimate the outfall mitigation requirements for the project, if any.

Solution:
A design spreadsheet/calculator was used to formulate the problem and solution. The length of project was specified as 430 ft. The elevation drop over the length of project was specified as 30 ft. Water quality credit may only be claimed for project segments with a longitudinal slope of less than 5%. Due to this, a 17 ft long - 50% slope boulder cascade will be utilized. This leaves 413 ft of SPSC at 5% slope. Assuming a 1-ft drop over the riffle segments and no elevation drop for the pool segments, then 20 pools and 21 riffle segments, at a design length of 10ft will be needed. The riffle channel and cascade cross-sections were designed using Manning equation such as to safely convey 31 cfs associated with the ultimate condition for the 100 year storm. A trial width for the riffle was selected (8 ft) and a cobble size with D_{50} = 6 inches. A trial depth was selected at 1.5 ft. This results in a riffle channel side slope of 2.67H:1V, which is acceptable. The spreadsheet/calculator was used to check the adequacy and stability of the selected geometric parameters. The selected geometry resulted in a channel that can accommodate 58 cfs. The velocity within the riffle channel is 7.3 ft/sec, however the flow was supercritical. Due to this, the cobble size was increased to 8 inches, this resulted in increased roughness, which rendered the flow conditions subcritical. The selected design riffle channel can accommodate 52 cfs at 6.49 ft/sec. A cascade cross-section with a 10 ft width and 0.5 ft depth will accommodate 34 cfs. Three followup pools with a minimum depth of 2 ft are required. See tabulated solution on page 21

The filter bed area was sized using the MDE filtering criteria to treat 33,487 ft^3 associated with an upstream drainage area of 25 acres with 10% imperviousness. An average 18 inch sand/woodchip filter media depth at 6ft width was selected. A 3ft ponding depth was selected. Utilizing the above parameters, the provided filter bed area exceeded the required filter bed area: see tabulated solution on Page 27. It should be noted that water quality credit was only claimed for 413 ft with a <5% longitudinal profile.

For this example, peak flow management of the 10 year storm is required.
The conservation of energy equation was used to calculate the minimum required pool depth that would result in a velocity of 4ft/sec or less within the pool. The minimum required pool depth was calculated at 1.5 ft/sec. However a 3ft deep pool was selected to satisfy the water quality requirement as shown above. This selection was used to preliminarily check the quantity management. This ensures that the velocity in the pool does not exceed 4 ft/sec. A total depth of 31.6 ft is required to render the hydraulic power associated with 42 cfs to hydraulic power levels associated with 20 cfs. However, the selected design provides additional energy dissipation with a total of 61.95 ft of total excavated pool depth.

A stable outfall is required at the SPSC tie-in location. A downstream field investigation of the connecting channel revealed an active incision/headcut with a height of 6 ft. Outfall mitigation is required. Two 3-ft high in-stream weirs are proposed at the SPSC tie-in location to arrest the downstream headcut and promote upstream channel aggradations to historic conditions. To ensure that the channel slope does not exceed the 5% maximum slope, a 60 ft boulder-lined transitional section will be required following each in-stream weir to traverse the longitudinal grade. A HEC-RAS model run is needed for the in-stream work to establish the proposed 100-year floodplain elevation and assess impacts, if any.

Input values shaded in Grey
Calculated values are noted with dotted pattern
Check parameters in bold

Checking the Channel Conveyance for the design flood				
Design Return Period (Yr)	T	100	1	10
Time of Concentration in minutes (Before Development)	t_c	20.00		
Pre development discharge (cfs)	Q_{pre}	20.0	2.0	12.0
Post development design discharge (cfs)	Q_{post}	31.0	3.0	16.0
Total available length (ft)	L	430	**Cascade Design (maximum 10 ft drop per segment)**	
Elevation drop over length (ft)	delta E	30.0	Design Width (ft)	10.00
Total Cascade Length for Project (ft)	$L_{cascade}$	17.00	Design Depth (ft)	0.50
Cascade Slope (ft/ft)	$Slope_{cascade}$	0.50	Roughness	0.05
Water Quality slope (ft/ft)	Slope	0.05	A	3.33
Length of Riffle Channel (ft), Minimum 8 ft	L_{riffle}	10	θ	0.20
Length of Pool (ft), Minimum 8 ft	L_{pool}	10	P	10.07
Cobble d50 size (ft) - choose - 8 inches	**d50**	**0.67**	R_h	0.33
Top width of SPSC riffle channel (ft)	W	8.0	Design Velocity (ft/sec)	10.09
Depth of SPSC riffle channel (ft)	D	1.5	Conveyed Q (cfs)	33.62
h_f, Minimum required dead storage depth within the pools of the SPSC (ft)	**h_f**	**1.9**	**Cascade is adequate**	
Enter Desired Pool Depth (ft)	h_f	3.0	Minimum Pool Depth following Cascade (ft)	1.80
Check Riffle Side Slope, Must be > 2H:1V		**2.67**	ok	
Check the Froude Number to ensure Subcritical Flow Conditions		**0.93**	subcritical/ok	
Computed Roughness	n	0.05		
Riffle Cross Section Area (ft2), for parabola	A	8.00		
Theta - Intermediate step for solving	θ	0.64		
Riffle Hydraulic Perimeter (ft), for parabola	P	8.70		
Riffle Hydraulic Radius (ft), using Chow 1959	R_h	0.92		
Calculated Flow for design parameters (cfs)	Q	51.95		
Check Riffle Velocity (ft/sec)	**V**	**6.49**		

Isbash curve for Stone Density = 165 lb/ft3		
Cobble d50 size	Allowable Velocity (Supercritical)	Allowable Velocity (Subcritical)
[inches]	[ft/sec]	[ft/sec]
4	5.1	7.1
5	5.7	8.0
6	6.3	8.7
7	6.8	9.4
8	7.2	10.1
9	7.7	10.7
10	8.1	11.3
11	8.5	11.8
12	8.8	12.3
15	9.9	13.8
18	10.8	15.1

Adequate conveyance of design storm

Selected Cobble Size is Adequate for 100 year storm

Subcritical Flow is Predominant

Checking Quantity Management

USDA 2006, n expressed in terms of d_{out} and d_{50} = 8 inches	n	0.04
The width at the entrance riffle	W_{in}	8.00
The velocity at the entrance riffle is calculated using Manning formula calculator and Q_{post} for the 1 year storm	V_{in}	6.49
The depth at the entrance riffle is calculated using Manning formula calculator and Q_{post} for the 1 year storm	D_{in}	1.50
Enter Trial Value : The total pool depth needed to render the power equivalent to 100-year predevelopment/desired levels. This should be compared against the total provided pool depth for adequacy.	D_{out}	**31.60**
This is the typical top width of the dead storage pool parabolic areas, 10:1 side slope	W_{out}	11
The area is for a semi parabola	A_{out}	240
Equivalent channel length (ft) required to satisfy the channel protection volume.	L_{add}	237
Theta - Intermediate step for solving	θ	1.48
Hydraulic Perimeter (ft), for semi parabola	P_{out}	65
Hydraulic Radius, using Chow 1959	R_h	3.69
Darcy Weisbach friction factor expressed in terms of L_{add}, v_{out},	f	0.21
Solved using Solver equation: Bernoulli equation rewritten in terms of d_{out} as the		**0.00**

Provided total pool depth (ft) =	**61.95**
hydraulic power for return period 100 year storm is satisfied	

Required Volume of Storage (Rational Hydrograph)

	100 Yr	1 Yr	10 Yr
Required Volume of Storage for the 100 Storm (ft3)	13199	1200	4800
Volume provided in pools (ft3)	8640		
Volume provided in voids (ft3)	1161		
Provided Volume of Storage (excludes infiltration) (ft3)	9801		

Peak Management of 100 year storm is not satisfied
Peak Management of 1 year storm is satisfied
Peak Management of 10 year storm is satisfied

Checking Quality Management

Site Drainage Area (Acres)	A	25
Contributory Impervious Area (Acres)	I	10
Volumetric Runoff Coefficient	Rv	0.41
Water Quality Volume, ft3	WQv	33487
Average Sand filter bed depth (ft) - MDE recommended value	$d_{f\,(Average\ of\ Pool\ and\ Riffle)}$	1.5
Width of sand filter (ft)	W_{sand}	6
Length of sand filter, where slope < = 5% (ft)	L_{sand}	413
Area of sand filter provided (ft2)	$A_{f\,Provided}$	**2478**
coefficient of permeability of filter media (ft/day)	k	3.50
height of water above filter bed- pool depth (ft)	h_f	3.00
design filter bed drain time (days), MDE recommended value	t_f	1.67
Required filter bed area (ft2)	$A_{f\,Required}$	**1910**

Water quality requirement is satisfied in SPSC

Hydraulic Rating Curve for Riffle Channel – First Trial D50 =6 inches – Use larger Cobble

D	W	A	Rh	n	Q	V	Froude #
0.1	3.16	0.21	0.07	-0.58	-0.02	-0.10	-0.05
0.2	4.47	0.60	0.13	0.13	0.40	0.67	0.26
0.3	5.48	1.10	0.20	0.08	1.52	1.39	0.45
0.4	6.32	1.69	0.26	0.07	3.50	2.07	0.58
0.5	7.07	2.36	0.33	0.06	6.42	2.72	0.68
0.6	7.75	3.10	0.39	0.05	10.36	3.34	0.76
0.7	8.37	3.90	0.46	0.05	15.37	3.94	0.83
0.8	8.94	4.77	0.52	0.05	21.52	4.51	0.89
0.9	9.49	5.69	0.59	0.05	28.83	5.06	0.94
1	10.00	6.67	0.65	0.05	37.34	5.60	0.99
1.1	10.49	7.69	0.71	0.04	47.09	6.12	1.03
1.2	10.95	8.76	0.78	0.04	58.11	6.63	1.07
1.3	11.40	9.88	0.84	0.04	70.41	7.13	1.10
1.4	11.83	11.04	0.90	0.04	84.03	7.61	1.13
1.5	12.25	12.25	0.96	0.04	98.97	8.08	1.16
1.6	12.65	13.49	1.02	0.04	115.26	8.54	1.19
1.7	13.04	14.78	1.08	0.04	132.92	9.00	1.22
1.8	13.42	16.10	1.15	0.04	151.96	9.44	1.24
1.9	13.78	17.46	1.21	0.04	172.40	9.87	1.26
2	14.14	18.86	1.27	0.04	194.24	10.30	1.28

Subcritical Flow (D = 0.1 to 1.1)

Supercritical Flow (D = 1.2 to 2)

100 Year Storm Level (D = 1.5)

Hydraulic Rating Curve for Riffle Channel – Second Trial D50 = 8 inches - Selected

D	W	A	Rh	n	Q	V	Froude #
0.1	3.16	0.21	0.07	-0.17	-0.07	-0.33	-0.18
0.2	4.47	0.60	0.13	0.26	0.20	0.33	0.13
0.3	5.48	1.10	0.20	0.12	1.08	0.98	0.32
0.4	6.32	1.69	0.26	0.09	2.70	1.60	0.45
0.5	7.07	2.36	0.33	0.07	5.18	2.20	0.55
0.6	7.75	3.10	0.39	0.07	8.58	2.77	0.63
0.7	8.37	3.90	0.46	0.06	12.95	3.32	0.70
0.8	8.94	4.77	0.52	0.06	18.36	3.85	0.76
0.9	9.49	5.69	0.59	0.05	24.84	4.36	0.81
1	10.00	6.67	0.65	0.05	32.43	4.86	0.86
1.1	10.49	7.69	0.71	0.05	41.15	5.35	0.90
1.2	10.95	8.76	0.78	0.05	51.05	5.83	0.94
1.3	11.40	9.88	0.84	0.05	62.14	6.29	0.97
1.4	11.83	11.04	0.90	0.05	74.44	6.74	1.00
1.5	12.25	12.25	0.96	0.05	87.98	7.18	1.03
1.6	12.65	13.49	1.02	0.05	102.78	7.62	1.06
1.7	13.04	14.78	1.08	0.04	118.84	8.04	1.09
1.8	13.42	16.10	1.15	0.04	136.20	8.46	1.11
1.9	13.78	17.46	1.21	0.04	154.86	8.87	1.13
2	14.14	18.86	1.27	0.04	174.83	9.27	1.16

Subcritical Flow (D = 0.1 to 1.4)

Supercritical Flow (D = 1.5 to 2)

100 Year Storm Level (D = 1.5)

Storage Capacity within one Pool

Stage	Surface Area	Incremental Storage (ft^3)	Cumulative Storage (ft^3)
0	**0.00**	**0.00**	**0.00**
0.1	0.48	0.02	0.02
0.2	1.92	0.12	0.14
0.3	4.32	0.31	0.46
0.4	7.68	0.60	1.06
0.5	12.00	0.98	2.04
0.6	17.28	1.46	3.50
0.7	23.51	2.04	5.54
0.8	30.71	2.71	8.25
0.9	38.87	3.48	11.73
1	47.99	4.34	16.08
1.1	58.07	5.30	21.38
1.2	69.10	6.36	27.74
1.3	81.10	7.51	35.25
1.4	94.06	8.76	44.00
1.5	107.97	10.10	54.11
1.6	122.85	11.54	65.65
1.7	138.69	13.08	78.72
1.8	155.48	14.71	93.43
1.9	173.24	16.44	109.87
2	191.95	18.26	128.13
2.1	211.63	20.18	148.31
2.2	232.26	22.19	170.50
2.3	253.86	24.31	194.81
2.4	276.41	26.51	221.32
2.5	299.93	28.82	250.14
2.6	324.40	31.22	281.35
2.7	349.83	33.71	315.07
2.8	376.23	36.30	351.37
2.9	403.58	38.99	390.36
3	431.89	41.77	432.13
3.1	461.16	44.65	476.78
3.2	491.40	47.63	524.41
3.3	522.59	50.70	575.11
3.4	554.74	53.87	628.98
3.5	587.85	57.13	686.11

Selected Depth of Pool ← 3

Storage provided in pools = 432 x # of pools (20) = 8,640 ft^3

Abbreviated List of Native Plants

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 maybe 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.

Common Name	Latin Name	Comments
American Holly	*Ilex opaca*	*(Male Only)*
Bald Cypress	*Taxodium distichum*	
Bayberry	*Myrica pensylvanica*	
Blue Flag Iris	*Iris versicolor*	
Christmas Ferns	*Polystichum acrostichoides*	
Cinnamon Fern	*Osmunda cinnamomea*	
Fringe Tree	*Chionanthus virginiana*	*(Male Only)*
Inkberry	*Ilex glabra*	*(Male Only)*
Little Bluestem	*Schizachyrium scoparium*	
Mountain Laurel	*Kalmia latifolia*	
Pitch Pine	*Pinus rigida*	
Switchgrass	*Panicum virgatum*	
Summersweet	*Clethra alinifolia*	
Sweetbay Magnolia	*Magnolia virginiana*	
Tussock Sedge	*Carex stricta*	
Virginia Sweetspire	*Itea virginica*	

For SPSC projects outside of the airport zone, the designer shall utilize the list of native plants as listed below:

Common Name	Latin Name
American Holly	*Ilex opaca*
Atlantic White Cedar	*Chamaecyparis thyoides*
Bald Cypress	*Taxodium distichum*
Bayberry	*Myrica pensylvanica*
Blue Flag Iris	*Iris versicolor*
Broomsedge	*Andropogon virginicus*
Christmas Ferns	*Polystichum acrostichoides*
Cinnamon Fern	*Osmunda cinnamomea*
Common Winterberry	*Ilex laevigata*

Common Name	**Latin Name**
Cranberry	*Vaccinum macrocarpon*
Early Lowbush	Blueberry *Vaccimiun pallidum*
Fragrant Water Lily	*Nymphea odorata*
Fringe Tree	*Chionanthus virginiana*
Golden Club	*Orontium aquaticum*
Highbush Blueberry	*Vaccinum corybosum*
Inkberry	*Ilex glabra*
Little Bluestem	*Schizachyrium scoparium*
Mountain Laurel	*Kalmia latifolia*
Pitch Pine	*Pinus rigida*
Redhead Grass	*Potamogeton perfoliatus*
Red Cedar	*Juniperus virginiana*
Royal Fern	*Osmunda regalis*
Serviceberry	*Amelanchier canadensis*
Switchgrass	*Panicum virgatum*
Smooth Alder	*Allnus serrulata*
Sour Gum	*Nessa sylvatica*
Summersweet	*Clethra alinifolia*
Swamp Azalea	*Rhododendron viscosum*
Swamp Bayberry	*Myrica heterphylla*
Sweetbay Magnolia	*Magnolia virginiana*
Tussock Sedge	*Carex stricta*
Virginia Chain Fern	*Woodwardia virginica*
Virginia Sweetspire	*Itea virginica*
Wax Myrtle	*Myrica cerifera*
Winterberry	*Ilex laevigata*
Yellow Pond Lilly	*Nuphar advena*

A complete list of native plants can be found under www.aacounty.org/IP/Resources/AANativePlants.pdf. Special attention shall be placed on diversity and dense placement of plant material within appropriate wetness zones throughout the site (MDE, 2000). Additional information on native plants for the Chesapeake Bay region can be found at www.nps.gov/plants/pubs/chesapeake. For information concerning Native Plant Nurseries, please visit www.aacounty.org/IP/Forms.cfm and scroll down to the "Forestry Forms and Fact Sheets" section.