Overview for high-gradient stormwater step-pool swale

Green Infrastructure: Swales can be an important tool for retention and detention of stormwater runoff. Depending on design and construction, swales may provide additional benefits, including cleaner air, carbon sequestration, improved biological habitat, and aesthetic value. See the section Green Infrastructure for stormwater management.

Download pdf (https://stormwater.pca.state.mn.us/index.php?title=File:Overview_for_bioretention_-_Minnesota_Stormwater_Manual_June_2022.pdf)

Stormwater step pools are defined by design features that address higher energy flows due to more dramatic slopes than **dry swales** (https://stormwater.pca.state.mn.us/index.php?title=Dry_swale_(Grass_swale)) or **wet swales** (https://stormwater.pca.state.mn.us/index.php?title=Wet_swale_(wetland_channel)). Using a series of pools, riffle grade control, **native species** vegetation and a sand seepage filter bed, flow velocities are reduced, treated, and, where applicable, infiltrated. The physical characteristics of the stormwater step pools are similar to Rosgen A or B stream classification types (https://cfpub.epa.gov/watertrain/moduleFrame.cfm?parent_object_id=1199), 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 (https://stormwater.pca.state.mn.us/index.php?title=References_for_high-gradient_stormwater_step-pool_swale)). 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 (Anne Arundel County, 2009 (https://stormwater.pca.state.mn.us/index.php?title=References_for_high-gradient_stormwater_step-pool_swale)). Stormwater step pools are designed with a wide variety of native plant species (https://stormwater.pca.state.mn.us/index.php?title=Plants_for_swales) depending on the hydraulic conditions and expected post-flow soil moisture at any given point within the stormwater step pool.

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Stormwater step pool. Courtesy of Limnotech.

Function within stormwater treatment train

Stormwater step pools may be located at the end of the **treatment train** (https://stormwater.pca.state.mn.us/index.php?title=Using_the_treatment_train_approach_to_BMP_selection), the main form of conveyance between or out of BMPs, or designed as **offline** configurations where the **Water Quality Volume** (https://stormwater.pca.state.mn.us/index.php?title=Water_quality_criteria) is diverted to the stormwater step pool. In any case, the practice may be applied as part of a stormwater management system to achieve one or more of the following objectives:

- reduce stormwater pollutants (**filtration** (https://stormwater.pca.state.mn.us/index.php?title=Filtration) or **infiltration** (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices) practices)
- increase groundwater recharge (infiltration practices)
- decrease runoff peak flow rates (filtration or infiltration practices)
- decrease the volume of stormwater runoff (infiltration practices)
- preserve **baseflow** in streams (infiltration practices)
- reduce thermal impacts of runoff (filtration or infiltration practices)

Typical applications

Typical applications of stormwater step pools with or without **underdrains** include the following, where relatively steep longitudinal slopes are present:

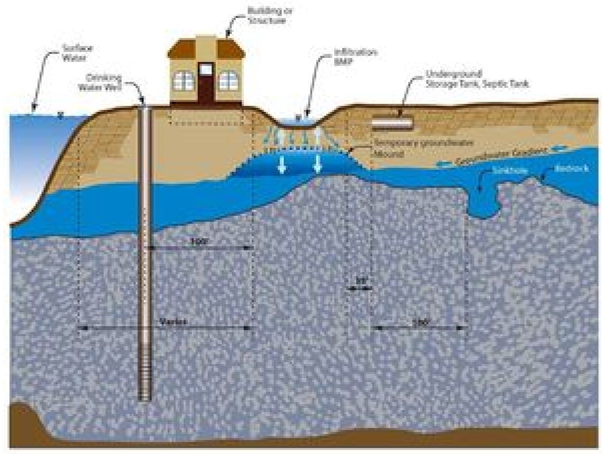
- individual lots for rooftop, driveway, and other on-lot impervious surface
- shared facilities in common areas for individual lots
- within right-of-ways along roads
- conveyance between detention structures and **receiving waters**
- retrofits of existing conveyance systems that are prone to gully erosion or incision

Infeasibility criteria

Certain site-specific conditions may make use of stormwater step pools without underdrains (infiltration) infeasible. Examples include:

- Where infiltrating water would threaten drinking water sources (e.g., in **Karst** (https://stormwater.pca.state.mn.us/index.php?title=Karst) areas)
- Where ordinances established by the local government with jurisdiction, such as setbacks (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_and_setback_(separation)_distances) from structures, conflict with the proposed location
- Where infiltrating water would threaten existing below grade basements

- Where in situ soil infiltration capacity (https://stormwater.pca.state.mn.us/index.php?title=Soils_with_low_infiltration_capacity) is too low or too high
- Where high levels of contaminants (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_and_contaminated_soils_and_groundwater) in soil or groundwater exist
- Where the only area available for siting does not allow for a safe overflow pathway to the **MS4** (Municipal Separate Storm Sewer System) or private storm sewer system
- Where reasonable concerns about erosion, slope failure, or down gradient flooding exist and cannot be overcome by swale design modifications



Schematic showing some horizontal and vertical separation distances from an infiltration BMP. A separation distance may be required, such as with a drinking water well, or recommended, as with an underground tank. (Source: CDM Smith) Not to scale.

The following site-specific conditions may make use of stormwater step pools swales with underdrains (filtration) infeasible:

- Where infiltrating water would threaten drinking water sources (e.g., stormwater step pools without impermeable liners in karst areas)
- Where inadequate separation distance from seasonally saturated soils or bedrock (https://stormwater.pca.state.mn.us/index.php?title=Shallow_soils_and_shallow_depth_to_bedrock) is available
- Where ordinances established by the local government with jurisdiction, such as setbacks from structures, conflict with the proposed location
- Where high levels of contaminants (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_and_contaminated_soils_and_groundwater) in soil or groundwater exist
- Where the only area available for siting does not allow for a safe overflow pathway to the municipal separate storm sewer system or private storm sewer system
- Where reasonable concerns about erosion, slope failure, or down gradient flooding exist and cannot be overcome by stormwater step pool design modifications

MPCA permit applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP) (https://stormwater.pca.state.mn.us/index.php?title=Construction_stormwater_program), which includes design and performance standards for permanent stormwater management systems. These standards must be applied in all projects in which at least 1 acre of new impervious area is being created, and the permit stipulates certain standards for various categories of stormwater management practices.

For regulatory purposes, stormwater step pools fall under the “Infiltration / Filtration" category described in the MPCA CGP. If used in combination with other practices, credit for combined stormwater treatment can be given. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the stormwater step pool will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice.

The following terms are thus used in the text to distinguish various levels of stormwater step pool design guidance:

- REQUIRED: Indicates design standards stipulated by the MPCA CGP (or other consistently applicable regulations).

- HIGHLY RECOMMENDED: Indicates design guidance that is extremely beneficial or necessary for proper functioning of the stormwater step pool, but not specifically required by the MPCA CGP.
- RECOMMENDED: Indicates design guidance that is helpful for stormwater step pool performance but not critical to the design.

Of course, there are situations, particularly retrofit projects, in which a stormwater step pool is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that additional and potentially more stringent design requirements may apply for a particular stormwater step pool, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Retrofit suitability

If adequate space exists, stormwater step pools are suitable for retrofit applications. These systems are used where topographic gradients and hydrology combine to develop greater erosive potential than where dry or wet swales of gentler slopes would suffice. Indicators of suitable locations may include evidence of open gully formation or where recent or proposed changes to site hydrology will increase the current condition's discharge of flow (e.g., new development, redevelopment, new routing of stormwater, conversion of native landscapes, etc.). However, space considerations often limit their use in **highly urban and ultra-urban environments** and some highway/road settings.

Special receiving waters suitability

The following table provides guidance regarding the use of stormwater step pools in areas upstream of special receiving waters.

Infiltration and filtration bmp[1] design restrictions for special waters and watersheds. See also Special waters and other sensitive receiving waters.
Link to this table

BMP Group	**A Lakes**	**B Trout Waters**	**receiving water** **C Drinking Water[2]**	**D Wetlands**	**E Impaired Waters**
Infiltration	RECOMMENDED	RECOMMENDED	NOT RECOMMENDED if potential stormwater pollution sources evident	RECOMMENDED	RECOMMENDED unless target TMDL pollutant is a soluble nutrient or chloride
Filtration	Some variations NOT RECOMMENDED due to poor phosphorus removal, combined with other treatments	RECOMMENDED	RECOMMENDED	ACCEPTABLE	RECOMMENDED for non-nutrient impairments

[1]Filtration practices include green roofs, bmps with an underdrain, or other practices that do not infiltrate water and rely primarily on filtration for treatment.

[2] Applies to groundwater drinking water source areas only; use the lakes category to define BMP design restrictions for surface water drinking supplies

Cold climate suitability

Stormwater step pools should remain effective water quality improvement systems for many years, even during winter conditions, if designed and constructed properly and it has been shown that hydraulic efficiency and **infiltration rates** can remain at levels used for design sizing. However, in cold climates, some special considerations (https://stormwater.pca.state.mn.us/index.php?title=Cold_climate_impact_on_runoff_management) are HIGHLY RECOMMENDED for stormwater step pools to ensure sustained functionality and limit the damage freezing temperatures and snow and ice removal may cause.

One concern with stormwater step pools (used for filtration) in cold weather is the ice that forms both over the top of the facility and within the soil interstices. To avoid these problems to the extent possible, it is HIGHLY RECOMMENDED that the facility be actively managed to keep it dry before it freezes in the late fall. This can be done by various methods, including limiting inflow and ensuring the underdrain is functional.

Even if the infiltration properties of a stormwater step pool are marginal for snowmelt runoff during the period of deep frost in the winter, the storage available in the facility will provide water quality benefit if it is dry entering the melt season. However, flow originating in an industrial area, a high traffic area where large amounts of salt are added, or another **potential stormwater hotspots (https://stormwater.pca.state.mn.us/index.php?title=Potential_stormwater_hotspots)** (PSH) should be diverted away from stormwater step pools if **pretreatment** (https://stormwater.pca.state.mn.us/index.php?title=Pretreatment) features have not been properly designed to handle such an increase in loading.

For all BMPs it is HIGHLY RECOMMENDED that snow and ice removal plans including predetermined locations for stockpiling be determined prior to or during the design process. Stormwater step pools cannot be used for significant snow storage areas as debris build-up, plant damage, and lower infiltration rates are likely to occur. Some snow storage is unavoidable when BMPs are adjacent to areas where snow removal is required, but it is critical that the property owner and snow and ice removal contractor have identified other areas for large scale snow storage.

Excessive deicing agents have the potential to create a hot spot in some locations that could lead to reduced infiltration rates or concentrations that exceed surface water or groundwater standards. Locations such as busy intersections on slopes, parking garage ramps or on walkways near the entrances of commercial buildings are likely to be heavily treated with deicing agents to avoid slip and falls or vehicle collisions. This should be taken into consideration when siting any stormwater step pool.

Plant selection is critical to ensure that the damaging effects of snow and ice removal do not severely impact plantings or seedings. Even a small amount of snow storage can break and uproot plants requiring additional maintenance in the spring. Woody trees and shrubs should be selected that can tolerate some salt spray (https://stormwater.pca.state.mn.us/index.php?title=Minnesota_plant_lists#Salt_tolerance) from plowing operations.

Water quantity treatment

Stormwater step pools can help reduce detention requirements for a site by providing elongated flow paths, longer times of concentration, and volumetric losses from infiltration and **evapotranspiration**. Generally, however, to meet site water quantity or peak discharge criteria, it is HIGHLY RECOMMENDED that another structural control (e.g., detention) be used in conjunction with a stormwater step pool.

Water quality treatment

Stormwater step pools can remove a wide variety of stormwater pollutants through chemical and bacterial degradation, sorption, and filtering. Surface water load reductions are also realized by virtue of the reduction in runoff volume.

Properly designed infiltration systems (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_high-gradient_stormwater_step-pool_swale) will accommodate a design volume based on the required water quality volume. Excess water must be by-passed and diverted to another BMP so that the design infiltration occurs within 48 hours if under state regulation, or generally within 72 hours under certain local and watershed regulations. In no case should the **bypass** volume be included in the pollutant removal calculation.

Design specifications should prevent putting contaminated runoff and excess water beyond that which will infiltrate within the given time frame. Any runoff containing toxic material or excess volume that cannot infiltrate should be diverted away from the infiltration system and reported as inflow to another treatment device.

Water quality performance of stormwater step pools can be diminished when plants die off in the fall and winter months as they are no longer able to uptake water and nutrients.

Pollutant removal values shown for dry swale in the adjacent table should be used for stormwater step pools.

Median pollutant removal percentages for several stormwater BMPs. Sources (http://stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs#References). More detailed information and ranges of values can be found in other locations in this manual, as indicated in the table.
Link to this table

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Infiltration (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_Best_Management_Practices)[2]	3	3	3	3	3	3	3	3
Biofiltration and Tree trench/tree box with underdrain	80	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	50	35	95	80
Sand filter	85	50	85	0	35	50	80	80

Practice	TSS	TP	PP	DP	TN	Metals[1]	Bacteria	Hydrocarbons
Iron enhanced sand filter (http://stormwater.pca.state.mn.us/index.php/Iron_enhanced_sand_filter_%28Minnesota_Filter%29)	85	74	85	60[6]	35	50	80	80
Dry swale	68	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	link to table (http://stormwater.pca.state.mn.us/index.php/Phosphorus_credits_for_bioretention_systems_with_an_underdrain)	35	0	80	80
Wet swale	35	0	0	0			0	
Constructed wet ponds[4, 5]	84	46	84	0	30	70	60	80
Constructed wetlands	73	38	69	0	30	70	60	80
Permeable pavement	74	41	82	0				
Green roofs	85	0	0	0				

TSS=Total suspended solids, TP=Total phosphorus, PP=Particulate phosphorus, DP=Dissolved phosphorus, TN=Total nitrogen

[1]Data for metals is based on the average of data for zinc and copper

[2]BMPs designed to infiltrate stormwater runoff, such as infiltration basin/trench, bioinfiltration, permeable pavement with no underdrain, tree trenches with no underdrain, and BMPs with raised underdrains.

[3]Pollutant removal is 100 percent for the volume infiltrated, 0 for water bypassing the BMP. For filtered water, see values for other BMPs in the table.

[4]Dry ponds do not receive credit for volume or pollutant removal

[5]Removal is for Design Level 2 (https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_stormwater_pond_as_a_BMP_in_the_MIDS_calculator#Pollutant_Reduction)

[6]Removal is for Tier 2 iron enhanced sand filter. Tier 1 removal is 40 percent, resulting in a TP removal of 65%

Limitations

The following general limitations should be recognized when considering installation of stormwater step pools without underdrains (infiltration).

- Limited monitoring data are available and field longevity is not well documented
- Failure can occur due to improper siting, design (https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_high-gradient_stormwater_step-pool_swale), construction (https://stormwater.pca.state.mn.us/index.php?title=Construction_specifications_for_high-gradient_stormwater_step-pool_swale) and

maintenance (https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_of_high-gradient_stormwater_step-pool_swale)
- Systems are susceptible to clogging by sediment and organic debris
- There is a risk of groundwater contamination depending on subsurface conditions, land use and aquifer susceptibility
- They are not ideal for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads

The following general limitations should be recognized when considering installation of stormwater step pools with underdrains (filtration).

- Limited monitoring data are available and field longevity is not well documented
- Failure can occur due to improper siting, design, construction and maintenance
- Systems are susceptible to clogging by sediment and organic debris
- They are not ideal for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads
- **Nitrification** of water in step pool media filters may occur where aerobic conditions exist.
- They offer limited or no water quantity control
- The potential to create odors exists

Related pages

- Terminology for high-gradient stormwater step-pool swale
- Overview for high-gradient stormwater step-pool swale
- Types of infiltration
- Types of filtration
- Design criteria for high-gradient stormwater step-pool swale
- Construction specifications for high-gradient stormwater step-pool swale
- Operation and maintenance of high-gradient stormwater step-pool swale
- Assessing the performance of high-gradient stormwater step-pool swale
- Check dams for stormwater swales
- Plants for swales
- Calculating credits for high-gradient stormwater step-pool swale
- Cost considerations (https://stormwater.pca.state.mn.us/index.php?title=Cost_considerations_for_dry_swale_(grass_swale))
- External resources for high-gradient stormwater step-pool swale
- References for high-gradient stormwater step-pool swale

Stormwater step pools are currently not included as a BMP in the MIDS calculator. The swale main channel BMP can be used, but the maximum allowable slope is 4 percent. To determine volume retention for slopes greater than 4 percent, you will need to develop a relationship between the slope and volume retained. To do this, determine volume retention at 0.5 percent slope increments for your site at slopes ranging from 0.5 to 4 percent. Determine the appropriate regression for volume retention and slope and calculate the volume retained at the slope for your site. The relationship is not linear. Links to MIDS calculator information are provided below.

- Requirements, recommendations and information for using dry swale (grass swale) without an underdrain in the MIDS calculator (https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_swale_without_an_underdrain_as_a_BMP_in_the_MIDS_calculator)
- Requirements, recommendations and information for using dry swale (grass swale) with an underdrain in the MIDS calculator (https://stormwater.pca.state.mn.us/index.php?title=Requirements,_recommendations_and_information_for_using_swale_with_an_underdrain_as_a_BMP_in_the_MIDS_calculator)

- Requirements, recommendations and information for using swale side slope as a BMP in the MIDS calculator