



## Best Management Practice Fact Sheet 16: Step Pool Stormwater Conveyance

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This fact sheet is one of a series on urban stormwater management practices.

Please refer to definitions in the glossary at the end of this fact sheet.

Glossary terms are *italicized* on first mention in the text. For a comprehensive list, see Virginia Cooperative Extension (VCE) publication 426-119, "Urban Stormwater: Terms and Definitions."

### What is Step Pool Stormwater Conveyance?

In urban areas, stormwater is directed into a stormwater conveyance system, which can include pipes, swales, or ditches. Often, pipes are the chosen method for conveying larger runoff flows in urban areas. When one of these pipes discharges at the top of a steep slope, *concentrated flow* can cause extensive *erosion*, creating deep gullies along the slope (see Figure 1). These gullies become a source of *sediment* and associated *nutrients* or other pollutants to *receiving streams*. The gullies can also become deep enough to intercept the *water table*, which, in turn, lowers local *groundwater* levels.



Figure 1. Eroded gully due to urban runoff.  
(Image courtesy of Erik Michelsen, Anne Arundel County Department of Public Works. Used with permission.)

*Step Pool Stormwater Conveyances* (SPSCs), also known as *Coastal Plain* outfalls or regenerative stormwater conveyances, are used to convey runoff from developed areas to streams, reducing erosion, improving stormwater quality, and recharging shallow *groundwater*. SPSCs direct runoff into a series of pools with beds (see Figure 2) composed of a *permeable*, sand-based *filter media* similar to that found in *rain gardens* and *bioretention* cells.



Figure 2. A Step Pool Stormwater Conveyance directs runoff from parking lots to Broad Creek in Annapolis, Maryland.

## How Does Step Pool Stormwater Conveyance Work?

On steep slopes, *rock weirs* are spaced across the channel, perpendicular to the flow direction at pre-determined distances downslope, creating a series of shallow pools that slow stormwater and reduce erosion. These rock weirs are designed to mimic the rocks and logs found in naturally occurring step-pool channels. The step-pool *channel morphology* of steep SPSCs dissipates flow energy during storm events, and the pool beds filter and absorb water during low flow conditions.

## Where Can Step Pool Stormwater Conveyance be Used?

SPSCs are effective for either *first-order streams* or eroded gullies with intermittent flows with valley and *channel slopes* between 2% and 10%. SPSCs with a slope greater than 5% will generally provide fewer water quality benefits than those on gentler slopes, so they should be avoided unless absolutely necessary, and should only be undertaken by an experienced designer. While an SPSC may be designed for a site with a valley or channel slope greater than 10%, these applications should be used with caution, and the design should be modified (e.g., by reinforcing the rock weirs) to compensate for the increased hydraulic forces that will result.

## Potential Advantages

- Can be used in a wide variety of locations if properly designed.
- Prevents erosion and subsequent increased downstream sediment pollution.
- Retains woody debris, which facilitates pollutant removal processes such as *denitrification*.
- Retains a wide range of aggregates, which are needed to form stable channels.
- Reconnects the stream with the floodplain and the water table.
- Facilitates establishment of vegetation.
- Fosters the creation of both aquatic and terrestrial *habitat* (MDNR 2018).

## Potential Limitations

- It is a relatively new *best management practice* (BMP), so design and maintenance experience is limited.
- Water quality credits are based upon relatively few studies. Information on crediting will improve as more SPSCs are implemented and monitored.

## How are Step Pool Stormwater Conveyances Designed and Built?

### General Design Guidelines

Although the SPSC is technically a constructed or modified channel, it should be designed to minimize alterations to the receiving stream and surrounding *habitat*. By constructing the SPSC in an existing first-order stream or erosion gully, runoff can continue to be discharged into the receiving stream at the same location, but with less energy. Designs should be modified on a site-by-site basis, depending on what is required to fit the SPSC within the existing channel, while ensuring the SPSC can convey the peak flow rate from a 100-year storm without causing scour of the weirs. Because the 100-year storm recurs relatively infrequently and most stormwater drainage systems are designed to only handle flows from 10-year or 25-year storms, this approach results in a conservative design. It is also important that the SPSC be connected to the receiving stream in a way that minimizes the potential for a *knickpoint* to form on the floodplain at the SPSC outlet, which could potentially undermine the SPSC. Because SPSCs can involve construction in a waterway, a permit from local and state agencies or the U.S. Army Corps of Engineers will likely be required prior to construction.

At its most basic level, an SPSC is a modified channel consisting of pools alternating with steps or cascades. Steps are constructed of large boulders and cobbles (see Figure 3) and have drops of no more than 1 foot, where a drop is the elevation difference between the low points on two consecutive weirs. Cascades are larger structures that can have drops up to 5 feet. The rock weirs are constructed in a shallow parabola that opens downstream, such that the arms of the weir form 70 degree angles with the bank. This shape will direct flows towards the center of the SPSC channel.



Figure 3. Step Pool Stormwater Conveyance weirs have a cobble apron on the upstream side, reinforced with boulders.

Pools are located between steps or cascades and should be at least 10 feet long and more than twice the length of the preceding rock weir or cascade to dissipate energy. Pools that are wider than they are long (length: width <1) and at least 1.5 feet deep provide better energy dissipation (Thompson, Hathaway, and Schwartz 2018).

If the stream to which the SPSC discharges is incised, it is recommended that a riffle grade control be installed in the receiving stream to provide a stable outfall for the SPSC and to limit the potential development of a knickpoint at the downstream end of the SPSC or within the channel. If the receiving stream is actively eroding, a rock weir may need to be placed in the receiving stream to further dissipate the SPSC flow energy.

## Construction

Material selection and sizing for the SPSC is largely dependent on the requirements that the rock weirs and channel remain structurally stable during the design flow while also creating the required weir and pool geometry. The *peak stream flow rate* from the 100-year storm event is used for the weir design and material sizing. Detailed design guidance is available from the Anne Arundel County Department of Public Works (Anne Arundel Bureau of Engineering 2012). When selecting materials for the various SPSC components (rock weirs, pool beds, and vegetation), it is important to select materials that will not affect water chemistry or clog the sand *filtration media*.

*Filtration media* should be placed in the pools for shallow groundwater recharge primarily using locally sourced sand. Where water quality benefits are a project goal, a sand-woodchip filtration media mixture similar

to those used in bioretention cells should be used, with an estimated 20% woodchip content by volume. Where water quality benefits are not a project goal, native soil with a comparable *infiltration rate* may be left in place instead, as long as the design guidelines are still met.

Construction of the SPSC should begin at the *outlet* and progress upstream. If sedimentation and clogging of the SPSC beds occur due to upstream construction, the affected pools should be scraped clean of fine sediment and vegetation at the completion of the overall project.

*Filter fabric* should be placed beneath weir footer rocks to ensure that rock weirs will not fail by winnowing or undercutting. Filter fabric must not extend beneath the pools, or it will interfere with *filtration* and *infiltration* functions. Wood mulch should be used on the side slopes of the SPSC for erosion protection if construction does not take place during a planting season. Invasive and nonnative vegetation should be removed from the site before planting.

## Post Construction Monitoring and Maintenance

It is recommended that routine post-construction monitoring be conducted for at least three years with periodic inspection thereafter as part of a regular stormwater management program. Corrective action should be taken if and when problems arise. Some monitoring and maintenance activities to ensure that the SPSC functions as intended include the following:

- Monitor pool depth to ensure the pools are not *aggrading* or *degrading*, and remove accumulated sediments or replace the filter bed media as necessary to maintain infiltration.
- Examine the SPSC vegetation to ensure that establishment is sufficient for *erosion* prevention, and replant or reseed vegetation as needed.
- Regularly examine the surrounding slopes for erosion, particularly where the weirs meet the surrounding slopes; extend the rock weirs higher on surrounding slopes if erosion of the adjacent slopes occurs due to flow around the rock weirs.
- Regularly examine the weirs for rock displacement after large flow events and replace them if necessary.
- Regularly examine the receiving stream for *aggradation* or *degradation* caused by the SPSC structure and reinforce the receiving stream if channel erosion occurs.

Consider requesting help from local conservation or volunteer-based organizations for monitoring work that can be performed by laypeople if resources for monitoring are scarce.

## Performance

Since SPSCs are new and the complex surface and subsurface flows are difficult to monitor, only a limited amount of scientific, peer-reviewed performance data are available. A study of an SPSC in the North Carolina Coastal Plain measured a median decrease in runoff volume and peak flow rate of 78% and 76%, respectively, over an 11-month period (Cizek et al. 2018). This study also documented median load reductions of 86%, 83%, and 93% of total nitrogen, total phosphorus, and total suspended solids in surface runoff, respectively, largely due to decreases in surface runoff volumes. Because SPSCs are designed to promote the infiltration and slow release of runoff, the pollutant load reductions will likely be lower when the overall system is considered (Cizek et al. 2018). Koryto et al. (2018) measured runoff and nutrient load reductions in both surface and subsurface flows in a scaled experimental SPSC in Raleigh, North Carolina. Surface flow runoff volumes were reduced by 80% during a 1-inch, 24-hour design storm and by 40% during a 1.5-inch, 24-hour event. Median total nitrogen (TN) and total phosphorus (TP) load reductions were 46% and 68% for the 1-inch storm event and 20% and 33% for the 1.5-inch storm event. However, SPSCs installed on steep slopes (>5%) or where there is a high water table may have limited runoff reduction and/or water quality benefits (Koryto, Hunt, and Page 2017; Thompson, Schwartz, and Hathaway 2020).

Several recommendations are available on how to estimate the amount of pollutants removed by SPSC systems. Berg et al. (2014) provides a method for estimating SPSC sediment and nutrient removal credits based upon retrofit curves. In contrast, WVDNR (2012) suggests a runoff volume reduction equal to the design volume of the practice, based upon a 1-inch water storm event, which results in a 90% total suspended solids (TSS) credit. A total nitrogen credit of 74% and a total phosphorus credit of 76% were also recommended based upon an assumption of performance similar to that of a Level 2 *dry swale*. Since this is an innovative practice with limited performance history, *water quality credits* should be assessed on a site-by-site basis.

## Expected Cost

Costs for SPSC systems are typically \$500 to \$750 per linear foot, depending on the amount of excavation or fill required to install the system (E. Michelsen, personal communication, Dec. 9, 2019).

## Additional Information

The Virginia departments of Conservation and Recreation (VA-DCR) and Environmental Quality (VA-DEQ) are the two state agencies that address nonpoint source pollution. The VA-DCR oversees agricultural conservation; VA-DEQ regulates stormwater through the Virginia Stormwater Management Program.

A wide variety of information on various BMPs can be found at the Virginia Stormwater BMP Clearinghouse website at <https://www.swbmp.vwrrc.vt.edu/>. The BMP Clearinghouse is jointly administered by VA-DEQ and the Virginia Water Resources Research Center. Since this practice is new, it has not yet been reviewed and placed on the Clearinghouse site. However, a review was conducted by an Expert Panel of the U.S. EPA Chesapeake Bay Program (Berg 2014). Performance information contained in this document is tentatively given based upon these and other cited sources, but verification is recommended.

## Online Resource

Step Pool Conveyance Systems, Anne Arundel County, Maryland <https://www.aacounty.org/departments/public-works/wprp/watershed-assessment-and-planning/step-pool-conveyance-systems/>

## Companion Virginia Cooperative Extension Publications

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## Glossary of Terms

**Aggrading, aggraded** – The process of deposition in streams.

**Best management practice (BMP)** – Any treatment practice for urban lands that reduces pollution from stormwater. A BMP can be either a physical structure or a management practice. Agricultural lands use a similar, but different, set of BMPs to mitigate agricultural runoff.

**Bioretention, bioretention cell** – A best management practice that is a shallow, landscaped depression that receives and treats stormwater with the goal of discharging water of a quality and quantity similar to that of a forested watershed. *Bioretention* cells typically

consist of vegetation, soils, an optional underdrain, and an outlet or *control structure*. Sometimes called “rain gardens.”

**Channel morphology** – The shape of a stream, including physical features such as steps, riffles, and pools.

**Channel slope** – The slope of the channel bed in the direction of streamflow, or longitudinal, direction.

**Coastal Plain** – A physiographic province in the southeastern United States, east of the fall line (east of I-95) which is typically characterized by flat terrain and a high water table.

**Concentrated flow** – Occurs when water concentrates into rivulets or channels; the opposite of sheet flow. Concentrated flow leads to greater water velocity and decreased time for infiltration and settling.

**Control structure** – Structure that regulates water discharge from a best management practice.

**Degrading, degraded** – Generally refers to processes which remove bed or bank material from streams.

**Denitrification** – An important part of the global hydrogeochemical cycle; is the process by which nitrate-nitrite (dissolved nitrogen) is converted to nitrogen gas.

**Dry swales** – Shallow, gently sloping channels with broad, vegetated side slopes and low-velocity flows. They are always located above the water table to provide drainage capacity.

**Erosion** – A natural process by either physical processes, such as water or wind, or chemical means that moves soil or rock deposits from one source and transports it to another. Excessive erosion is considered an environmental problem that is very difficult to reverse.

**Filter fabric** – A synthetic material placed between soil and placed rock or gravel to prevent the rocks from sinking into the surrounding soil.

**Filter media, filtration media, engineered filter media** – Designed material that removes pollutants through filtration; usually consists of sand, organic matter, or a proprietary product.

**Filtration** – A treatment method that removes pollutants by straining, settling, and similar processes.

**First-order streams** – Channels with the smallest contributing drainage areas, which are upstream of the confluence with another first-order stream.

**Groundwater** – Water located beneath the earth’s surface and stored in soil pore spaces, rock fractures, and underground aquifers.

**Habitat** – The environment where organisms, like plants, normally live.

**Infiltration** – The process by which water (surface water, rainfall, or runoff) enters the soil.

**Infiltration rate** – See percolation rate.

**Knickpoint** – A sharp increase in channel bed slope that can migrate upstream due to increased local bed erosion, leading to channel incision.

**Nutrients** – Substances required for growth of all biological organisms. When considering water qualities, the nutrients of greatest concern in stormwater are nitrogen and phosphorus, because they are often limiting in downstream waters. Excessive amounts of these substances are pollution and can cause algal blooms.

**Outlet** – The point of exit of water from a downspout or other best management practice, usually through a control such as an outlet structure.

**Peak stream flow rate** – The highest water flows within a stream during a storm event.

**Percolation rate** – The speed at which water will infiltrate into unsaturated soil. Also known as infiltration rate.

**Permeability** – See permeable.

**Permeable** – A surface that water can easily flow through (porous); allows infiltration into it.

**Pervious** – A ground surface that is porous and allows infiltration into it.

**Rain garden** – Often used interchangeably with bioretention; however, it typically refers to a less formal design and installation process. Typically implemented in residential areas by homeowners.

**Receiving stream** – Stream downstream from SPSC.

**Recharge** – The process by which groundwater is replenished. Typically occurring in longer periods of time.

**Rock weirs, rock weirs** – Stone structures used to raise the bed of a channel and pond water upstream of the weir.

**Sediment, sediments** – Soil, rock, or biological material particles that are eroded, transported, and then deposited. In water environments, sediment is transported along a watershed by flowing water.

**Sedimentation** - the deposition of sediment due to settling.

**Settling** – The process by which particles that are

heavier than water fall to the bottom under the influence of gravity.

**Stable channel** – A channel that is not experiencing extensive erosion or sediment deposition. The average cross sectional shape of a stable channel remains constant over time even though the channel may migrate.

**Step Pool Stormwater Conveyance (SPSC)** – SPSC, also known as Coastal Plain outfalls or regenerative stormwater conveyances, are used to convey runoff from developed areas to streams without erosion, while also improving stormwater quality, and recharging shallow groundwater. SPSCs direct runoff into a series of pools with beds composed of a permeable, sand-based filter media similar to that found in rain gardens and bioretention cells.

**Stormwater** – Water that originates from impervious surfaces during rain events; often associated with urban areas. Also called runoff.

**Stormwater conveyance system** – Means by which stormwater is transported in urban areas.

**Stormwater management** – The management of runoff from pre- to post-development, often using stormwater treatment practices and best management practices to manage quality and control release into receiving bodies of water.

**Stormwater treatment practice** – A type of best management practice that is structural and reduces pollution in the water that runs through it.

**Sustainable** – The ability of the system to endure and remain productive over a long period of time.

**Water quality credits** – Represent the estimated amount of pollutants removed by a BMP in mass per year for use in water quality management planning. In the Chesapeake Bay watershed, these credits are primarily for nitrogen, phosphorus, and sediment removal.

**Water table** – The depth at which soils are fully saturated with water.

**Watershed** – A unit of land that drains to a single “pour point.” Boundaries are determined by water flowing from higher elevations to the pour point. A pour point is the point of exit from the watershed, or where the water would flow out of the watershed if it were turned on end.

**Weir** – An obstruction placed across a flowing stream, ditch, or pipe, causing water to pool and rise. The elevation difference between water surface and weir elevation is proportional to the flow across it.

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