Chapter 8 – Selection Considerations for Stormwater BMPs

Introduction

This chapter provides guidance on selecting appropriate structural stormwater Best Management Practices (BMPs) based on the type of proposed land development activity, the applicable stormwater management requirements, the physical characteristics of the site, and other factors. The information presented in this chapter is intended to help designers and reviewers:

- Screen out unsuitable BMPs for a project site
- Select the most appropriate BMPs for a project site
- Locate stormwater BMPs appropriately on a project site
- Demonstrate that all reasonable efforts have been taken to comply with the stormwater management standards and performance criteria.

What's New in this Chapter?

- Updated BMP selection matrices consistent with re-organized functional classifications
- New flowchart to aid in the BMP selection process for a given project and site
- Prioritization of retention BMPs in the selection process consistent with updated stormwater management standards and performance criteria
- New selection factors related to climate resilience

The BMP selection process and factors presented in this chapter are applicable to new development and redevelopment activities, as well as stormwater retrofits. Chapter 9 - Stormwater Retrofits contains additional information on selection considerations specifically for stormwater retrofits. Other selection factors may also be considered in addition to those described in this chapter.

Stormwater BMP Selection Process

The flowchart in Figure 8- 1 outlines a recommended process for selecting stormwater BMPs for a given project and site to meet the applicable retention, treatment, and peak runoff attenuation requirements addressed in Chapter 4 - Stormwater Management Standards and Performance Criteria of this Manual. The process is focused on selection of structural stormwater BMPs after:

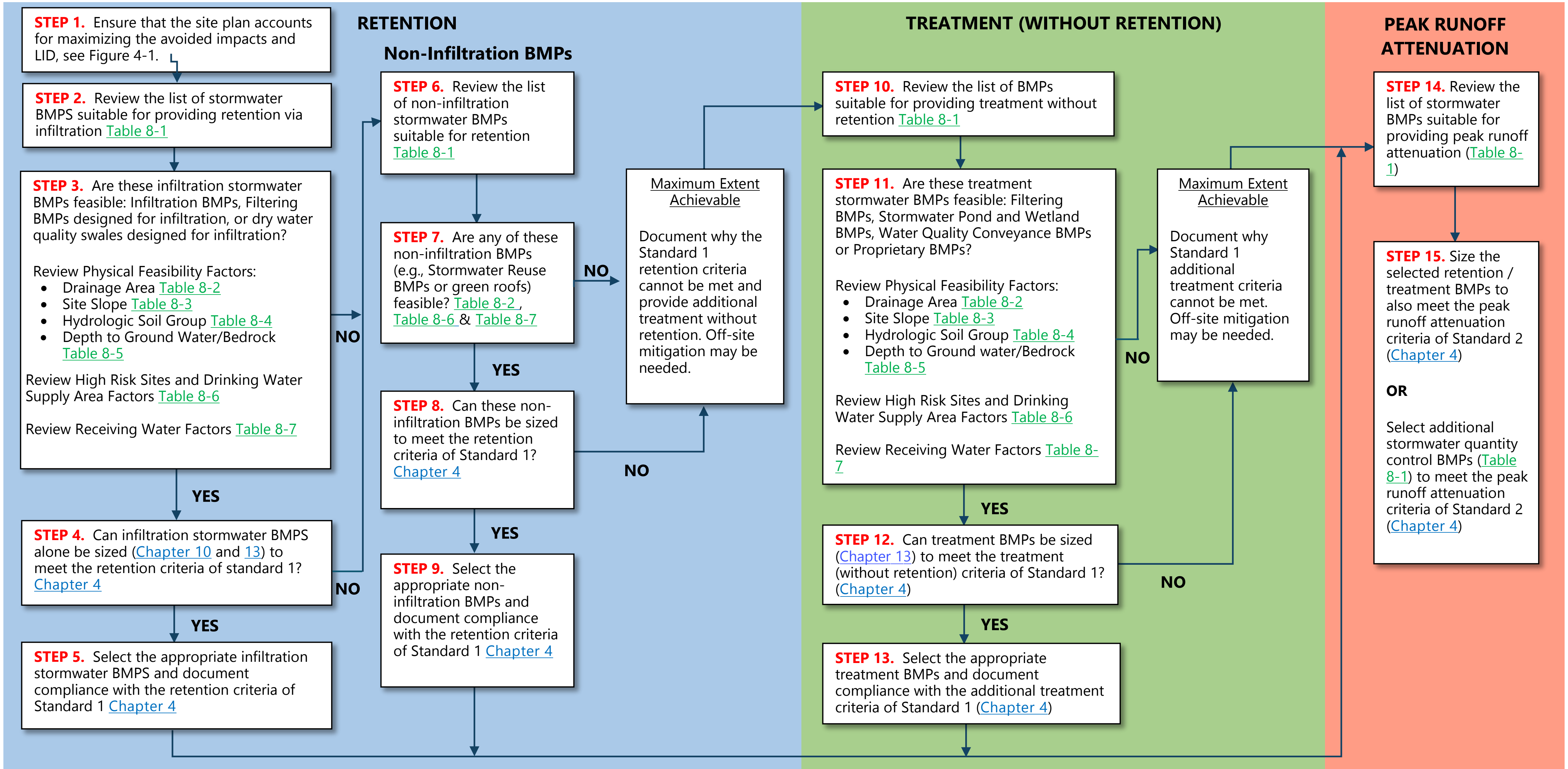
- Initial data has been collected to define existing site conditions
- Stormwater retention, treatment, and peak runoff attenuation requirements have been determined based on the stormwater management standards and performance criteria (Chapter 4 - Stormwater Management Standards and Performance Criteria)

- LID site planning and design approaches, including the use of Impervious Area (Simple) Disconnection, have been considered and applied to the MEA (Chapter 5 - Low Impact Development Site Planning and Design Strategies).

The recommended process incorporates the BMP selection factors and summary matrix tables that are presented in the following sections of this chapter. This process is meant to help the designing qualified professional[65] select stormwater BMP(s) using good engineering/design judgement and a consistent and repeatable approach that also demonstrates compliance with the stormwater management standards and performance criteria, while promoting creative and site-specific stormwater management design.

[65] As defined in the General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities.

Figure 8- 1 Recommended Stormwater BMP Selection Process



Stormwater BMP Selection Factors

Stormwater Management Suitability

Table 8- 1 provides a summary comparison of the structural stormwater BMPs addressed in this Manual relative to their suitability for providing various stormwater management functions and their ability to provide credit toward meeting the standards and performance criteria described in Chapter 4 - Stormwater Management Standards and Performance Criteria, including stormwater retention and treatment (Standard 1) and peak runoff attenuation (Standard 2).

As described in Chapter 7 - Overview of Structural Stormwater Best Management Practices and Chapter 10 - General Design Guidance for Stormwater Infiltration Systems, stormwater BMPs designed specifically for infiltration (i.e., Infiltration BMPs, Filtration BMPs, and dry water quality swales) are the preferred practices for meeting the stormwater retention requirement because they reduce stormwater runoff volumes and pollutant loads and provide groundwater recharge. Many of these practices can also be designed to attenuate peak runoff rates, providing both stormwater quality and quantity control in a single facility.

Stormwater Reuse BMPs (rain barrels and cisterns) and green roofs can also be used to satisfy the retention requirements although these practices do not infiltrate runoff or provide groundwater recharge. Filtering BMPs (bioretention systems, tree filters, and sand filters) can provide stormwater retention when specifically designed for infiltration, although they are generally less cost-effective than Infiltration BMPs and therefore are typically used where site characteristics limit the use of Infiltration BMPs.

Most Infiltration BMPs, Filtering BMPs, Stormwater Pond and Wetland BMPs, and Water Quality Conveyance BMPs are suitable choices for stormwater treatment, and most require the use of one of the Pretreatment BMPs identified in this Manual to preserve the pollutant removal efficiency, extend the service life, and reduce maintenance costs of the main stormwater BMP. In addition to pretreatment, Proprietary BMPs can also be used as stand-alone treatment systems (without retention) when selected and designed in accordance with the evaluation criteria described in Chapter 11 - Proprietary Stormwater BMPs.

Table 8- 1 Stormwater Management Suitability

BMP Category	BMP Type	Retention		Treatment	Pretreatment	Peak Runoff Attenuation (5)	Requires Pretreatment?
		Volume Reduction	Infiltration/ Recharge				
Pretreatment BMPs	Sediment Forebay				💧		No
	Pretreatment Vegetated Filter Strip				💧		No
	Pretreatment Swale				💧		No
	Deep Sump Hooded Catch Basin				💧		No
	Oil Grit Separator				💧		No
	Proprietary Pretreatment Device				(1)		No
Infiltration BMPs	Infiltration Trench	💧	💧	💧		💧	**Yes**
	Underground Infiltration System	💧	💧	💧		💧	**Yes**
	Infiltration Basin	💧	💧	💧		💧	**Yes**
	Dry Well	(2)	(2)	(2)			No
	Infiltrating Catch Basin	(3)	(3)	(3)			**Yes**
	Permeable Pavement	💧	💧	💧		💧	No
Filtering BMPs	Bioretention	(4)	(4)	💧		💧	**Yes**
	Sand Filter	(4)	(4)	💧		💧	**Yes**
	Tree Filter	(4)	(4)	💧			**Yes**
Stormwater Pond BMPs	Wet Pond			💧		💧	**Yes**
	Micropool Extended Detention Pond			💧		💧	**Yes**
	Wet Extended Detention Pond					💧	**Yes**
	Multiple Pond System			💧		💧	**Yes**
Stormwater Wetland BMPs	Subsurface Gravel Wetland			💧			**Yes**
	Shallow Wetland			💧			**Yes**
	Extended Detention Shallow Wetland			💧		💧	**Yes**
	Pond/Wetland System			💧		💧	**Yes**

BMP Category	BMP Type	Retention		Treatment	Pretreatment	Peak Runoff Attenuation (5)	Requires Pretreatment?
		Volume Reduction	Infiltration/ Recharge				
Water Quality Conveyance BMPs	Dry Water Quality Swale	💧	💧	💧		💧	**Yes**
	Wet Water Quality Swale			💧		💧	**Yes**
Stormwater Reuse BMPs	Rain Barrel	💧					No
	Cistern	💧				(7)	**Yes**
Proprietary BMPs	Manufactured Treatment System			(6)	💧		No
Other BMPs and BMP Accessories	Green Roof	💧				💧	No
	Dry Extended Detention Basin					💧	**Yes**
	Underground Detention (no infiltration)					💧	**Yes**

Notes:

(1) When used for pretreatment. See Proprietary BMPs for use as stand-alone treatment.
(2) Clean roof runoff only.
(3) Requires pretreatment BMP separate from the infiltrating catch basin itself.
(4) When designed for infiltration.
(5) When designed as an on-line system.
(6) See Chapter 11 - Proprietary Stormwater BMPs for use of proprietary stormwater BMPs as stand-alone treatment.
(7) May provide peak runoff attenuation depending on the volume of water in the cistern at the start of a storm event.

Legend				
	💧	💧	💧	Suitable for providing stormwater management function
	(See notes)	(See notes)	(See notes)	Suitable for providing stormwater management function under certain conditions or with design restrictions as noted
				Generally not suitable for providing stormwater management function

Physical Feasibility Factors

The physical characteristics of a site can dictate the feasibility of specific stormwater BMPs. A site's physical characteristics may restrict or preclude the use of certain BMPs or make a particular BMP too costly or ineffective for meeting stormwater management objectives. While every site has its own individual characteristics that need to be evaluated, the primary physical feasibility factors that should be considered for most sites are (Table 8-2):

- Contributing drainage area
- Site slope
- Soil infiltration capacity (Hydrologic Soil Group)
- Depth to seasonal high groundwater and bedrock

These factors are discussed in general terms below, followed by color-coded matrix tables that summarize the factors for each type of stormwater BMP. Chapter 13 - Structural Stormwater BMP Design Guidance contains additional information on physical feasibility and selection considerations for specific BMPs. Chapter 10 provides minimum required horizontal setback distances for stormwater infiltration systems.

Screening-level information may be used to initially evaluate soil characteristics and subsurface conditions at a site for the purpose of stormwater management planning, concept design, and retrofit screening, as described in the Initial Screening step of the soil evaluation guidance in Chapter 10. For final selection and design of stormwater BMPs, soil characteristics and subsurface conditions (soil infiltration capacity, depth to seasonal high groundwater table, and depth to bedrock) should be based on the results of test pits/soil borings and field infiltration testing (if necessary), which is also addressed in Chapter 10 and the BMP-specific design guidance presented in Chapter 13 - Structural Stormwater BMP Design Guidance.

Contributing Drainage Area

The efficiency of many stormwater BMPs decreases with increasing drainage area, runoff volume, and hydraulic load. Other BMPs require a minimum drainage area to maintain a permanent pool, wetlands, or submerged conditions. Table 8-2 indicates the general suitability of stormwater BMPs for various drainage areas, included minimum and maximum drainage areas, where applicable. Table 8-2 also identifies contributing drainage areas that may be suitable under certain conditions or with design restrictions. The minimum and maximum drainage areas presented in Table 8-2 should not be considered inflexible limits and may be increased or decreased slightly where a stormwater BMP supports other management objectives.

Site Slope

The ground slope at and immediately adjacent to the location of a stormwater BMP, as well as the slope of the contributing drainage area and drainage flow paths, are important factors in determining the feasibility of stormwater practices. As summarized in Table 8-3, most stormwater BMPs are limited to sites with slopes less than 10% to 15%, while the use of some

BMPs such as water quality swales and permeable pavement is restricted to slopes of approximately 5% or less.

Soil Infiltration Capacity

The feasibility and effectiveness of stormwater BMPs can be heavily influenced by soil infiltration capacity. As such soil health and soil type are incredibly important factors to the planning and ultimately the success of stormwater design. Table 8-4 summarizes the suitability of various types of stormwater BMPs based on Hydrologic Soil Group (as determined in the field from soil texture class), which is an indicator of the runoff potential and infiltration capacity of the underlying soils.

As described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems, stormwater infiltration systems are most suitable in soils with infiltration rates of 0.3 inch per hour or greater, at the location of the proposed infiltration system (or within the allowable horizontal testing distances as described above) and at or below the bottom of the system. Soils with infiltration rates of 0.3 inch per hour or greater generally correspond to Natural Resources Conservation Service Hydrologic Soil Group (HSG) A and B soils. Stormwater infiltration systems can also be suitable in soils with lower infiltration rates, including HSG C and D soils, provided the recommended sizing, drain time, horizontal setbacks, and vertical separation criteria are met and the system is designed with an underdrain. Research by the University of New Hampshire Stormwater Center and EPA Region 1 has shown that substantial stormwater infiltration and recharge can occur in lower infiltration rate soils. Ultimately, providing some infiltration is better than none, particularly for retrofit applications.

Other BMPs such as Stormwater Ponds, Stormwater Wetlands, and wet water quality swales rely on a permanent pool or saturated soil conditions and are best suited to sites with poorly drained soils such as HSG C and D soils.

Depth to Seasonal High Groundwater

The depth to the seasonal high groundwater table (SHGT) is a key factor in evaluating the feasibility and ultimately the design of many types of stormwater BMPs. For infiltration systems, adequate vertical separation between the bottom of the system and SHGT (generally 3 feet or more, but as low as 2 feet in some instances) is necessary to ensure adequate pollutant removal in the unsaturated zone and sufficient hydraulic capacity for proper functioning of the system. For filtering systems designed for infiltration, the vertical separation may consist of a combination of the filter layer (e.g., bioretention soil media) and the underlying native soil, provided that the bottom of the system is at least 1 foot above the SHGT. Stormwater BMPs designed with an underdrain and impermeable liner may be used in areas where the required vertical separation to SHGT cannot be met.

For stormwater ponds and wetlands, SHGT should be at or above the bottom of the system to maintain a permanent pool and wetland vegetation. An impermeable liner may be required for stormwater detention basins where SHGT is above the bottom of the basin to maximize the available storage volume within the basin.

Table 8-5 summarizes the suitability of stormwater BMPs based on depth to SHGT as determined from test pits or soil borings (refer to Chapter 10 for soil evaluation methods).

Depth to Bedrock

Depth to bedrock is another key consideration in the selection and design of stormwater BMPs. A minimum separation distance of 3 feet between the bottom of the system and bedrock or other impermeable material or subsurface layer is required for most BMPs. This distance can be reduced in some situations.

Table 8-5 summarizes the suitability of stormwater BMPs based on depth to bedrock as determined from test pits or soil borings (refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation methods).

Table 8-2. Physical Feasibility – Contributing Drainage Area

BMP Category	BMP Type	Contributing Drainage Area				
		< 0.5 ac	0.5 - 1 ac	1 - 5 ac	5 - 10 ac	> 10 ac
Infiltration BMPs	Infiltration Trench	💧	💧	💧		
	Underground Infiltration System	💧	💧	💧		
	Infiltration Basin	💧	💧	💧	💧	
	Dry Well	💧	💧	Multiple connected		
	Infiltrating Catch Basin	💧	💧	Multiple connected		
	Porous Asphalt	Not Cost Effective	(1)	(1)	(1)	(1)
	Pervious Concrete	(1)	(1)	(1)	(1)	(1)
	Permeable Concrete Interlocking Pavers	(1)	(1)	(1)	(1)	(1)
Filtering BMPs	Bioretention	(2)	💧	💧		
	Sand Filter	💧	💧	💧		
	Tree Filter	💧	Multiple connected			
Stormwater Pond BMPs	Wet Pond	(4)	(4)	(4)	(4)	💧
	Micropool Extended Detention Pond	(4)	(4)	(4)	(4)	💧
	Wet Extended Detention Pond	(4)	(4)	(4)	(4)	💧
	Multiple Pond System	(4)	(4)	(4)	(4)	💧
Stormwater Wetland BMPs	Subsurface Gravel Wetland	(4)	(4)	(4)	💧	💧
	Shallow Wetland	(4)	(4)	(4)	(4)	💧
	Extended Detention Shallow Wetland	(4)	(4)	(4)	(4)	💧

BMP Category	BMP Type	Contributing Drainage Area				
		< 0.5 ac	0.5 - 1 ac	1 - 5 ac	5 - 10 ac	> 10 ac
	Pond/Wetland System	(4)	(4)	(4)	(4)	💧
Water Quality Conveyance BMPs	Dry Water Quality Swale	(3)	(3)	(3)		
	Wet Water Quality Swale	(3)	(3)	(3)		
Stormwater Reuse BMPs	Rain Barrel	Small roof areas only				
	Cistern	💧	💧	Larger systems based on water demand		
Proprietary BMPs	Manufactured Treatment System	💧	💧	💧	Larger systems if allowed by manufacturer	
Other BMPs and BMP Accessories	Green Roof	💧	💧	💧	💧	💧
	Dry Extended Detention Basin			(5)	(5)	💧
	Underground Detention (no infiltration)	💧	💧	💧	💧	Max 25 AC

Notes:

(1) Contributing drainage area should not exceed 3 times area of permeable pavement.
(2) Rain gardens and other small-scale bioretention systems. For curb inlet planters, the recommended maximum ratio of contributing impervious drainage area to planter bed area is 10:1.
(3) No limit if runoff enters swale as sheet flow. May be suitable for larger areas, but limitations are most often associated with linear projects. The aid of a level spreader and larger filter strips will enhance these practices.
(4) Smaller drainage areas may be suitable if intercepting groundwater or with sufficient surface runoff to support permanent pool, required wetland depths, or submerged gravel bed. An impermeable liner may be required if the system is located in permeable soils and the bottom of the system does not intercept groundwater.
(5) Drainage areas smaller than 10 acres may require an excessively small outlet structure susceptible to clogging.

Legend	💧	Suitable
	(See notes)	Suitable under certain conditions or with design restrictions as noted
		Generally not suitable

Table 8-3. Physical Feasibility – Site Slope

BMP Category	BMP Type	Site Ground Slope (1)		
		Less than 2%	2% - 6%	6% - 10%
Infiltration BMPs	Infiltration Trench	💧	💧	💧
	Underground Infiltration System	💧	💧	💧
	Infiltration Basin	💧	💧	💧
	Dry Well	💧	💧	💧
	Infiltrating Catch Basin	💧	💧	💧
	Porous Asphalt	💧	5% max	
	Pervious Concrete	💧	5% max	
	Permeable Concrete Interlocking Pavers	💧	5% max	
Filtering BMPs	Bioretention	💧	💧	💧
	Sand Filter	💧	💧	💧
	Tree Filter	💧	💧	💧
Stormwater Pond BMPs	Wet Pond	💧	💧	(2)
	Micropool Extended Detention Pond	💧	💧	(2)
	Wet Extended Detention Pond	💧	💧	(2)
	Multiple Pond System	💧	💧	(2)
Stormwater Wetland BMPs	Subsurface Gravel Wetland	💧	💧	(2)
	Shallow Wetland	💧	💧	(2)
	Extended Detention Shallow Wetland	💧	💧	(2)
	Pond/Wetland System	💧	💧	(2)

BMP Category	BMP Type	Site Ground Slope (1)		
		Less than 2%	2% - 6%	6% - 10%
Water Quality Conveyance BMPs	Dry Water Quality Swale	💧	Check dams required	
	Wet Water Quality Swale	💧	Check dams required	
Stormwater Reuse BMPs	Rain Barrel	Not Applicable		
	Cistern	Not Applicable		
Proprietary BMPs	Manufactured Treatment System	Not Applicable		
Other BMPs and BMP Accessories	Green Roof	Ground Slope Not Applicable (max 20% roof slope)		
	Dry Extended Detention Basin	💧	💧	(2)
	Underground Detention (no infiltration)	💧	💧	💧

Notes:
(1) Refers to post-construction slope at the BMP site.
(2) More difficult and costly installation for site slopes of greater than 6% due to the need for a potentially large embankment and other design modifications. Limited to 9.4% resultant slope. Embankment slope may be 2-33% with a level spreader and 2-15% without.

Legend		
	💧	Suitable
	(See notes)	Suitable under certain conditions or with design restrictions as noted
		Generally not suitable

Table 8-4. Physical Feasibility – Soil Infiltration Capacity (Hydrologic Soil Group)

BMP Category	BMP Type	Hydrologic Soil Group (HSG)			
		A	B	C	D
Infiltration BMPs	Infiltration Trench	💧	💧	(4)(5)	
	Underground Infiltration System	💧	💧	(4)(5)	
	Infiltration Basin	💧	💧	(4)(5)	
	Dry Well	💧	💧	(4)(5)	
	Infiltrating Catch Basin	💧	💧	(4)(5)	
	Porous Asphalt	💧	💧	(4)(5)	
	Pervious Concrete	💧	💧	(4)(5)	
	Permeable Concrete Interlocking Pavers	💧	💧	(4)(5)	
Filtering BMPs	Bioretention	💧	💧	(4)(5)	(4)(5)
	Sand Filter	💧	💧	(4)(5)	(4)(5)
	Tree Filter	💧	💧	(4)(5)	(4)(5)
Stormwater Pond BMPs	Wet Pond	(1)	(1)	(1)	💧
	Micropool Extended Detention Pond	(1)	(1)	(1)	💧
	Wet Extended Detention Pond	(1)	(1)	(1)	💧
	Multiple Pond System	(1)	(1)	(1)	💧
Stormwater Wetland BMPs	Subsurface Gravel Wetland	(2)	(2)	(2)	💧
	Shallow Wetland	(1)	(1)	(1)	💧
	Extended Detention Shallow Wetland	(1)	(1)	(1)	💧
	Pond/Wetland System	(1)	(1)	(1)	💧

BMP Category	BMP Type	Hydrologic Soil Group (HSG)			
		A	B	C	D
Water Quality Conveyance BMPs	Dry Water Quality Swale	💧	💧	(4)(5)	(4)(5)
	Wet Water Quality Swale	(3)	(3)	💧	💧
Stormwater Reuse BMPs	Rain Barrel	Not Applicable			
	Cistern	Not Applicable			
Proprietary BMPs	Manufactured Treatment System	Not Applicable			
Other BMPs and BMP Accessories	Green Roof	Not Applicable			
	Dry Extended Detention Basin	💧	💧	Liner recommended to prevent groundwater inflow	
	Underground Detention (no infiltration)	💧	💧	💧	💧

Notes:

NRCS Hydrologic Soil Group (HSG) as determined from field-verified soil textural class of the soil (refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation methods).

(1) An impermeable liner is required if the bottom of the system does not intercept groundwater.
(2) The system should be lined with an impermeable liner to prevent groundwater exchange with runoff in the subsurface gravel bed.
(3) Feasible if constructed with an impermeable liner but wet water quality swales are generally impractical in HSG A and B soils
(4) Underdrain Recommended
(5) Dispersed/Sheet flow

Legend		
	💧	Suitable
	(See notes)	Suitable under certain conditions or with design restrictions as noted
		Generally not suitable or very limited suitability

Table 8-5. Physical Feasibility – Depth to Seasonal High Groundwater Table and Bedrock

BMP Category	BMP Type	Depth to Seasonal High Groundwater Table (1)				Depth to Bedrock		
		< 1 ft	1 – 2 ft	2 – 3 ft	> 3 ft	< 2 ft	2 – 3 ft	> 3 ft
Infiltration BMPs	Infiltration Trench			(2)	💧		(2)	💧
	Underground Infiltration System			(2)	💧		(2)	💧
	Infiltration Basin			(2)	💧		(2)	💧
	Dry Well			(2)	💧		(2)	💧
	Infiltrating Catch Basin			(2)	💧		(2)	💧
	Porous Asphalt			(2)	💧		(2)	💧
	Pervious Concrete			(2)	💧		(2)	💧
	Permeable Concrete Interlocking Pavers			(2)	💧		(2)	💧
Filtering BMPs	Bioretention		(3)	(2)	💧	(3)	(2)	💧
	Sand Filter		(3)	(2)	💧	(3)	(2)	💧
	Tree Filter		(3)	(2)	💧	(3)	(2)	💧
Stormwater Pond BMPs	Wet Pond	💧	💧	(4)		💧	💧	💧
	Micropool Extended Detention Pond	💧	💧	(4)		💧	💧	💧
	Wet Extended Detention Pond	💧	💧	(4)		💧	💧	💧
	Multiple Pond System	💧	💧	(4)		💧	💧	💧
Stormwater Wetland BMPs	Subsurface Gravel Wetland	💧	💧	(4)		💧	💧	💧
	Shallow Wetland	💧	💧	(4)		💧	💧	💧
	Extended Detention Shallow Wetland	💧	💧	(4)		💧	💧	💧
	Pond/Wetland System	💧	💧	(4)		💧	💧	💧

BMP Category	BMP Type	Depth to Seasonal High Groundwater Table (1)				Depth to Bedrock		
		< 1 ft	1 – 2 ft	2 – 3 ft	> 3 ft	< 2 ft	2 – 3 ft	> 3 ft
Water Quality Conveyance BMPs	Dry Water Quality Swale			(2)	💧		(2)	💧
	Wet Water Quality Swale	💧	💧	(4)		💧	💧	💧
Stormwater Reuse BMPs	Rain Barrel	Not Applicable				Not Applicable		
	Cistern	Not Applicable				Not Applicable		
Proprietary BMPs	Manufactured Treatment System	Not Applicable				Not Applicable		
Other BMPs and BMP Accessories	Green Roof	Not Applicable				Not Applicable		
	Dry Extended Detention Basin	(6)	💧	💧	💧	(5)	💧	💧
	Underground Detention (no infiltration)	💧	💧	💧	💧	💧	💧	💧

Notes:

Depth from bottom of infiltration systems or top of filtering systems to seasonal high groundwater table and bedrock or other impermeable material or subsurface layer as determined from test pits or soil borings (refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation methods).

(1) Stormwater BMPs designed with an underdrain system and impermeable liner may be used in areas where the required vertical separation to SHGT and bedrock cannot be met. Such systems are suitable for providing treatment but do not provide retention credit.
(2) Strictly residential uses or for stormwater retrofits where the minimum 3-foot separation cannot be met due to existing site constraints and there is little risk to groundwater quality, or where groundwater is already impacted (classified as GB) and there is little risk to groundwater quality from the infiltrated stormwater.
(3) For unlined filtering systems, the bottom of the filtering system should be at least 1 foot above SHGT and bedrock.
(4) Liner required in permeable soils.
(5) At least 1 foot of separation required.
(6) Liner recommended.

Legend			
	💧	💧	Suitable
	(See notes)	(See notes)	Suitable under certain conditions or with design restrictions as noted
			Generally not suitable

High Risk Sites and Drinking Water Protection Areas

Certain land use activities and site characteristics restrict or preclude the use of some stormwater BMPs, particularly near groundwater and surface drinking water supplies. Table 8-6 summarizes the suitability of stormwater BMPs based on the following factors:

- Land Uses with Higher Potential Pollutant Loads
- Contaminated sites
- Groundwater drinking water supply areas
- Surface drinking water supply areas

Land Uses with Higher Potential Pollutant Loads

Certain land uses or land use activities can result in higher potential stormwater pollutant loads. Chapter 10 - General Design Guidance for Stormwater Infiltration Systems identifies designated Land Uses with Higher Potential Pollutant Loads (LUHPPLs), which include a number of specific industrial and commercial uses and activities. Infiltration of stormwater from LUHPPLs is only allowed for the specific LUHPPLs identified in Table 10-4, at the discretion of the review authority and under the conditions listed in Chapter 10. An impermeable liner is generally required for stormwater BMPs that receive stormwater from LUHPPLs and that could potentially discharge to groundwater, including BMPs that intercept groundwater (Stormwater Pond and Wetland BMPs and wet water quality swales) and dry detention basins, to reduce the risk of groundwater contamination.

Contaminated Sites

As addressed in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems, infiltration of stormwater in areas with soil or groundwater contamination such as brownfield sites and urban redevelopment areas can mobilize contaminants. Infiltration BMPs should not be used where subsurface contamination is present from prior land use due to the increased threat of pollutant migration associated with increased hydraulic loading from infiltration systems, unless contaminated soil is removed and the site is remediated, or if approved by CT DEEP on a case-by-case basis. Filtering BMPs and dry water quality swales may be used in areas with subsurface contamination if designed with an underdrain system and impermeable liner. Other non-infiltration BMPs may also be used on such sites with an impermeable liner.

Groundwater Drinking Water Supply Area

Groundwater is a major source of drinking water in Connecticut for residences that rely on small private wells and larger water distributors. This applies to both water supply aquifers and Class GA and GAA groundwaters as defined by CT DEEP. Groundwater is also the source of dry weather flows (baseflow) in watercourses, which is critical for maintaining suitable habitat. It is important to maintain a high-quality recharge to groundwater in water supply aquifers and Class GA and GAA waters.

Infiltration of stormwater within Aquifer Protection Areas and other groundwater drinking water supply areas can potentially contaminate groundwater drinking water supplies. As discussed in Chapter 10, aboveground Infiltration BMPs such as infiltration basins or bioretention systems designed for infiltration should be used for paved surface runoff to provide an opportunity for volatilization of volatile organic compounds to the extent possible before the stormwater can infiltrate into the ground. Subsurface Infiltration BMPs (i.e., infiltration trenches, infiltration chambers, dry wells, infiltrating catch basins) should only be used to infiltrate clean roof runoff.

Infiltration of stormwater within public or private wellhead protection areas (see minimum horizontal setback distances for public and private wells in Recommended Minimum Horizontal Setback Distances for Stormwater Infiltration Systems) should be limited to clean roof runoff only.

Surface Drinking Water Supply Areas

Surface waters that supply drinking water are especially susceptible to contamination by bacteria and other pathogens. Other contaminants-of-concern may be defined for specific water supply systems by the owner/operator or the State Department of Health. Stormwater BMPs for sites within drinking water supply watersheds should target these potential contaminants. The Public Health Code also requires a 100-foot separation distance between drainage or treatment practice outlets and public water supply tributaries.

Stormwater infiltration or surface stormwater discharges in close proximity to surface drinking water supply reservoirs or tributaries to such water supplies can threaten drinking water quality. Stormwater infiltration systems should be located a minimum distance horizontally from surface drinking water supplies as described in Chapter 10 (Recommended Minimum Horizontal Setback Distances for Stormwater Infiltration Systems). Infiltration of clean roof runoff is allowed within the horizontal setback distances. Outlets of stormwater BMPs should be located at least 200 feet from a public water supply reservoir and 100 feet from streams tributary to a public water supply reservoir, consistent with the Connecticut Public Health Code.

Table 8-6. High Risk Sites and Drinking Water Supply Area Suitability

BMP Category	BMP Type	Land Uses with Higher Potential Pollutant Loads	Contaminated Sites (2)	Groundwater Drinking Water Supply Areas (3)	Surface Drinking Water Supply Areas (4)
Infiltration BMPs	Infiltration Trench	(1)		Clean roof runoff only	(5)
	Underground Infiltration System	(1)		Clean roof runoff only	(5)
	Infiltration Basin	(1)		💧	(5)
	Dry Well	(1)		Clean roof runoff only	(5)
	Infiltrating Catch Basin	(1)		Clean roof runoff only	(5)
	Porous Asphalt	(6)	(6)	💧	(5)
	Pervious Concrete	(6)	(6)	💧	(5)
	Permeable Concrete Interlocking Pavers	(6)	(6)	💧	(5)
Filtering BMPs	Bioretention	(1)	(6)	💧	(5)
	Sand Filter	(1)	(6)	💧	(5)
	Tree Filter	(1)	(6)	💧	(5)
Stormwater Pond BMPs	Wet Pond	Liner required	Liner required	💧	(5)
	Micropool Extended Detention Pond	Liner required	Liner required	💧	(5)
	Wet Extended Detention Pond	Liner required	Liner required	💧	(5)
	Multiple Pond System	Liner required	Liner required	💧	(5)
Stormwater Wetland BMPs	Subsurface Gravel Wetland	Liner required	Liner required	💧	(5)
	Shallow Wetland	Liner required	Liner required	💧	(5)
	Extended Detention Shallow Wetland	Liner required	Liner required	💧	(5)

BMP Category	BMP Type	Land Uses with Higher Potential Pollutant Loads	Contaminated Sites (2)	Groundwater Drinking Water Supply Areas (3)	Surface Drinking Water Supply Areas (4)
	Pond/Wetland System	Liner required	Liner required	💧	(5)
Water Quality Conveyance BMPs	Dry Water Quality Swale	(1)	(6)	💧	(5)
	Wet Water Quality Swale	Liner required	Liner required	💧	(5)
Stormwater Reuse BMPs	Rain Barrel	💧	💧	💧	💧
	Cistern	💧	💧	💧	💧
Proprietary BMPs	Manufactured Treatment System	💧	💧	💧	(5)
Other BMPs and BMP Accessories	Green Roof	💧	💧	💧	💧
	Dry Extended Detention Basin	Liner required	Liner required	💧	(5)
	Underground Detention (no infiltration)	💧	💧	💧	(5)

Notes:

(1) Infiltration of stormwater from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) is only allowed for the specific LUHPPLs listed in Table 10-4, at the discretion of the review authority and under the conditions listed in Chapter 10 (i.e., receive treatment by another BMP prior to infiltration).

(2) Infiltration BMPs should not be used where site contamination is present unless contaminated soil is removed and the site is remediated, or if approved by CT DEEP on a case-by-case basis. An impermeable liner may also be required.

(3) Aquifer Protection Areas and other groundwater drinking water supply areas. Infiltration within public or private wellhead protection areas should be limited to clean roof runoff only.

(4) Infiltration systems should be located a minimum distance horizontally from surface drinking water supplies as described in Table 10-3. Infiltration of clean roof runoff is allowed within the horizontal setback distances.

(5) Outlets of stormwater BMPs should be located at least 200 feet from a public water supply reservoir and 100 feet from streams tributary to a public water supply reservoir.

(6) Liner and underdrain required.

Legend		
	💧	Suitable
	(See notes)	Suitable under certain conditions or with design restriction as noted
		Generally not suitable

Receiving Waters

Selection of stormwater BMPs should consider the type and sensitivity of the downstream receiving waters. All stormwater BMPs should be selected and designed with consideration of stormwater pollutants of concern for the receiving waterbody, such as pollutants associated with a known water quality impairment or Total Maximum Daily Load (TMDL). Table 8-7 summarizes the suitability of stormwater BMPs based on some of the several common types of receiving waters and associated pollutants of concern:

- Coldwater streams (thermal/temperature)
- Freshwater lakes and ponds (phosphorus and sediment)
- Coastal waters and estuaries (nitrogen and bacteria)

Note that this is just a summary of some of the common types of receiving waters and the associated pollutant types (for example bacteria can often be associated with freshwater lakes and ponds too).

Coldwater Streams

Coldwater streams are areas or reaches of streams with water cold enough throughout the year to support coldwater fish species. Coldwater streams, including Class B streams or managed stocked streams, can be adversely impacted by stormwater runoff with elevated temperatures. In addition, the rate and volume of stormwater discharges from new developments are especially critical to these systems, as they could impact the flood carrying capacity of the watercourse and increase the potential for channel erosion.

Infiltration BMPs and Filtering BMPs are recommended for sites that discharge to or are located within the drainage areas of coldwater streams. Stormwater BMPs that provide treatment by infiltration and filtration can moderate runoff temperatures by thermal exchange with cooler subsurface materials. Stormwater BMPs with large permanent pools that are exposed to direct sunlight such as Stormwater Pond and Wetland BMPs can discharge stormwater with increased temperatures and should not be used for sites that discharge within 200 feet of coldwater streams.

Freshwater Lakes and Ponds

Lakes and ponds are especially sensitive to sediment and nutrient loadings. Excess sediments and nutrients are the cause of algal blooms in these surface waters, leading to eutrophication and degradation. These conditions often result in costly dredging and rehabilitation projects. In freshwater systems, phosphorus is typically the limiting nutrient, that is, much less phosphorus is needed compared to other nutrients such as nitrogen to create eutrophic conditions. As a result, stormwater BMPs should focus on phosphorus removal for stormwater discharges to lakes and ponds and watercourses that feed lakes and ponds. Infiltration BMPs and Filtering BMPs are generally most effective for removing phosphorus.

Coastal Waters and Estuaries

Coastal and estuarine waters are more sensitive to nitrogen loadings than freshwater systems. In saltwater systems, nitrogen tends to be the limiting nutrient as opposed to phosphorus. Excess loading of nitrogen is a major source of water quality impairments in Connecticut's coastal embayments and Long Island Sound. Bacteria are also a concern given the sensitivity of public swimming areas and shellfish beds to bacterial loadings and the many bacteria-impaired waters along Connecticut's highly urbanized coastline.

Stormwater BMPs that incorporate vegetative uptake and microbial nitrogen removal in an anaerobic subsurface zone (anoxic conditions) such as Stormwater Pond and Wetland BMPs (e.g., subsurface gravel wetlands) are generally more effective for nitrogen removal, while Infiltration and Filtering BMPs are generally more effective for reducing bacteria loads. Bioretention systems can also be designed with a submerged Internal Water Storage zone within the lower gravel storage reservoir for enhanced nitrogen removal.

Stormwater BMPs that rely on adequate vertical separation distance to groundwater (e.g., infiltration systems) are also more vulnerable to rising groundwater levels when located in coastal areas that are predicted to experience substantial sea level rise.

Other Selection Factors

Other factors should be considered when selecting the most appropriate stormwater BMP for a project site. These include but are not limited to:

Maintenance

Although all stormwater BMPs require regular maintenance, some BMPs require more frequent inspection and cleaning, special equipment, and/or staff training. BMPs should be selected that are compatible with the equipment, labor resources, and available funding of the parties responsible for maintenance. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices and Chapter 13 - Structural Stormwater BMP Design Guidance of this Manual for general and BMP-specific maintenance requirements.

Affordability

Construction costs of stormwater BMPs vary considerably depending on system type (surface versus subsurface), configuration (on-line versus off-line), materials, pretreatment requirements, and system sizing. BMPs should be selected for maximum cost-effectiveness to meet the stormwater management standards and performance criteria outlined in this Manual. Long-term operation and maintenance costs, including periodic replacement of the entire system or system components (e.g., clogged filter media), should also be considered.

Community Acceptance and Co-Benefits

Certain stormwater BMPs may have stronger community acceptance than others based on aesthetics and reported nuisance problems. Stormwater BMPs that provide other benefits in addition to stormwater management (i.e., green infrastructure) such as streetscape improvements, reduction in heat island effect, greening of public spaces, and flood resilience may be preferred and have stronger acceptance by the community than traditional gray infrastructure systems.

Table 8-7. Receiving Water Selection Factors

BMP Category	BMP Type	Coldwater Streams (Thermal)	Freshwater Lakes & Ponds (Phosphorus & Sediment)	Coastal Waters & Estuaries (5) (Nitrogen & Bacteria)
Infiltration BMPs	Infiltration Trench	💧	💧	💧
	Underground Infiltration System	💧	💧	💧
	Infiltration Basin	💧	💧	💧
	Dry Well	💧	💧	💧
	Infiltrating Catch Basin	💧	💧	💧
	Porous Asphalt	💧	💧	💧
	Pervious Concrete	💧	💧	💧
	Permeable Concrete Interlocking Pavers	💧	💧	💧
Filtering BMPs	Bioretention	(1)	💧	(4)
	Sand Filter	(1)	💧	💧
	Tree Filter	(1)	💧	💧
Stormwater Pond BMPs	Wet Pond	(6)	💧	(2)
	Micropool Extended Detention Pond	(6)	(3)	(2)
	Wet Extended Detention Pond	(6)	(3)	(2)
	Multiple Pond System	(6)	(3)	(2)
Stormwater Wetland BMPs	Subsurface Gravel Wetland	💧	(3)	(2)
	Shallow Wetland	(6)	(3)	(2)
	Extended Detention Shallow Wetland	(6)	(3)	(2)

BMP Category	BMP Type	Coldwater Streams (Thermal)	Freshwater Lakes & Ponds (Phosphorus & Sediment)	Coastal Waters & Estuaries (5) (Nitrogen & Bacteria)
	Pond/Wetland System	(6)	(3)	(2)
Water Quality Conveyance BMPs	Dry Water Quality Swale	(1)	💧	💧
	Wet Water Quality Swale		(3)	(2)
Stormwater Reuse BMPs	Rain Barrel	💧	💧	💧
	Cistern	💧	💧	💧
Proprietary BMPs	Manufactured Treatment System		💧	
Other BMPs and BMP Accessories	Green Roofs	💧		
	Dry Extended Detention Basin	(6)		
	Underground Detention (no infiltration)	💧		

Notes:

(1) When designed for infiltration. When not designed for infiltration, surface discharge should be greater than 200 feet from coldwater stream.
(2) Provide long detention times (greater than 48 hours extended detention) for more effective bacteria removal.
(3) Provide larger permanent pool and/or longer flow path through system to increase residence time for more effective phosphorus removal.
(4) Design with submerged filter bed (Internal Water Storage zone or Internal Storage Reservoir) for enhanced nitrogen removal.
(5) Design to account for projected sea level rise and associated rise in groundwater to maintain required depth to seasonal high groundwater table.
(6) Discharge not allowed within 200 feet of coldwater streams.

Legend		
	💧	Suitable
	(See notes)	Suitable under certain conditions or with design restrictions as noted
		Generally not suitable

Chapter 9 – Stormwater Retrofits

Introduction

This chapter provides guidance for retrofitting sites that are already developed to reduce the adverse impacts of existing stormwater runoff. A "retrofit" is a project that modifies an existing developed site for the primary purpose of improving the quality of and reducing the quantity of stormwater discharge. This is primarily achieved through disconnecting, and therefore reducing, Directly Connected Impervious Area (DCIA), as defined in Chapter 2 - Stormwater Impacts.[66] Stormwater retrofits can be used to disconnect DCIA by converting impervious surfaces to pervious surfaces, redirecting runoff from impervious surfaces to adjacent pervious areas, and adding new or modifying existing structural stormwater Best Management Practices (BMPs) to infiltrate or reuse stormwater runoff from impervious areas.

What's New in this Chapter?

- Consistency with stormwater retrofit requirements in the CT DEEP stormwater general permits
- New guidance on retrofit planning approaches
- Updated information on stormwater retrofit types and applications
- Use of stormwater retrofits for DCIA disconnection and reduction
- Use of EPA stormwater BMP performance curves for retrofit sizing and crediting
- Updated information on other resources and tools for stormwater retrofit planning and design

This chapter describes the reasons for and benefits of stormwater retrofits, various retrofit approaches and types, identification and design of stormwater retrofits, quantifying retrofit benefits (i.e., crediting), and common retrofit applications. Additional guidance on stormwater retrofits can be found in the information resources at the end of this chapter.

Why Retrofit? – Objectives and Benefits of Stormwater Retrofits

The objective of stormwater retrofitting is to improve the water quality mitigation functions of existing developed sites either lacking or having insufficient stormwater controls. In Connecticut, prior to the 1970s, site drainage design did not require stormwater detention for controlling

[66] Impervious area with a direct hydraulic connection to a storm drainage system or a waterbody via continuous paved surfaces, gutters, drainpipes, or other conventional conveyance and detention structures that do not reduce runoff volume is referred to as "Directly Connected Impervious Area (DCIA)." DCIA includes impervious surfaces that contribute stormwater runoff to a stream, other waterbody, or wetland. Impervious areas that are not directly connected to a storm drainage system, receiving waterbody, or wetland are considered "disconnected" and therefore not considered DCIA. DCIA can be disconnected through retrofits that retain and/or treat the appropriate portion of the Water Quality Volume as described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

post-development peak flows. As a result, drainage, flooding, and erosion problems are common in many older developed areas. Furthermore, local and state stormwater regulatory requirements and the resulting stormwater designs in the 1980s and 1990s focused on detention and controlling peak rates of runoff, without regard for the quality of runoff, runoff volume, groundwater recharge, or other hydrologic impacts. Therefore, much of the existing, older development in Connecticut still lacks adequate stormwater controls.

Retrofits can be used to achieve stormwater and water quality objectives such as reducing pollutant loads to impaired water bodies and meeting pollutant load reduction targets in Total Maximum Daily Loads (TMDLs). Other related benefits of stormwater retrofits, particularly those that incorporate green infrastructure and Low Impact Development (LID) techniques, include:

- Recharging groundwater to support streamflow and drinking water supplies.
- Reducing flood risk by reducing runoff volumes.
- Mitigating impacts of climate change (increased precipitation, flooding, drought, and higher temperatures).
- Providing habitat.
- Improving community aesthetics and overall quality of life.

The CT DEEP MS4 General Permit requires regulated municipalities, CTDOT, and other state and federal entities to implement stormwater retrofits to disconnect and reduce DCIA and track the progress of their DCIA reduction efforts relative to specific reduction goals. Permit holders and/or municipalities can also identify stormwater retrofits as part of an off-site mitigation program for new development and redevelopment projects that are unable to fully comply with stormwater management requirements on-site.

Retrofit Approaches

There are two major approaches to implementing stormwater retrofits – the opportunistic approach and the retrofit planning approach (SNEP Network, 2022).[67] The two approaches can be used together in a complementary fashion to develop and implement a successful retrofit program.

Opportunistic Approach

The opportunistic approach involves integrating stormwater retrofits into already planned construction projects. Retrofits are generally more cost-effective when implemented in conjunction with planned infrastructure upgrades since construction of the retrofit can be coupled with other planned site disturbance and improvements. An example of an opportunistic retrofit is incorporation of bioretention planters, roadside bioswales, infiltrating catch basins, or underground infiltration chambers into a planned roadway improvement project. This approach

[67] Southeast New England Program (SNEP) Network. 2022. *Stormwater Retrofit Manual.* Developed in conjunction with University of New Hampshire Stormwater Center, EPA Region 1, and state agencies.

is best suited to Connecticut municipalities and the Connecticut Department of Transportation (CTDOT), who are responsible for regular planned maintenance and improvement projects. Stormwater retrofits can be incorporated into infrastructure improvements as part of municipal and state capital improvement plans.

The opportunistic approach is most effective when the project owner:

- Proactively identifies upcoming retrofit opportunities, such as construction projects identified in capital improvement plans, and includes retrofits in the planning and design of these projects.
- Develops a targeted suite of preferred structural stormwater BMPs to be used with retrofit projects, including typical details, specifications, and installation approaches that work best for the project owner.
- Selects and designs retrofits such that the BMPs can be maintained using available staff resources and equipment.
- Allows for some changes, as necessary, to the base design to maximize stormwater treatment.
- Budgets for some increases in project costs to include the retrofit in a planned improvement project as a trade-off for more costly stand-alone retrofits in the future.
- Tailors the scale and type of stormwater BMPs to the project they are being paired with. Projects that already impact grading and the drainage system likely provide additional opportunities to incorporate more sophisticated controls by allowing for changes to the stormwater system and taking advantage of mobilization of the required construction equipment. In addition, projects with larger overall construction costs may provide more opportunity to absorb relatively lower-cost SCMs.
- Seeks low-cost creative solutions as the first option. Small, inexpensive modifications to site drainage patterns can have large impacts. For example, a simple curb cut can allow stormwater runoff from an impervious area to be treated over an adjoining pervious area.

Planning Approach

In the planning approach, stormwater retrofit opportunities are identified and prioritized through a proactive planning process. This approach results in the selection of retrofits that will have the greatest water quality or other benefits at the lowest cost. The planning approach is typically most effective for identifying retrofits to meet the requirements of a permit, watershed plan, or TMDL implementation plan.

In Connecticut, the MS4 General Permits require regulated municipalities and the CTDOT to develop stormwater retrofit plans to meet the DCIA disconnection and reduction goals specified in the permit. The retrofit plan must identify and prioritize sites that may be suitable for retrofit and include a prioritized list of retrofit projects.

The MS4 General Permits also requires regulated municipalities and the CTDOT to allow for off-site stormwater mitigation when a new development or redevelopment project cannot fully meet the retention or treatment requirements on-site. The retrofit planning process can be used to identify retrofit projects that could be implemented as part of an off-site stormwater mitigation program, as described in Chapter 4 - Stormwater Management Standards and Performance Criteria. Eligible retrofits are typically located on another site within the same CT DEEP Subregional Basin or USGS HUC12 watershed (and preferably the same municipality) as the project site. The proposed retrofit project can be funded directly by the project proponent, or the project proponent can propose a fee to be paid by the project proponent to be deposited into a dedicated account of the municipality for use by the municipality to fund in whole or in part the stormwater retrofit.

Developing and implementing a stormwater retrofit plan typically involves the following basic steps:

Step 1. Identify and Quantify Goals

This first step involves identifying and quantifying specific goals for the retrofit program. Goals may include making progress towards DCIA reduction targets specified in the MS4 General Permits, pollutant reduction targets identified in a watershed plan or TMDL, installation of a specific type and/or number of retrofits, or implementing retrofits within a specified budget and timeframe. Preferences for or avoidance of certain types of BMPs, maintenance capabilities and limitations, and planned infrastructure improvement projects should be identified at this stage. Other program goals should also be identified such as flood reduction, reduced heat island effect, and other social, economic and community benefits.

Step 2. Gather Background Information and Data

The next step in the process involves gathering background information and data that are used in the desktop screening process in Step 3. Background information and data typically include:

- Aerial imagery.
- Drainage system mapping.
- Mapping of priority areas based on MS4 regulated areas, impervious cover, and water quality impairments.
- Parcel ownership and land use.
- Road classification and width for right-of-way opportunities.
- Topography/slope, soils, and other mapped physical site characteristics.

Step 3. Conduct Desktop Screening

Using the geospatial information gathered in Step 2, conduct a desktop screening analysis to initially identify potential sites for retrofits. Potential sites for consideration could be sites where a construction project is already planned or sites that could be retrofitted independently of other projects. Sites with older or ineffective stormwater BMPs can also be considered for retrofits in the form of upgrades and improvements. The initial screening process typically involves a desktop analysis to identify parcels or areas within the public right-of-way that meet certain site suitability criteria for structural stormwater BMPs (soils, depth to groundwater, impervious cover, available space, etc.), land ownership (i.e., publicly owned land often provides greater opportunity for retrofits), and other factors like public visibility and demonstration value.

Step 4. Perform Detailed Site Assessment

Once potential retrofit sites are identified, a more detailed assessment of each site is performed to verify the feasibility of retrofits, identify specific areas on the site best suited for retrofits, and identify possible stormwater BMP types. Site opportunities and constraints are identified during this process including site drainage patterns and areas, storm drainage system configuration, available space, utility conflicts, and site operations. In addition to a site walk and visual observation, the site assessment may also involve field data collection such as field survey, soil investigation (test pits, soil borings, and field infiltration testing), utility research, etc.

Step 5. Develop Design Concepts

Once the site assessment process is completed, the list of potential retrofit sites is refined by eliminating sites that are not suitable for retrofits. Retrofit concepts are typically developed for the remaining sites with the greatest potential for retrofits. Retrofit design concepts are then developed to a level of detail, often consisting of a plan view sketch and typical construction details, required to estimate benefits and costs for planning purposes.

Step 6. Estimate Benefits and Costs

Once the retrofit design concepts are developed, preliminary order-of-magnitude cost estimates are developed for each retrofit concept along with initial estimates of pollutant load reductions and/or DCIA reduction. The stormwater BMP performance curves developed by EPA and the University of New Hampshire Stormwater Center (see Chapter 4 – Stormwater Management Standards and Performance Criteria) and the section at the end of this chapter) can be used to quantify the pollutant load reduction benefit of specific BMP retrofits, as well as to inform retrofit prioritization and final BMP selection and sizing.

Step 7. Prioritize Sites for Implementation

Retrofit sites and BMPs are prioritized based on criteria that reflect the retrofit goals identified in Step 1. These criteria may include but are not limited to:

- Estimated total cost and available budget.
- Estimated pollutant reduction achieved.
- Estimated cost per pollutant reduction (i.e., cost effectiveness).
- Feasibility (ownership, ease of construction, access, physical site constraints, maintenance burden, community acceptance, etc.)

- Degree to which the retrofit achieves other goals (flood reduction, heat island reduction, reduced heat island effect, demonstration value, and other social, economic and community benefits).

The prioritization method can be quantitative (i.e., scoring and weighing factors), semi-quantitative (scoring combined with non-numeric ratings), or qualitative.

Step 8. Implement Retrofit Projects

Stormwater retrofits should be implemented (i.e., design, permitting, and construction) according to the priorities identified in the planning process as funding and opportunities become available. The final stormwater retrofit designs may be different than the concepts developed during the retrofit planning phase due to the collection and analysis of more detailed site information. During the design process, site specific survey, soil analysis, and site evaluation can present factors that may change the size, type, or exact location of the retrofit BMPs.

The opportunistic and planning approaches to stormwater retrofitting can also be combined. For example, the stormwater retrofit planning process may serve as a pipeline for retrofit projects to be included in a capital infrastructure plan, while planned capital projects may be identified for inclusion in a retrofit plan.

Retrofit Types

There are many types of stormwater retrofits that can be used to disconnect and reduce DCIA and provide other benefits as described earlier in this chapter. The major types of retrofits addressed in this Manual are described below.

Impervious Area Conversion

Impervious area conversion involves removing and replacing existing excess impervious surfaces (pavement, buildings, etc.) with pervious vegetated surfaces (lawn, meadow, woods) and restoring the pre-development infiltration rate and storage capacity (i.e., porosity) of the underlying soils. Conversion of the impervious surface to a vegetated pervious surface results in a reduction in runoff volume and pollutant loads and an increase in infiltration and groundwater recharge.

Opportunities to convert impervious surfaces to pervious surfaces are common on older, developed sites where historical development patterns and zoning or subdivision regulations dictated excessive amounts of impervious coverage associated with parking lots, roads, and buildings. These developments also typically pre-date regulatory requirements for stormwater quality controls, so much of the impervious area on these sites is often directly connected to the drainage system or surface waters (i.e., DCIA).

Common examples of impervious area conversion retrofits include:

- Eliminating unused or underutilized parking spaces in parking lots and replacing them with vegetation or for impervious area disconnection strategies (see discussion below).
- Reducing paved shoulder widths.
- Reducing lane widths (e.g., road diet with pavement removal).
- Replacing pavement in parking lot islands and medians with vegetation.
- Replacing the center portion of paved cul-de-sac bulbs with vegetation or structural stormwater BMPs (see discussion below).

Such conversions should not preclude roadway and parking lot design and safety standards.

The subgrade below pavement is often highly compacted, with low infiltration and water storage capacity, and lacking organic material in the soil structure to support vegetative growth. An important aspect of converting impervious surfaces to pervious vegetated surfaces is to ensure that the converted area has similar hydrologic functions and characteristics as a natural, undeveloped area in terms of runoff and infiltration. This typically requires modification of the soils beneath the previously paved surface to restore the pre-development infiltration rate and porosity (similar to that of the native underlying soils) and improve the soil quality to support vegetation. The subgrade should be treated by scarification, ripping (tilling), or use of a shatter-type soil aerator to a depth of 9 to 12 inches or more depending on site and soil conditions. A soil test by the University of Connecticut Soil Testing Laboratory, another university soil testing laboratory, or a commercial soil testing laboratory is recommended to determine the suitability of soils for plant growth and to classify the permeability (in terms of Hydrologic Soil Group) of the restored pervious area. Amendment with 2 to 4 inches of topsoil or organic material may be required to improve plant establishment or restore soil permeability.

Chapter 5 - Low Impact Development Site Planning and Design Strategies provides design criteria for impervious area conversion in the context of redevelopment projects. The design guidance in Chapter 5 is also applicable to stormwater retrofits.

Impervious Area (Simple) Disconnection

Impervious area disconnection, also called "simple disconnection," involves re-directing stormwater runoff from impervious surfaces as sheet flow onto adjacent vegetated pervious surfaces where it has the opportunity for treatment and infiltration, as described further in Chapter 5 - Low Impact Development Site Planning and Design Strategies. For new development and redevelopment, impervious area disconnection is an important Low Impact Development (LID) site planning and design strategy. Impervious area disconnection is also a simple, low-cost stormwater retrofit technique by utilizing the existing vegetated areas (i.e., lawn, meadow, or woods) that are typically adjacent to impervious areas, such as roads, parking lots, and buildings, for stormwater management.

Common applications of impervious area disconnection retrofits include:

- Installing inlet curb cut openings to allow runoff from a roadway to sheet flow to an adjacent vegetated median.
- Installing inlet curb cut openings in a parking lot to allow runoff to bypass existing catch basins and sheet flow to vegetated areas around the perimeter of the lot. The existing catch basins in the parking lot can function as overflow structures to convey runoff in excess of the water quality storm.
- Grading an uncurbed parking lot towards a vegetated island.
- Disconnecting building roof downspouts from the drainage system to adjacent pervious areas.

The feasibility and success of impervious area disconnection depends on several factors including the ability to re-direct runoff from the impervious area to the pervious area (often requiring grading or a curb-cut), as well as the ability of the pervious area to disperse (via a level spreader) and infiltrate runoff for storm events up to the water quality design storm. Key characteristics of the receiving pervious area include:

- Ground slope.
- Soil infiltration capacity and depth to groundwater.
- Size of the pervious area relative to the size of the contributing impervious area.
- Density of vegetation.
- Use of devices such as level spreaders to disperse the discharge and provide sheet flow, as needed, to disperse the flow and avoid flow concentration and short circuiting through the pervious area.

Sites with flatter slopes, pervious soils, and a dense stand of vegetation are better suited for maintaining dispersed flow. Flows for larger storm events should bypass or exit the pervious area in a controlled manner.

Chapter 5 - Low Impact Development Site Planning and Design Strategies provides design criteria for impervious area disconnection focused on new development and redevelopment projects. The design guidance in Chapter 5 is also applicable to stormwater retrofits.

Modifying Existing Structural Stormwater BMPs

Existing stormwater BMPs and related stormwater infrastructure originally designed for conveyance and stormwater quantity control can be modified to improve pollutant and runoff reduction performance. Depending on site conditions, such enhancement may be more cost-effective than constructing new structural stormwater BMPs. These types of retrofits can include modification of existing BMPs and stormwater infrastructure that was not designed with stormwater quality in mind, as well as rehabilitation of existing functional stormwater BMPs to improve their performance.

Key considerations for identifying and evaluating the feasibility of these types of retrofits include:

- Will the retrofit meet the project objectives and qualify for retention and/or treatment credits by meeting the design requirements in this Manual?
- Is the retrofit feasible based on existing site conditions?
- Is the retrofit cost-effective when compared to other retrofit alternatives?

An evaluation of existing site conditions and the existing stormwater infrastructure is required to determine the need for modifications to the conveyance system, if the retrofitted system should be designed in an on-line or off-line configuration, and how these decisions may impact project feasibility and cost.

Common opportunities for modifying existing stormwater BMPs and related stormwater infrastructure for enhanced pollutant and runoff reduction performance include:

Detention Basin Retrofits

Traditional dry detention basins are effective for stormwater quantity control but provide very limited pollutant removal. Dry detention basins, which were commonly used as the sole stormwater management practice for many older developments, can be modified to function as dry extended detention basins, infiltration basins, stormwater ponds, or stormwater wetlands for more effective retention of stormwater and enhanced pollutant removal. This is one of the most common and easily implemented retrofits since it typically requires little or no additional land area, requires minimal or no earthwork, utilizes an existing facility for which there is already some resident acceptance of stormwater management, and involves minimal impacts to environmental resources.

Detention basin retrofits should result in improved pollutant and/or runoff volume reduction performance, without a significant reduction in stormwater quantity control performance. Some detention basin upgrades may result in a partial loss of flood storage and peak discharge control. Detention basin retrofits that result in reduced basin storage volume (e.g., conversion to stormwater wetlands or stormwater ponds) should include a hydrologic and hydraulic analysis of the existing system and proposed changes to ensure that the modified basin will continue to provide adequate stormwater quantity control and will not cause flooding or other undesirable conditions for adjacent infrastructure or site uses. The basin’s total storage volume may need to be increased to offset loss of storage volume. If the existing basin is constructed with an earthen berm, the stability of the embankment should be also evaluated relative to the proposed modifications.

Conversion to Infiltration Basin. Detention basins that remain dry between storm events, are in well-drained soils, and have three feet or more of vertical separation between the bottom of the basin and the seasonal high groundwater table are good candidates for conversion to infiltration basins. The major benefit of this type of retrofit is retention of stormwater and the associated reduction in runoff volume and pollutant loads. Common modifications to convert detention basins to infiltration basins include:

- Conduct test pits or soil borings to confirm soil characteristics, depth to the seasonal high groundwater table, and depth to bedrock or other confining layer, and perform field infiltration testing consistent with the guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Till or scarify the bottom of the existing basin to restore soil infiltration capacity or excavate and replace the existing soil with a more uniform, permeable soil or engineered soil media.
- Modify the existing outlet structure by plugging or capping the low-level orifice and creating a new raised orifice to retain and infiltrate the Required Retention Volume, while maintaining a high-level overflow or orifice for stormwater quantity control and to convey flows for larger storms.
- Incorporate pretreatment (e.g., sediment forebays) at basin inlets.
- Revegetate the bottom of the basin to stabilize the basin surface and to establish a healthy vegetative root system, which helps maintain soil infiltration capacity.

Refer to the Infiltration Basin section in Chapter 13 and Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for additional design guidance.

Conversion to Stormwater Pond or Stormwater Wetland. Detention basins that tend to remain wet between storm events, are in poorly drained soils, or have minimal vertical separation between the bottom of the basin and the seasonal high groundwater table are ideal for conversion to wet stormwater ponds or stormwater wetlands. This type of retrofit can significantly improve the pollutant removal performance of the basin by introducing additional pollutant removal mechanisms associated with a permanent pool of water and wetland vegetation. Common modifications to convert detention basins to wet stormwater ponds or stormwater wetlands include:

- Conduct test pits or soil borings to confirm soil characteristics, depth to the seasonal high groundwater table, and depth to bedrock or other confining layer consistent with the soil evaluation guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Modify the existing outlet structure by plugging or capping the low-level orifice and creating a new raised orifice to maintain a permanent pool of water and support wetland vegetation, while maintaining a high-level overflow or orifice for stormwater quantity control and to convey flows for larger storms.
- Excavate the basin bottom to intercept the groundwater table and create more permanent pool storage.
- Add gravel and underdrain piping if converting the basin to a subsurface gravel wetland.

- Increase the flow path from inflow to outflow and eliminate short-circuiting by using baffles, earthen berms, or micro-pond topography to increase residence time of water in the pond and improve settling of solids.
- Replace paved low-flow channels with meandering vegetated swales.
- Provide a high flow bypass to avoid resuspension of captured sediment/pollutants during high flows.
- Incorporate stilling basins at inlets and outlets and pretreatment (e.g., sediment forebays) at basin inlets.
  - Regrade the basin bottom to create a wetland area near the basin outlet or revegetate parts of the basin bottom with wetland vegetation to enhance pollutant removal, reduce mowing, and improve aesthetics.
  - Create a wetland shelf along the perimeter of a wet basin to improve shoreline stabilization, enhance pollutant filtering, and enhance aesthetic and habitat functions.
  - Create a low maintenance “no-mow” wildflower ecosystem in the drier portions of the basin.

Refer to the Stormwater Pond BMPs and Stormwater Wetland BMPs sections in Chapter 7 for additional design guidance.

Drainage Channel Retrofits

Conventional grass swales and ditches that were constructed primarily as surface stormwater drainage channels provide little if any pollutant removal and limited or no infiltration and volume reduction. Drainage channels are common along some roads and highways or as perimeter features around parking lots. Drainage channels can be modified to reduce flow velocities; create opportunities for ponding, infiltration, and establishment of wetland vegetation; and enhance pollutant removal.

Grass swales and ditches can be converted to wet or dry water quality swales, or linear bioretention systems (i.e., bioswales). Similar to detention basins, the most appropriate retrofit approach depends largely on the soil and groundwater conditions at the site. Drainage channels located in well-drained soils with adequate vertical separation to the seasonal high groundwater table are ideal for conversion to dry water quality swales or linear bioretention, while drainage channels in poorly drained soils and shallow groundwater are better suited for conversion to wet water quality swales.

Conversion to Dry Water Quality Swale or Linear Bioretention. This type of retrofit can significantly improve the retention, infiltration, and volume reduction benefits of drainage channels. If the soils are not conducive to infiltration, the drainage channel can be converted to a lined bioretention system with an underdrain to improve the treatment effectiveness of the channel. Common modifications to convert conventional grass swales and ditches to dry water quality swales or linear bioretention systems include:

- Conduct test pits or soil borings to confirm soil characteristics, depth to the seasonal high groundwater table, and depth to bedrock or other confining layer, and perform field infiltration testing consistent with the guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Conduct minor grading and/or reshaping of the channel cross section.
- Excavate and replace the existing soil with engineered bioretention soil media.
- Incorporate pretreatment (e.g., sediment forebays) at inlets to the channel.
- Add check dams.
- Add underdrain if necessary.
- Establish a dense vegetative cover or adequately stabilized landscaped surface throughout the channel to promote pollutant removal and infiltration.

Refer to the Dry Water Quality Swale and Bioretention sections in Chapter 13 for additional design guidance.

Conversion to Wet Water Quality Swale. This type of retrofit can significantly improve the pollutant removal performance of the drainage channel by introducing additional pollutant removal mechanisms associated with a permanent pool of water and wetland vegetation. Common modifications to convert conventional grass swales and ditches to wet water quality swales include:

- Conduct test pits or soil borings to confirm soil characteristics, depth to the seasonal high groundwater table, and depth to bedrock or other confining layer consistent with the soil evaluation guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Conduct minor grading and/or reshaping of the channel cross section.
- Modify or install an outlet structure to maintain a permanent pool of water and support wetland vegetation or excavate the channel bottom to intercept the groundwater table.
- Incorporate a high-level overflow or orifice in the outlet structure for stormwater quantity control and to convey flows for larger storms.
- Incorporate pretreatment (e.g., sediment forebays) at inlets to the channel.
- Add check dams.

- Plant with emergent wetland plants.

Refer to the Wet Water Quality Swale section in Chapter 13 for additional design guidance.

Note that these drainage channel retrofits are only applicable to man-made stormwater conveyances and should not be implemented within natural stream channels or regulated wetlands or watercourses.

Bioretention System Retrofits

Many existing bioretention systems constructed in the past 20 years were based on older, outdated designs. While these systems may still function adequately, their treatment and infiltration/retention performance may be improved by incorporating relatively simple modifications that reflect current state-of-the-practice for bioretention system design. These design modifications are part of the standard design guidance for new bioretention systems as presented in the Bioretention section of Chapter 13.

Internal Water Storage. For systems with an underdrain, modify the underdrain outlet structure to incorporate an upturned outlet (using an elbow or capped "T" pipe) to create a thicker saturated zone (also called an Internal Water Storage zone or Internal Storage Reservoir) that extends into the bottom of the bioretention soil media. This type of underdrain configuration increases infiltration and evapotranspiration and enhances removal of nitrogen through the creation of an anaerobic or anoxic Internal Water Storage zone. The combined volume reduction and nitrogen treatment benefits of this modification can result in significant nitrogen load reductions. The upturned pipe should be located inside the outlet structure, if possible, to facilitate maintenance access.

Filter Media Amendments. Many of the earlier bioretention system designs incorporated compost as the organic component of the bioretention soil mix. Compost-based bioretention soil mixes have been shown to export nutrients and are therefore no longer recommended. The soil media in aging bioretention systems that receive heavy pollutant loads may be beyond its useful life in terms of pollutant removal. In these instances, bioretention systems can be modified by amending the bioretention soil to enhance pollutant removal, particularly phosphorus removal, and extend the life of the bioretention soil media. Organic matter (sphagnum peat moss or wood derivatives such as shredded wood, wood chips, ground bark, or wood waste) can be mixed into the existing bioretention soil layer. Other soil amendments such as zerovalent iron and/or drinking water treatment residuals (alum) may be used to further enhance phosphorus sorption. This is an emerging area of research and practice that includes fungal mycelium, biochar, and other innovative filter media amendments.

Forebays. Sediment forebays and similar pretreatment measures not only facilitate bioretention maintenance but have also been shown to be effective for removal of phosphorus, nitrogen, and metals in addition to sediment.[68] The addition of a forebay can therefore enhance pollutant removal and extend the life of the bioretention soil media.

New Structural Stormwater BMPs

New structural stormwater BMPs can be strategically located to manage stormwater runoff from directly connected impervious areas on existing developed sites. Such areas are considered disconnected when stormwater runoff is retained on-site using Infiltration BMPs or Stormwater Reuse BMPs that are selected, sized, and designed following the guidance contained in other sections of this Manual. However, it is important to note that not all structural BMPs will disconnect DCIA, treatment alone does not treatment alone does not retain the WQV and strategic planning is necessary to do so.

Stormwater retrofits involving installation of new structural stormwater BMPs generally fall into three major categories depending on where the BMPs are applied:

Close to the Source. This is the most common type of stormwater retrofit, which involves installation of small-scale structural stormwater BMPs close to the source of runoff generation and prior to runoff entering the storm drainage system. Because they are located close to the source, these retrofits provide greater flexibility for siting, manage smaller runoff volumes, and are more cost-effective than drainage system or outfall retrofits. Numerous examples exist of these types of retrofits. Common examples include off-line infiltration systems located within parking lot or roadway medians, and rain barrels or cisterns used for collection and reuse of rooftop runoff.

Within the Drainage System. Existing drainage systems can be modified to improve pollutant removal and provide retention/infiltration. The pollutant removal benefits provided by these types of retrofits are typically limited to removal of coarse solids and floatables. They also commonly involve new subsurface structures and modification of the storm drainage system, which can be less cost-effective than other types of retrofits. In some cases, conventional drainage systems can be retrofitted with infiltrating catch basins, perforated pipe, and other underground infiltration systems to meet retention requirements. Drainage system retrofits are most cost-effective when combined with retrofits installed close to the source to reduce the volume of runoff that reaches the drainage system. Common examples of drainage system retrofits include:

- Replacing older style catch basins with deep-sump, hooded catch basins.
- Installing hoods on existing catch basins.
- Installing new infiltrating catch basins upgradient of existing catch basins or replacing existing catch basins with infiltrating catch basins.

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[68] Johnson J. & Hunt W. 2016. Evaluating the spatial distribution of pollutants and associated maintenance requirements in an 11-year-old bioretention cell in urban Charlotte, NC. Journal of Environmental Management. 184 (Pt 2), 363–370.

- Use of manufactured or proprietary devices (such as smaller grates) that catch sediments, trash, organic matter, and other particulates.
- Replacing existing storm drains with perforated drainpipe.
- Installing new tree filters upgradient of existing catch basins or replacing existing catch basins with tree filters.
- Installing proprietary filtration devices in existing catch basins (i.e., catch basin inserts) or other manufactured treatment devices within the drainage system to capture sediment and other pollutants.
- Elimination of curbing.

At the Outfall. New stormwater BMPs can be constructed at or just upgradient of the outfalls of existing drainage systems. Due to the "end-of-pipe" nature of these retrofits, such BMPs are commonly designed as off-line systems, requiring the use of flow diversion structures to retain and/or treat runoff from the water quality storm and bypass larger flows. Most structural stormwater BMPs can be used for this type of retrofit, given sufficient space and maintenance access. However, BMPs designed for wet conditions such as stormwater ponds and wetlands tend to be most conducive to outfall retrofits given the frequent presence of shallow groundwater and poorly drained soils at outfall locations. For these reasons, the feasibility of infiltration BMPs at outfalls is often limited.

Structural stormwater BMPs should be selected to address the water quality objectives for the site (e.g., for specific target pollutants associated with a water quality impairment) and any secondary objectives or co-benefits such as flood reduction, habitat restoration, and community enhancement. Potential constraints may include site conditions, owner preferences and limitations, maintenance considerations, cost/budget considerations, and the overall approach (opportunistic versus planning approach). Refer to Chapter 8 - Selection Considerations for Stormwater BMPs for selection of appropriate BMPs for retrofit applications.

Once suitable structural stormwater BMPs are selected based on water quality objectives and site constraints, the BMPs should be sized to meet the retention and/or treatment requirements presented in Chapter 4 - Stormwater Management Standards and Performance Criteria. Retrofit BMPs are generally sized to maximize retention/treatment performance given the site and project constraints. Stormwater BMP Performance Curves can be used for optimizing sizing in terms of costs and benefits. Retrofit sizing and credits (i.e., quantifying the pollutant and DCIA reduction benefits), including the use of the BMP Performance Curves for retrofit sizing, are further described in the Retrofit Sizing and Crediting section of this chapter. Chapter 10 - General Design Guidance for Stormwater Infiltration Systems and the BMP-specific design guidance in Chapter 13 - Structural Stormwater BMP Design Guidance provide additional design considerations for retrofits involving new structural stormwater BMPs.

Retrofit Applications

Retrofits can be incorporated into a wide range of land use settings and sites, including within the roadway right-of-way (ROW) as well as on public and privately-owned developed parcels of land. The following sections summarize common ROW and parcel-based retrofit applications.

Roads and Right-of Way Retrofits

Retrofit opportunities exist along most types of roads. The road functional classification (interstate, arterial, collector, and local), intensity of adjacent development (urban, suburban, rural), and other right-of-way characteristics will dictate the suitability of retrofit types and specific structural stormwater BMPs.

Divided Highways

Open spaces associated with highway ROW areas such as medians, shoulders, and interchanges present opportunities to incorporate new stormwater BMPs. Opportunities also exist to retrofit existing linear stormwater conveyances (i.e., grass drainage channels) and detention basins, such as the drainage channel retrofits described in the previous section, to provide increased retention and enhanced treatment of stormwater. Traffic, safety, and maintenance access are important considerations for determining appropriate locations for highway ROW retrofits. Common retrofit approaches for highway ROW areas include:

- Pavement disconnection to a vegetated filter strip or other qualifying pervious area adjacent to the highway (i.e., simple disconnection).
- Conversion of existing grass swales to water quality swales or linear bioretention using check dams and other modifications.
- Conversion of existing dry detention basins to infiltration basins or stormwater ponds or wetlands.
- Installation or new linear vegetated stormwater BMPs in grassed medians.
- Replacing older style catch basins with deep-sump, hooded catch basins or infiltrating catch basins.
- Retrofit of drainage system outfalls that discharge directly to receiving waterbodies using off-line retention or treatment stormwater BMPs.

Urban Roads

Roads and streets in urban settings such as downtown areas, village centers, and heavily developed commercial corridors present a variety of retrofit opportunities as well as some unique challenges associated with urban development. Urban landscape features such as streets, sidewalks, parkways, and green spaces can be modified to be multi-functional by incorporating small-scale vegetated surface stormwater BMPs (also referred to as “green infrastructure” or "green stormwater infrastructure) to provide retention and filtration of stormwater, while achieving other functions such as accommodating bicycle lanes, providing traffic calming, and aesthetic/streetscape improvements (i.e., "green streets" approaches). Given limited space and numerous physical constraints that typically exist in urban settings, opportunities also exist for subsurface retrofits within the ROW to intercept, store belowground, and infiltrate stormwater that would otherwise enter the existing drainage system using underground infiltration systems located below the road surface or sidewalks.

Urban roads with limited vegetation/trees, wide roads and sidewalks, and large amounts of impervious area tend to be good candidates for retrofits. Common retrofit approaches for urban roads include:

- Addition of bioretention stormwater planters, bioswales, and tree filters within existing green space between the road and sidewalks.
- Creation of bioretention bump outs to reduce impervious area, manage stormwater, provide traffic calming, and improve pedestrian safety.
- Use of curb inlets to intercept and divert surface runoff into new off-line stormwater BMPs, while using the existing drainage system as the overflow to convey runoff from larger storm events.
- Use of permeable pavement for on-street parking stalls, sidewalks, crosswalks, etc.
- Use of underground infiltration systems (chambers and infiltrating catch basins) below roads and sidewalks in areas with inadequate land area or space to accommodate surface practices.
- Narrowing of wide sidewalks and re-grading to vegetated filter strips.

Surface and subsurface utilities can pose significant challenges to the design, construction, and maintenance of stormwater BMPs, especially in urban areas. Utility management should be considered early in the planning and design of urban retrofits. Effective planning and design of urban retrofits should include the following considerations:

- Coordinate with public and private utilities to determine the presence of existing utilities within the project limits as well as design and construction requirements for utility-related construction.
- Locate existing utilities during the design phase.
- Verify separation requirements between proposed stormwater BMPs and existing on-site utilities with the utility owner.

- Where stormwater BMP are proposed with sidewalks, utility poles should be at the back of the sidewalk. Where possible, locate utilities outside the sidewalk limits. Sidewalks should continue to meet accessibility requirements following the installation of the retrofits.

- If fire hydrants are present near the proposed stormwater BMPs or must be relocated, coordinate with the local fire department/district and water utility owner for design and construction requirements.

- Consider the potential for conflict with overhead utilities. These conflicts include both permanent fixed objects and constructability issues. Consult the utility pole owner, and NESC & OSHA guidelines.

- Relocating utilities should be carefully considered during the selection of a stormwater BMP. Relocation can be costly and requires early coordination with the utility owner. The proposed relocation design must be reviewed and approved by the utility owner.

- The configuration of a stormwater BMP must allow utility owner access to all mains and service laterals for maintenance.

- Infiltrating BMPs should not be sited adjacent to or above existing utility trenches, which can result in "short circuiting" of the BMP drainage mechanisms if preferential flow is through the bedding material of the utility trench. Impermeable liners can be used to minimize the potential for short-circuiting.

Residential Subdivisions

Many older residential subdivisions have wide roads, traditional curb and gutter drainage systems, limited existing vegetation/trees, and limited stormwater quality controls. Opportunities exist to reduce or disconnect impervious areas within the ROW, coupled with potential on-lot improvements that can be made by private property owners to further disconnect driveways, roof, patios, etc. from the municipal drainage system. Common retrofit approaches for residential subdivisions and similar suburban residential neighborhoods include:

- Narrowing road widths and replacing sidewalks on one side of the road with vegetated filter strips or water quality swales.

- Replacing older style catch basins with deep-sump, hooded catch basins or infiltrating catch basins.

- Elimination of curbing and closed drainage systems.

- Addition of bioretention stormwater planters, bioswales, and tree filters within existing green space between the road and sidewalks.

- Creation of bioretention bump outs to reduce impervious area, manage stormwater, provide traffic calming, and improve pedestrian safety.

- Conversion of large, paved cul-de-sac bulbs to vegetated surfaces or installation of bioretention of infiltration BMPs within these areas.

- Providing incentives for homeowners to disconnect roof leaders and runoff from other impervious surfaces on their lots using simple disconnection, rain barrels, dry wells, and permeable pavement.

Parcel Based Retrofits

Parking lots and building roof areas (i.e., large impervious areas that are directly connected to the existing drainage system) provide numerous opportunities for potential for parcel-based stormwater retrofits on public and private property. All of the retrofit types described in the previous section – conversion of existing impervious areas to pervious areas, simple disconnection, and addition of new stormwater BMPs – can be implemented as parcel-based retrofits.

Publicly owned (e.g., municipal- or state-owned) parcels typically offer the most immediate potential for retrofits because they avoid the cost of land acquisition, the need for cooperation with private landowners, and allow the municipal or state jurisdiction to have direct control over retrofit construction and maintenance. Certain types of private parcels such as institutional facilities (e.g., private colleges and universities) and commercial properties with large impervious areas may be good candidates for retrofits but require landowners who are willing to construct and maintain the retrofits. Stormwater utility fees and associated impervious area reduction credits can be used to incentivize retrofits on private property.

Parking Lots

Parking lots in municipal, commercial, and institutional land use settings can be ideal candidates for a wide range of stormwater retrofits. Sites with excess or under-utilized parking provide opportunities for conversion of impervious areas to pervious areas and the use of pervious pavement in parking stalls or overflow parking areas. Small-scale infiltration and treatment BMPs (bioretention, tree filters, water quality swales, etc.) can be added to existing landscaped areas in parking islands and around the perimeter of parking lots, depending on the configuration of the existing storm drainage system and location of drainage structures relative to the existing green space. Curb cuts and grading can be used to disconnect portions of parking lots by re-directing sheet-flow to adjacent vegetated areas. Parking lots also provide opportunities for subsurface retrofits (infiltrating catch basins and underground infiltration systems) where space is limited, or existing surface drainage structures are not conveniently located.

Repaving or replacement of existing parking lots, as well as redevelopment of older commercial properties (often designed with excess parking, high impervious coverage, and limited stormwater controls) are good opportunities for incorporating retrofits in conjunction with other planned infrastructure improvements. Common examples of parking lot stormwater retrofits include:

Incorporating Bioretention into Parking Lot Islands and Landscaping. Parking lot islands and landscaped areas can be converted into functional bioretention areas, tree filters, and dry water quality swales using curb cuts located upgradient of existing catch basins.

Removing Curbing and Adding Slotted Curb Stops. Curbs along the edges of parking lots can sometimes be removed or slotted to re-route runoff to vegetated areas, buffer strips, or bioretention facilities. The capacity of existing swales may need to be evaluated and expanded as part of this retrofit option.

Incorporating New BMPs around the Perimeter of Parking Lots. New retention and treatment BMPs such as infiltration trenches and basins, bioretention, tree filters, and dry water quality swales can often be incorporated into the green space around the perimeter of parking lots provided there is adequate setbacks to adjacent properties and infrastructure.

Use of Permeable Paving Materials. Existing conventional pavement in overflow parking or other low-traffic areas can sometimes be replaced with alternative, permeable materials. Site-specific factors including traffic volumes, soil permeability, maintenance, sediment loads, and land use must be carefully considered for the successful application of permeable paving materials for retrofit applications.

Installation of Subsurface Retrofits. Underground infiltration systems such as infiltration chambers can be installed below parking lots on space-constrained sites. Existing catch basins can also be retrofitted or replaced with infiltrating catch basins.

Building Roof Areas

Building roofs that are directly connected to the storm drainage system are ideal candidates for disconnection using infiltration BMPs, stormwater reuse BMPs, or green roof installations. In residential settings, roof runoff can typically be disconnected by re-directing downspouts to lawn areas, rain gardens, dry wells, or rain barrels. Commercial and institutional buildings typically generate larger volumes of runoff and contain high pollutant levels, requiring adequate pretreatment and more space for surface infiltration/filtration systems or larger underground infiltration systems. Common examples of stormwater retrofits for building rooftops include:

- Disconnecting residential roof downspouts and re-directing them to existing vegetated areas (i.e., simple disconnection), dry wells, or rain barrels.
- Disconnecting roof leaders from larger commercial and institutional buildings, which are often hard piped into the existing storm drainage system, and re-directing them to existing vegetated areas (i.e., simple disconnection), infiltration basins, bioretention cells, or underground infiltration systems.
- Capture of roof runoff at sites with landscaped areas or turf fields (e.g., schools, playgrounds, outdoor recreational facilities) using cisterns and stormwater reuse systems for irrigation to reduce runoff volumes and municipal water usage.

- Conversion of flat building roof areas to vegetated roofs using modular green roof systems.

Retrofit Selection

While some form of retrofitting is possible on most sites, existing developed sites often have characteristics that can limit the type of stormwater retrofits and structural stormwater BMPs that are possible and their overall effectiveness. Table 9- 1 lists site-specific factors to consider in determining the appropriateness of stormwater retrofits for a particular site.

Table 9- 1 Site Considerations for Determining the Appropriateness of Stormwater Retrofits

Factor	Consideration
Retrofit Purpose	➢ What are the primary and secondary (if any) purposes of the retrofit project? ➢ Are the retrofits designed primarily for DCIA and pollutant reduction, stormwater quantity control, or a combination of both? ➢ Will the retrofit project meet or make cost-effective progress towards goals? ➢ Will the retrofit accomplish other goals/benefits (e.g., flood reduction, habitat creation, community enhancements)?
Space	➢ Is there adequate space and setback distances for new surface-based stormwater BMPs?
Existing Drainage Patterns and Storm System Configuration	➢ Are existing catch basins located adjacent to and at a higher elevation than nearby green space? ➢ Does the existing configuration of the storm drainage system allow for use of the existing catch basins as overflow structures or are new overflow devices and flow diversion structures required, which would increase cost?
Contributing Drainage Area	➢ Is the retrofit compatible with the size of the contributing drainage area? ➢ Can the retrofit be sized with sufficient storage to meet the retention/treatment standards? ➢ Is the drainage area sufficient to maintain the required hydrology and vegetation for wet practices?
Site Slope	➢ Is the site topography consistent with the recommended slope limitations of the proposed retrofit?

Factor	Consideration
Subsurface Conditions	➢ Are the subsurface conditions at the site (soil infiltration capacity, depth to the seasonal high groundwater table, and depth to bedrock) consistent with the proposed retrofit? ➢ Does site contamination present a conflict for the proposed retrofits?
Utilities	➢ Do the locations of existing utilities (including private wells and on-site wastewater systems) present conflicts with the proposed retrofits or require relocation or design modifications?
Conflicting Land Uses	➢ Are the retrofits compatible with existing uses of the site and adjacent land uses of nearby properties?
Wetlands, Sensitive Receiving Waters, and Vegetation	➢ How do the retrofits affect adjacent or downgradient wetlands, sensitive receiving waters, and vegetation? ➢ Do the retrofits minimize or mitigate impacts where possible?
Construction/Maintenance Access	➢ Does the site have adequate construction and maintenance access and sufficient construction staging area? ➢ Are maintenance responsibilities for the retrofits clearly defined and who will be performing the maintenance? ➢ Is the owner aware of and willing to take responsibility for O&M costs? ➢ What is the required inspection and maintenance frequency? ➢ Are there special maintenance equipment needs?
Permits and Approvals	➢ Which local, state, and federal regulatory agencies have jurisdiction over the proposed retrofit project? ➢ Can regulatory approvals be obtained for the retrofits?
Public Safety	➢ Does the retrofit increase the risk to public health and safety?
Cost	➢ What are the capital and long-term maintenance costs associated with the stormwater retrofits? ➢ Are the retrofits cost-effective in terms of anticipated benefits?

Source: Adapted from Claytor, Center for Watershed Protection, 2000.[69]

Physical constraints that are common on existing developed sites can present design challenges that limit the ability of stormwater retrofits to fully meet the stormwater management standards, performance criteria, and BMP-specific design guidance presented in this Manual. For example,

[69] Claytor, R.A. Center for Watershed Protection. 2000. *The Practice of Watershed Protection*. Ellicott City, Maryland.

the minimum recommended horizontal setback distance between a proposed infiltration retrofit and an existing building may not be feasible, although a groundwater mounding analysis or use of an impermeable liner may mitigate the risk of water intrusion into the building foundation. Similarly, conversion of an existing dry detention basin to an infiltration basin may not fully meet the require Required Retention Volume, given the need to preserve storage for peak flow attenuation, but the modification would provide substantial retention of stormwater as compared to existing conditions while providing adequate stormwater quantity control.

Retrofitted facilities may not be as effective in reducing pollutant loads as newly designed and installed facilities. However, in most cases, some improvements in pollutant reduction, runoff reduction, groundwater recharge, and stormwater quantity control are possible even if the retrofit does not fully meet all the management standards, performance criteria, and design guidance due to site constraints. Research and recent practice have shown that retrofits designed for less-than-optimal conditions can still provide significant pollutant reduction and hydrologic benefits. This approach to stormwater retrofitting is based on the following rationale:

- Implementing small-scale retrofits is better than not retrofitting.
- Providing some retention and infiltration is better than none.
- Where retention/infiltration is not possible, providing some pretreatment and treatment is better than none.
- Any impervious surface disconnection is an improvement over existing condition.

Rather than preclude the use of retrofits that cannot fully meet the management standards, performance criteria, and design guidance, this Manual promotes the use of retrofits whenever possible by providing flexibility in retrofit sizing and crediting, as discussed in the following section.

For retrofits involving the addition of new structural stormwater BMPs or upgrades to existing stormwater BMPs, the guidance provided in Chapter 8 - Selection Considerations for Stormwater BMPs should be consulted to screen out unsuitable retrofits and help select the most appropriate retrofits for a given site.

Retrofit Sizing and Crediting

This section provides guidance on sizing of stormwater retrofits and quantifying the benefits of retrofits (i.e., credits) in terms of disconnecting and reducing DCIA.

Stormwater BMP Performance Curves

As introduced in Chapter 4 - Stormwater Management Standards and Performance Criteria, the EPA Region 1 stormwater BMP performance curves can be used to help select, size, and quantify the pollutant reduction benefits of stormwater retrofits. Use of the performance curves is becoming widely accepted in New England for sizing and quantifying the benefits of stormwater BMPs in general, including retrofit applications.

Benefits of Using Performance Curves for Stormwater Retrofit Design

The curves (SNEP Network, 2022):

- Are highly flexible to accommodate site constraints.
- Encourage the use of multiple smaller BMPs when larger retrofits are not feasible.
- Credit a range of sizes including smaller sizes.
- Credit a range of pollutants to help connect performance with specific pollutant goals.
- Allow for crediting non-conforming designs (i.e., designs that cannot fully meet the stormwater management standards, performance criteria, and design guidance).
- Allow for crediting existing systems as they are currently functioning.
- Support optimization and cost-effective designs.
- Are based on the most recent stormwater BMP performance data.

The performance curves provide estimates of the long-term cumulative pollutant removal performance of a BMP as a function of the BMP size (physical storage capacity). The performance curves relate the depth of runoff treated from the impervious area to average annual pollutant reduction for various types of structural stormwater BMPs and stormwater pollutants (TSS, TP, TN, Zinc, and fecal indicator bacteria). The curves can be used to size stormwater BMPs and to quantify the pollutant removal benefit (i.e., credit) for a range of sizes and types of BMPs.

Chapter 4 - Stormwater Management Standards and Performance Criteria provides an overview of the performance curves, how they were developed, and their basic use for quantifying the pollutant reduction benefits of structural stormwater BMPs and documenting compliance with the minimum required pollutant load reductions when the Required Retention Volume cannot be retained on-site. Appendix C provides the corresponding EPA stormwater BMP performance curves and equations for calculating the static storage volume for each type of structural stormwater BMP presented in this Manual.

The Stormwater Retrofit Manual developed by the Southeast New England Program (SNEP) Network in collaboration with the University of New Hampshire Stormwater Center, EPA Region 1, and state agencies and the other information sources listed at the end of this chapter provide additional information on the use of stormwater BMP performance curves for retrofit design.

Retrofit Sizing Guidance

In retrofit settings, similar to new development and redevelopment applications, stormwater BMPs should be designed to meet the retention and treatment requirements of Standard 1 – Runoff Volume and Pollutant Reduction as follows (refer to Table 4-2 in Chapter 4):

- Retain on-site the applicable post-development stormwater runoff volume (i.e., the "Required Retention Volume"), which is equal to 100% or 50% of the site's Water Quality Volume (WQV) depending on the existing DCIA of the site and the amount of proposed land disturbance. When the Required Retention Volume is retained on-site using suitable stormwater retention practices (refer to Table 8- 1.), the retrofit is presumed to meet or exceed the minimum required average annual pollutant load reductions for TSS, TP, and TN, as described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

- In cases where the volume of stormwater runoff retained on-site does not fully meet the Required Retention Volume due to physical site constraints or other factors, retain runoff on-site to the "Maximum Extent Achievable" (for the definition see Standard 1 Section of Chapter 4) and provide additional stormwater treatment without retention for the post-development runoff volume above that which can be retained up to 100% of the site's WQV.

- In cases where the additional stormwater treatment requirement cannot be achieved on-site, provide stormwater treatment to the "Maximum Extent Achievable."

Where stormwater treatment is proposed in addition to or in lieu of stormwater retention (i.e., when the retrofit cannot fully meet the retention requirement), the designer should use the stormwater BMP performance curves to:

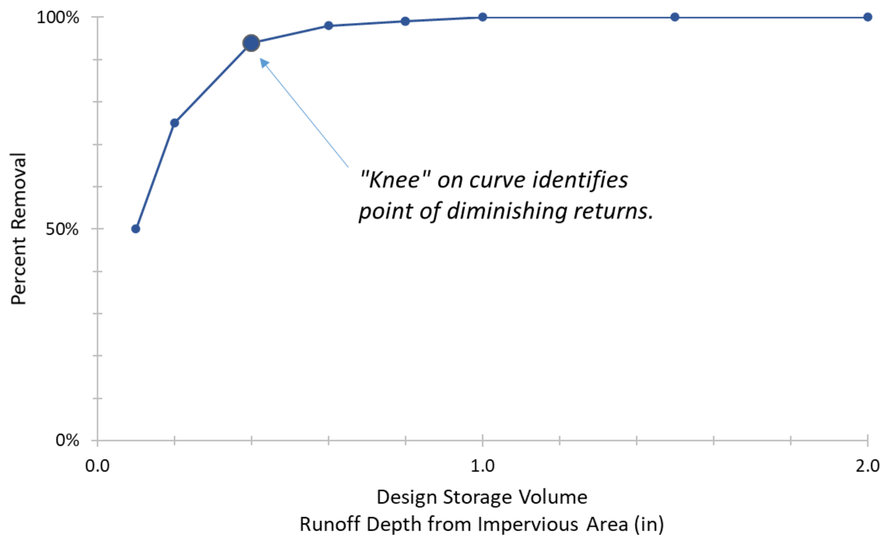
- Optimize retrofit sizing based on anticipated pollutant reduction performance, and

- Document that the proposed retrofit meets or exceeds the minimum required average annual pollutant load reductions for TSS, TP, and TN, as described in Chapter 4 - Stormwater Management Standards and Performance Criteria and Appendix C – BMP Performance Curves and Static Storage Volume Calculation Methods

The performance curves show significant pollutant reduction for design storage volumes in the smaller range (0.1 to 0.5-inch over the contributing impervious area), providing flexibility for retrofits that cannot fully meet the retention and/or treatment requirements. Stormwater BMPs with a design storage volume smaller than 0.1 inch likely do not provide sufficient pollutant reduction benefit due to their lack of capacity to capture, hold, and treat stormwater and therefore are not recommended. Structural stormwater BMPs sized to store less than the WQV can still achieve substantial pollutant load reductions, which allows for the use of smaller structural controls for retrofit applications and on sites with limited space and other physical constraints, while still meeting pollutant removal goals.

Furthermore, the performance curves show that stormwater BMPs provide diminishing pollutant reduction benefits above a certain size (the "knee" of the curve – see Figure 9-1 for an example). Some curves are steeper and have a more obvious point of diminishing returns while some are flatter and show more gradual increases in performance. The knee of the curve is typically in the range of 0.35 to 0.5 inches of runoff over the impervious area for all pollutants and BMP types.[70]

Figure 9-1. Example of Stormwater BMP Performance Curve Showing Point of Optimal Pollutant Load Reduction Performance (Knee of the Curve)[68]



It is important to note the following issues regarding use of the performance curves for retrofit sizing:

- While the knee of the curve represents a point of diminishing returns in terms of cost-effectiveness, the design storage volume corresponding to the knee may not achieve the minimum required average annual pollutant load reductions as outlined in Chapter 4 - Stormwater Management Standards and Performance Criteria, in which case larger design storage volumes may be necessary to demonstrate compliance with Standard 1.

- The performance curves provide flexibility to select and size retrofits in a cost-effective manner, but the curves should not be used to minimize treatment. Instead, they should be used to maximize/optimize retention and treatment performance given physical site constraints. The performance curves provide a basis for justifying the use of smaller retrofits strictly in terms of pollutant load reduction, but their use is not meant to replace the retention standard and associated design guidance described in Chapter 4 - Stormwater Management Standards and Performance Criteria and elsewhere in this Manual. On-site retention of stormwater volumes up to the Required Retention Volume

70 Southeast New England Program (SNEP) Network. 2022. *Stormwater Retrofit Manual.* Developed in conjunction with University of New Hampshire Stormwater Center, EPA Region 1, and state agencies.

(100% or 50% of the site's WQV) is important to maintain or restore pre-development /hydrology (i.e., volume, rate, and temperature of runoff) and groundwater recharge, in addition to providing pollutant load reduction benefits.

Getting Credit for Retrofits – DCIA Disconnection

DCIA is considered disconnected when the appropriate portion of the Water Quality Volume has been retained and/or treated as described in Chapter 4 - Stormwater Management Standards and Performance Criteria. This can be accomplished by using any of the stormwater retrofit types described previously in this chapter, including impervious area conversion, impervious area (simple) disconnection, new structural stormwater BMPs, and modifying existing stormwater BMPs.

Each type of retrofit must meet specific criteria and conditions to receive credit for DCIA disconnection and to meet Standard 1 – Runoff Volume and Pollutant Reduction of this Manual. Table 9- 2 summarizes, for each major type of retrofit, the criteria and conditions that must be met for DCIA to be considered disconnected, and the amount of DCIA reduction credit associated with the disconnection.

Additional Information and Resources on Stormwater Retrofits

The following documents provide additional information and resources on the planning and design of stormwater retrofits from organizations within Connecticut, elsewhere in New England, and nationally.

- Stormwater Retrofit Manual, Southeast New England Program (SNEP) Network (2022)
- Connecticut Department of Transportation MS4 Resources, CTDOT
- Rhode Island Department of Transportation Linear Stormwater Manual, RIDOT (2019)
- Coastal Stormwater Management Through Green Infrastructure: A Handbook for Municipalities, US EPA (2014)

Table 9- 2 Stormwater Retrofit Criteria for DCIA Disconnection and Reduction Credit

Retrofit Type	When is DCIA Considered Disconnected?	DCIA Reduction Credit
Impervious Area Conversion	➢ Existing excess impervious surfaces (pavement, buildings, etc.) are removed and replaced with pervious vegetated surfaces (lawn, meadow, woods), AND ➢ The infiltration rate and porosity of the underlying soils are restored to pre-development conditions through scarification, ripping (tilling), or use of a shatter-type soil aerator, as necessary, AND ➢ The soil is amended, as necessary, to support vegetation. ➢ Soil testing or other documentation to the satisfaction of the review authority is needed to classify / demonstrate the permeability of the restored pervious area.	**Full Credit** Impervious area[1] (in acres) converted and restored to pervious area.
Impervious Area (Simple) Disconnection	➢ Stormwater runoff from impervious surfaces is re-directed as sheet flow onto adjacent vegetated pervious areas (i.e., lawn, meadow, or woods), AND ➢ The contributing impervious area and the receiving pervious area meet the design criteria for simple disconnection as described in Chapter 5 - Low Impact Development Site Planning and Design Strategies ➢ Soil testing is needed to classify the permeability of the receiving pervious area.	**Full Credit** Impervious area[1] (in acres) from which runoff is re-directed to adjacent vegetated pervious areas.
New or Modified Structural Stormwater BMPs	➢ The applicable post-development stormwater runoff volume (i.e., Required Retention Volume) is fully retained on-site using suitable stormwater retention practices as described in Chapter 4 - Stormwater Management Standards and Performance Criteria.	**Full Credit** Impervious area[1] (in acres) from which stormwater is retained using new or modified stormwater BMP.

[1]Credit only available if existing impervious area is directly connected.

Retrofit Type	When is DCIA Considered Disconnected?	DCIA Reduction Credit
	➢ The applicable post-development stormwater runoff volume retained on-site does not fully meet the Required Retention Volume due to physical site constraints or other factors, but runoff is retained on-site to the "Maximum Extent Achievable" (see Chapter 4 - Stormwater Management Standards and Performance Criteria.) and additional stormwater treatment without retention is provided for the post-development runoff volume above that which can be retained up to 100% of the Water Quality Volume, AND ➢ The proposed retrofit meets or exceeds the minimum required average annual pollutant load reductions (TSS, TP, TN) as demonstrated using stormwater BMP performance curves.	**Full Credit** Impervious area[1] (in acres) from which stormwater is retained or treated using new or modified stormwater BMP.
New or Modified Structural Stormwater BMPs continued	➢ In cases where the additional stormwater treatment requirement cannot be achieved on-site, but stormwater is treated to the "Maximum Extent Achievable" (see Chapter 4 - Stormwater Management Standards and Performance Criteria.)	**Partial Credit** **(X% Reduction)** The amount of DCIA reduction is determined using the stormwater BMP performance curves. • Obtain DCIA (also called "Effective IA" in the BMP performance curves) reduction percentage from the appropriate performance curve based on the type of BMP and the appropriate Hydrologic Soil Group. • Multiply the DCIA reduction percentage by the impervious area[1] draining to the stormwater BMP. If a stormwater BMP performance curve for DCIA or Effective IA does not exist for a given BMP type, estimate the DCIA reduction percentage based on the most representative curve. Table 4-2 of the Regional Retrofit Manual describes a crosswalk of appropriate representative curves. Should a BMP not be mentioned in this table justification for choosing the appropriate curve should be based on function and where necessary HSG.

[1]Credit only available if existing impervious area is directly connected.

Chapter 10 – General Design Guidance for Stormwater Infiltration Systems

Introduction

On-site infiltration of stormwater using LID site planning and design strategies and structural stormwater Best Management Practices (BMPs) is fundamental to preserving pre-development site hydrology, including groundwater recharge, and minimizing stormwater pollutant loads. As described in Chapter 4 - Stormwater Management Standards and Performance Criteria and Chapter 7 - Overview of Structural Stormwater Best Management Practices of this Manual, stormwater infiltration systems are a key practice for meeting the stormwater retention requirements of the runoff volume and pollutant reduction standard (Standard 1). Stormwater infiltration is therefore an important and integral element of stormwater management systems for many types of land development projects. Infiltration-based stormwater BMPs also require careful siting and design for an effective long-term performance.

What's New in this Chapter?

- This chapter is a new addition to the Connecticut Stormwater Quality Manual
- Provides general design guidance for stormwater infiltration systems, which are a key practice for meeting on-site stormwater retention requirements
- Includes updated guidance on soil evaluation and infiltration system sizing methods

This chapter provides general guidance on the design of infiltration-based structural stormwater BMPs, including:

Infiltration BMPs

- Infiltration Trench
- Infiltration Chamber
- Infiltration Basin
- Dry Well
- Infiltrating Catch Basin
- Permeable Pavement

Filtering BMPs (when designed for infiltration, i.e., unlined)

- Bioretention
- Tree Filter
- Surface Sand Filter

Water Quality Conveyance BMPs (when designed for infiltration, i.e., unlined)

- Dry Water Quality Swale

The information in this chapter is intended for use with the BMP-specific design guidance in Chapter 13 - Structural Stormwater BMP Design Guidance for stormwater infiltration practices. Chapter 8 - Selection Considerations for Stormwater BMPs provides selection and siting considerations for infiltration systems and other structural stormwater BMPs, while Chapter 9 - Stormwater Retrofits addresses stormwater retrofits including use of infiltration systems to retrofit existing developed sites and drainage systems.

Soil Evaluation Guidance

A soil evaluation is required for all proposed stormwater infiltration systems to confirm critical soil characteristics and subsurface conditions at the location of the proposed system including soil types, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rates (or hydraulic conductivity). This information is used to determine if stormwater infiltration is appropriate for use at the site and to support the design of the infiltration system.

The soil evaluation should be conducted by a Qualified Professional, which is an individual with demonstrated expertise in soil science, including, **but not limited to**:

- a Connecticut Registered Professional Engineer,
- a Connecticut Registered Landscape Architect
- a Qualified Professional Engineer as defined in the CT DEEP MS4 General Permit,
- a qualified soil erosion and sediment control professional as defined in the General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities,
- a Certified Soil Scientist,
- or a Professional Geologist.

Initial Screening

Initial screening of the site is recommended early in the design process to rule out sites or portions of sites that are likely unsuitable for stormwater infiltration systems. Initial feasibility screening could involve the use various information sources including but not limited to:

- Previous geotechnical investigations conducted at the site and documented in a report by a qualified geotechnical consultant

- Septic system percolation testing on-site, within 200 feet of the proposed infiltration system and at the same elevation (septic system percolation testing cannot be used for determining field infiltration rates – see below)

- Natural Resources Conservation Service (NRCS) soil mapping showing Hydrologic Soil Groups (HSG)

- Areas classified as Somewhat Poorly Drained, Poorly Drained, or Very Poorly Drained based on NRCS Soil Drainage Class mapping.

If the results of the initial screening step as determined by a Qualified Professional show that an infiltration rate greater than the minimum required infiltration rate (see General Design Guidance) is probable, the project proponent should proceed with test pits/soil borings and, under certain conditions, field infiltration testing, as discussed below. Initial screening results cannot be used in place of test pits/soil borings and field infiltration (or conductivity) testing.

Test Pits and Soil Borings

Test pits or soil borings are required for ALL proposed stormwater infiltration systems (and all other structural stormwater BMPs) to verify soil type, USDA soil textural class, and NRCS HSG soil classifications.

- Perform test pits or soil borings to a minimum depth of 3 feet below the elevation of the bottom of the proposed infiltration system (i.e., the portion of the system in contact with the underlying soil) and within 20 feet horizontally of the proposed system.
- Excavate test pits or install encased soil or hollow stem auger borings at a frequency of:
    - 1 test pit or boring per 2,000 square feet of infiltration area, but no fewer than 1 test pit or boring per location where infiltration is proposed
    - 1 test pit or boring per 5,000 square feet of permeable paving surface for permeable pavement installations, but no fewer than 2 test pits or borings per location where permeable pavement is proposed
    - 1 test pit or boring per 100 linear feet of linear BMP (infiltration trench, linear underground infiltration system, linear bioretention system, and water quality swale) but no fewer than 1 test pit or boring per linear BMP
    - Minimum test pit or soil boring frequencies for other structural stormwater BMPs are addressed in Chapter 13 - Structural Stormwater BMP Design Guidance
    - Sites with historic fill (due to the highly variable subsurface) should include additional borings and/or assure infiltration proceeds below the elevation of the fill and into natural subsoil.
- Test pit/soil boring stakes are to be left in the field for inspection purposes and survey and should be clearly labeled as such.
- Test pits should be of adequate size, depth, and construction to allow a person to enter and exit the pit and complete a soil profile description.
- If borings are drilled, continuous soil borings should be taken using a probe, split-spoon sampler, Shelby tube, or equivalent device. Samples should have a minimum 2-inch diameter.

- Determine USDA soil textural class at the bottom of the proposed infiltration system and 3ft below the bottom of the proposed infiltration system through visual field inspection by a Qualified Professional. Soil textural class represents the relative composition of sand, silt, and clay in soil. Classification of soil texture should be consistent with the USDA Textural Triangle. Geotechnical lab testing (grain-size sieve analysis and hydrometer tests) of soil samples collected from the test pits or soil borings may be used for the soil textural analysis and USDA textural soil classification. Soils must not be composited from one test pit or bore hole with soils from another test pit or bore hole for purposes of the textural analysis.

- The soil description should include all soil horizons in the test pit or soil boring.

- Determine depth to seasonal high groundwater table (SHGT) (if within 3 feet of the bottom of the proposed infiltration system). Depth to SHGT may be identified based on redoximorphic features in the soil. When redoximorphic features are not available, installation of temporary push point wells or piezometers should be considered. Ideally, such wells should be monitored in the spring when groundwater is typically highest and the results should be compared to nearby groundwater wells monitored by the USGS to estimate whether regional groundwater is below normal, normal, or above normal.

- Determine depth to bedrock (if within 3 feet of the bottom of the proposed infiltration system).

Field Infiltration Testing

Field infiltration testing is required when one or more of the following conditions exist:

- Stormwater infiltration is proposed in HSG C or D soils, as field verified through test pits or soil boring

- The Dynamic Method is used for infiltration system sizing (see below for sizing methods) regardless of USDA soil textural class or Hydrologic Soil Group

- Highly compacted soils are observed indicated or in areas of sand/gravely soils

In general, field infiltration testing is not required for infiltration systems proposed in HSG A or B soils, as field verified through test pits or soil borings, when the Static Method is used for system sizing; default infiltration rates based on the field verified USDA soil textural class may be used as the design infiltration rate. Field infiltration testing is not required for Filtering BMPs or Dry Water Quality Swales that are not designed for infiltration (i.e., designed with an impermeable liner). However, these exclusions from testing do not apply to coastal areas.

The field infiltration test method should be representative of vertical water infiltration through the soil, excluding lateral flows, under field saturated conditions. The testing should be performed by a Qualified Professional. Acceptable test methods include:

- Double-ring infiltrometer (most current ASTM method)
- Turf-tec infiltrometer method (commercially adapted version of the double-ring infiltrometer method)
- Guelph permeameter (most current ASTM method)
- Falling head permeameter (most current ASTM method)
- Borehole infiltration test (falling head infiltration test conducted in a borehole casing)
- Other equivalent methods approved by the review authority

Septic system percolation testing, performed in accordance with the guidelines of the Connecticut State Health Code or otherwise, is not acceptable for determining field infiltration rates because percolation tests overestimate the saturated hydraulic conductivity rate. Septic system percolation testing may be used as a screening tool to determine whether a site is suitable for stormwater infiltration practices (see the Initial Screening step above). Lab permeability testing is also not acceptable for determining soil infiltration rates since lab tests do not adequately represent in-situ or field conditions.

- Perform infiltration testing at or below the elevation of the bottom of the proposed infiltration system (i.e., the portion of the system in contact with the underlying soil) and within 10 feet horizontally of the proposed system.
- Perform infiltration testing at a frequency of:
    - 1 infiltration test per 2,000 square feet of infiltration area, but no fewer than 1 test per location where infiltration is proposed
    - 1 infiltration test per 5,000 square feet of permeable paving surface for permeable pavement installations, but no fewer than 2 tests per location where permeable pavement is proposed
    - 1 infiltration test per 100 linear feet of linear BMP, including Infiltration BMPs (infiltration trenches, linear underground infiltration systems), unlined Filtering BMPs (linear bioretention systems), and unlined dry water quality swales, but no fewer than 1 test pit or boring per linear BMP.

Soil Evaluation Documentation

The project proponent should prepare a plan of the site clearly delineating the NRCS Hydrologic Soil Groups throughout the entire site and the specific location(s) where infiltration is proposed. Deviations from the NRCS Soil Surveys and special conditions discovered during additional investigations (relative to infiltration potential) should be noted on the plan and described. The plan should identify the locations of all borings, test pits, and infiltration tests, including the location of any known prior tests. Test pit or boring logs should be provided with the plan, identifying in cross section the soil types, seasonal high groundwater table elevation, depth to bedrock and other restrictive layers, and other appropriate information. Infiltration test results/logs should also be included.

General Design Guidance

Soil Infiltration Rate

- Stormwater infiltration systems are most suitable in soils with infiltration rates of 0.3 inch per hour or greater at the location of the proposed infiltration system (or within the allowable horizontal testing distances as described above) and at or below the bottom of the system. Soils with infiltration rates of 0.3 inch per hour or greater generally correspond to Natural Resources Conservation Service Hydrologic Soil Group (HSG) A and B soils.

- Stormwater infiltration systems can also be suitable in soils with lower infiltration rates, HSG C and D soils provided the recommended sizing and drain time, horizontal setbacks, and vertical separation criteria are met and the system is designed with an underdrain criteria can be met. Research by the University of New Hampshire Stormwater Center and EPA Region 1 has shown that substantial stormwater infiltration and recharge can occur in lower infiltration rate soils. Ultimately, providing some infiltration is better than none, particularly for retrofit applications.

Pre-treatment should be evaluated on a case-by-case basis but is generally be required for all infiltration systems that collect runoff from impervious surfaces. If the infiltration rate of the underlying soils is greater than 8.3 inches per hour[71], the entire volume of runoff to be infiltrated should be treated, prior to infiltration, using one or more of the Filtering BMPs, Stormwater Pond and Wetland BMPs, or Water Quality Conveyance BMPs presented in Chapter 7 - Overview of Structural Stormwater Best Management Practices. Treatment BMPs that precede an infiltration system may be an integral part of the system (e.g., an unlined bioretention system) or a stand-alone treatment BMP such as a sand filter. In areas with higher infiltration rates, a larger separation distance to the SHGT may be needed to attain adequate treatment prior to discharge to groundwater. The soil infiltration rate should be determined from an acceptable field evaluation of the soils at the site of the proposed infiltration system, which consists of test pits/soil borings to determine the USDA textural soil classification and, when necessary, field infiltration testing.

- Soils may be amended to modify infiltration rates. Infiltration rates of amended soils should be subject to field infiltration testing to confirm actual infiltration rates.

[71] The primary concerns with infiltration rates above 8.3 inches per hour are a diminished ability to attenuate pollutants due to the relatively short contact time between the soil and infiltrating stormwater and a higher potential for rapid contaminant transport to groundwater.

- If it is determined that the minimum required infiltration rate is not possible at the location of the proposed infiltration system, other potential on-site locations should be evaluated for infiltration feasibility.

Design Infiltration Rate

The infiltration rate used for the design of a stormwater infiltration system (i.e., design infiltration rate) should be determined from the soil evaluation results as described in Soil Evaluation Guidance section.

- Table 10- 1 summarizes the appropriate approach for determining the design infiltration rate depending on: 1) the field-verified soil textural class and corresponding NRCS Hydrologic Soil Group classification at the location of the proposed infiltration system, and 2) the infiltration system sizing method.

Table 10- 1 Determining Design Infiltration Rates[4] for Stormwater Infiltration Systems

Sizing Method	NRCS Hydrologic Soil Group (HSG)			
	A	B	C	D
Static Method	Default Infiltration Rate[1] (Table 10-2) USDA Soil Textural Class[3]	Default Infiltration Rate[1] (Table 10-2) USDA Soil Textural Class[3]	50% of Slowest Field Measured Infiltration Rate[2] Field Infiltration Testing	50% of Slowest Field Measured Infiltration Rate[2] Field Infiltration Testing
Dynamic Method	50% of Slowest Field Measured Infiltration Rate[2] Field Infiltration Testing	50% of Slowest Field Measured Infiltration Rate[2] Field Infiltration Testing	50% of Slowest Field Measured Infiltration Rate[2] Field Infiltration Testing	50% of Slowest Field Measured Infiltration Rate[2] Field Infiltration Testing

Notes:

[1] Default infiltration rate of the most restrictive USDA soil textural class below the bottom of the proposed infiltration system.

[2] 50% of the most restrictive (i.e., slowest) field measured infiltration rate below the bottom of the proposed infiltration system.

[3] USDA soil textural class as determined from test pits or soil borings and textural analysis.

[4] If a loam surface is proposed for a surface infiltration system, use a design infiltration rate of 0.5 inch per hour (1 foot per day) for the loam surface when considering the most restrictive layer and the appropriate design infiltration rate. For Filtering BMPs (bioretention, tree filters, and sand filters) that rely on infiltration and for dry water quality swales, the design infiltration rate should be equal to 50% of the slowest field measured infiltration rate of the soils beneath the filtering system or the infiltration rate of the bioretention soil media (0.5 inches per hour, which is typical for bioretention soil) or sand filter media (1.75 inches per hour for a typical sand filter), whichever is lower.

- Default infiltration rates (Table 10- 2) may be used when sizing infiltration systems in HSG A or B soils using the Static Method. The design infiltration rate should otherwise be equal to 50% of the slowest field measured infiltration rate.

- For Filtering BMPs (bioretention, tree filters, and sand filters) that rely on infiltration and for dry water quality swales, the design infiltration rate should be equal to 50% of the slowest field measured infiltration rate of the soils beneath the filtering system or the infiltration rate of the bioretention soil media (0.5 inches per hour, which is typical for bioretention soil) or sand filter media (1.75 inches per hour for a typical sand filter), whichever is lower. Higher infiltration rates may be used for the engineered soil media or sand filter media based on permeability testing of representative samples of the materials to be used.

- If a loam surface is proposed for a surface infiltration system, use a design infiltration rate of 0.5 inch per hour (1 foot per day) for the loam surface when considering the most restrictive layer and the appropriate design infiltration rate.

Table 10- 2 Default (Rawls) Infiltration Rates for Use as Design Infiltration Rates with Static Method Sizing

USDA Soil Textural Class[1]	Hydrologic Soil Group	Default Infiltration Rate (inches/hour)
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	A	1.02
Loam	B	0.52
Silt Loam	B	0.27
Sandy Clay Loam	C	50% of Slowest Field Measured Infiltration Rate Determined from Field Infiltration Testing
Clay Loam	D	50% of Slowest Field Measured Infiltration Rate Determined from Field Infiltration Testing
Silty Clay Loam	D	50% of Slowest Field Measured Infiltration Rate Determined from Field Infiltration Testing
Sandy Clay	D	50% of Slowest Field Measured Infiltration Rate Determined from Field Infiltration Testing
Silty Clay	D	50% of Slowest Field Measured Infiltration Rate Determined from Field Infiltration Testing
Clay	D	50% of Slowest Field Measured Infiltration Rate Determined from Field Infiltration Testing

Source: The infiltration rates shown in this table are saturated hydraulic conductivities for uncompacted soils adapted from Rawls, Brakensiek, and Saxton (1982).[72]

Notes:
[1] Soil textural class as determined from field soil evaluation described in Soil Evaluation Guidance.

[72] Rawls, W. I., D. L. Brakensiek, and K. E. Saxton. 1982. Soil water characteristics. Transactions of the American Society of Agricultural Engineers, 25(5):13I6-1328.

Maximum Drain Time

Infiltration systems should be designed to completely drain within 48 hours after the end of a storm event to allow for sufficient storage in the system for the next storm event. This includes the volume of ponded water below the maximum design ponding elevation and the volume associated with void spaces in the engineered porous media such as engineered soil media and aggregate layers.

Slope

Infiltration systems are not recommended in areas with natural slopes greater than 10 percent (5 percent for permeable pavement) and should be located at least 50 feet from slopes greater than 15 percent when upgradient of such slopes. Steep slopes can cause water leakage in the lower portions of the basin, may reduce infiltration rates due to lateral water movement, or may result in seepage and slope failure of downgradient areas with slopes greater than 15 percent. Proximity to steep slopes and waterbodies should take into account subsurface conditions (e.g. soils, water table, ledge, waterbodies). Ignoring this can result in costly infrastructure failure and exfiltration of undertreated/untreated stormwater. Consultation with DEEP is recommended for infiltration systems near slopes greater than 15 percent.

Contributing Drainage Area

The recommended maximum contributing drainage areas for Infiltration BMPs are as follows:

- Infiltration Basins: 10 acres
- Infiltration Trenches: 5 acres
- Underground Infiltration Systems: 5 acres
- Dry Wells and Infiltrating Catch Basins: 1 acre
    - Larger areas allowed when multiple structures connected together
- Permeable Pavement:
    - Permeable pavement can be used to manages stormwater that falls on the pavement surface, as well as runoff from adjacent impervious areas.
    - Contributing drainage area to the permeable pavement should not exceed three times the surface area of the permeable pavement.
    - Runoff from upgradient permeable surfaces should be minimal.
    - Porous asphalt installations of 0.5 acre or less are generally not cost effective.

While theoretically feasible, provided soils are sufficiently permeable, infiltration from larger contributing drainage areas can lead to problems such as groundwater mounding, clogging, and compaction.

Recommended maximum contributing drainage areas for Filtering BMPs such as bioretention, tree filters, and sand filters are addressed in the BMP design guidance in Chapter 13 - Structural Stormwater BMP Design Guidance.

Horizontal Setbacks

Infiltration systems should be located a minimum distance horizontally from certain site features to minimize potential for adverse impacts to water quality and existing infrastructure. Table 10-3 provides recommended minimum horizontal setback distances for stormwater infiltration systems. Larger setback distances are encouraged where feasible.

Table 10- 3 Recommended Minimum Horizontal Setback Distances for Stormwater Infiltration Systems

Site Feature (on-site or off-site)	Type of Feature	Minimum Horizontal Setbacks (feet)
Private Drinking Water Supply Wells	Water Quality	100[4]
Public Drinking Water Supply Wells	Water Quality	200[4]
Public Water Supply Reservoir	Water Quality	200[4]
Streams Tributary to Public Water Supply Reservoir	Water Quality	100[4]
Surface Waterbodies and Wetlands	Water Quality	50[4]
On-site Subsurface Sewage Disposal Systems (Septic Systems) - any component	Infrastructure	
Single-Family Residential Uses		50[1]
All Other Uses		75[2]
Other Stormwater Infiltration Systems	Infrastructure	25
Infiltration System Upgradient of Building Foundations (basement or slab)	Infrastructure	50
Infiltration System Downgradient of Building Foundations (basement or slab)	Infrastructure	10
Buried Fuel Tank	Infrastructure	25[3]
Upgradient of Slopes >15%	Infrastructure	50

Notes:

[1] Consistent with the Connecticut Public Health Code, distance shall be reduced to 25 feet to a leaching system if Minimum Leaching System Spread (MLSS) is not applicable or the stormwater infiltration system is not upgradient or downgradient of the leaching system. Distances for stormwater infiltration systems designed to infiltrate up to the Water Quality Volume may be further reduced to 10 feet with the approval of the applicable review authority (Local Director of Health or CT Department of Public Health) if the results of a groundwater mounding analysis demonstrate that the stormwater infiltration system will not adversely impact the proper operation of the subsurface sewage disposal system, including any increase in the SHGT under the leaching system.

[2] Consistent with the Connecticut Public Health Code, distance shall be reduced to 50 feet to a leaching system if MLSS is not applicable or the stormwater infiltration system is not upgradient or downgradient of the leaching system, or with the approval of the applicable review authority (Local Director of Health or CT Department of Public Health) if the results of a groundwater mounding analysis demonstrate that the stormwater infiltration system will not adversely impact the proper operation of the subsurface sewage disposal system, including any increase in the SHGT under the leaching system. The applicable review authority (Local Director of Health or CT Department of Public Health) may require increased distances or further engineering assessment on the operation of the leaching system if localized groundwater mounding is a concern.

[3] May be reduced to 10 feet if stormwater infiltration system is downgradient of fuel tank.

[4] Infiltration of clean roof runoff is allowed within these setback areas.

Refer to the additional guidance later in this chapter for stormwater infiltration systems located within Aquifer Protection Areas (and other groundwater drinking supply areas).

If the minimum required setbacks associated with infrastructure site features (as listed in Table 10- 3) cannot be met, a groundwater mounding analysis should be performed (see below). The mounding analysis should demonstrate that the proposed stormwater infiltration system will not adversely impact the associated infrastructure and that the infiltration system will function consistent with the performance criteria and design guidance in this Manual.

The infrastructure-related setbacks may also be relaxed in the case of stormwater retrofits where the retrofit would otherwise be infeasible (e.g., on existing developed sites with limited space and physical constraints). A groundwater mounding analysis may be required by the review authority in these situations.

Filtering BMPs designed with an underdrain and impermeable liner may be used in areas with unacceptable horizontal setbacks for infiltration. Such systems are suitable for providing treatment but do not provide retention credit.

Vertical Separation to Groundwater and Bedrock

Inadequate vertical separation distance between infiltration systems and the seasonal high groundwater table (SHGT) and bedrock can result in insufficient pollutant removal in the unsaturated zone below the system and concerns over localized groundwater contamination, as well as reduced hydraulic performance of the system due to groundwater mounding.

For infiltration systems, at least 3 feet of separation is recommended to provide adequate treatment of stormwater within the unsaturated zone and prior to entry into the groundwater system. This can be accomplished by ensuring at least a 3-foot layer of native soil, filter media such as bioretention soil media, or some combination of both above the SHGT and bedrock. At least 1 foot of vertical separation is also recommended from the bottom of the infiltration system to the SHGT and bedrock for improved hydraulic performance (see Figure 13-17.).

Guidance on vertical separation to the SHGT and bedrock is provided below for Infiltration BMPs and Filtering BMPs designed for infiltration (i.e., without an impermeable liner).

Infiltration BMPs

The following guidance applies to the design of infiltration trenches, underground infiltration systems, infiltration basins, dry wells, infiltrating catch basins, and permeable pavement.

- The bottom of the infiltration system (i.e., the portion of the system in contact with the underlying soil) should be located at least 3 feet above the SHGT and bedrock or other impermeable material or subsurface layer, as documented by an on-site soil evaluation.
- The 3-foot vertical separation distance from the bottom of the infiltration system to the SHGT and bedrock may be reduced to 2 feet in the following situations:

  - For strictly single and multi-family residential uses (i.e., stormwater runoff from residential rooftops, driveways, and parking areas, but not roadways), or
  - For stormwater retrofits where the minimum 3-foot separation cannot be met due to existing site constraints and there is little risk to groundwater quality from the infiltrated stormwater, or
  - Where groundwater is already impacted (classified as GB) and there is little risk to groundwater quality from the infiltrated stormwater.

A groundwater mounding analysis may be required by the review authority in these situations to ensure adequate hydraulic performance of the system.

The 3-foot vertical separation distance from the bottom of the infiltration system to the SHGT and bedrock may not be reduced for infiltration of stormwater from land uses or activities with higher potential pollutant loads (see the guidance later in this section).

- Stormwater BMPs designed with an underdrain system and impermeable liner may be used in areas where the required vertical separation to the SHGT and bedrock cannot be met. Such systems are suitable for providing treatment but do not provide retention credit.

Filtering BMPs and Dry Water Quality Swales

The following guidance applies to the design of the following unlined (i.e., designed for infiltration) BMPs: bioretention systems, sand filters, tree filters, and dry water quality swales.

- The top of the filtering system should be located at least 3 feet above the SHGT and bedrock, as documented by an on-site soil evaluation. The "top of the filtering system" is the ground surface within the footprint of the filter (interface between the ground and overlying water during ponding):
  - For bioretention and other filtering systems installed with a grass cover, the top of the soil layer within which the grass is planted will be considered the "top of the filtering system."
  - When river stone or other stone is used as a cover material, the top of the filter media below the stone (bioretention soil or other filter media) will be considered the "top of the filtering system."
  - The elevation of the ponded water surface is not the "top of the filtering system."
- The 3-foot vertical separation distance from the top of the filtering system to the SHGT and bedrock may be reduced to 2 feet in the following situations:
  - For strictly single and/or multi-family residential uses (i.e., stormwater runoff from residential rooftops, driveways, and parking areas, but not roadways), or

  - For stormwater retrofits where the minimum 3-foot separation cannot be met due to existing site constraints and there is little risk to groundwater quality from the infiltrated stormwater, or

  - Where groundwater is already impacted (classified as GB) and there is little risk to groundwater quality and the seasonal baseflow volume from the infiltrated stormwater.

A groundwater mounding analysis may be required by the review authority in these situations to demonstrate adequate hydraulic and/or treatment performance of the system.

The 3-foot vertical separation distance from the top of the filtering system to the SHGT and bedrock may not be reduced for infiltration of stormwater from land uses or activities with higher potential pollutant loads (see the guidance later in this section).

- The bottom of the filtering system (i.e., the portion of the system in contact with the underlying soil) should be located at least 1 foot above the SHGT and bedrock, as documented by an on-site soil evaluation, for improved hydraulic performance of the system.

- The 1-foot separation distance between the bottom of the filtering system and the SHGT and bedrock may be reduced provided that the groundwater mound remains below the bottom of the filtering system as demonstrated by a groundwater mounding analysis. If the mounding analysis shows that the maximum elevation of the groundwater mound will be above the bottom of the filtering system, increase the separation to the SHGT and bedrock such that the bottom of the filtering system remains at or above the maximum elevation of the groundwater mound beneath the system.

- Stormwater BMPs designed with an underdrain system and impermeable liner may be used in areas where the required vertical separation to the SHGT and bedrock cannot be met. Such systems are suitable for providing treatment but do not provide retention credit.

Groundwater Mounding Analysis

Infiltration systems have the potential to cause a localized rise in the groundwater surface – referred to as a groundwater "mound" – given the right subsurface conditions. A groundwater mounding analysis can be performed to predict the extent of a groundwater mound and assess the hydraulic impact on the groundwater table and infiltration system design, so as to avoid adverse hydraulic impacts. Potential adverse hydraulic impacts include, but are not limited to, exacerbating a naturally or seasonally high groundwater table, so as to cause surficial ponding, flooding of basements, or interference with the proper operation of subsurface sewage disposal systems, or other subsurface structures within the zone of influence of the groundwater mound, or interference with the proper functioning (hydraulic performance or pollutant removal) of the infiltration system itself.

A groundwater mounding analysis is recommended for stormwater infiltration systems if one or more of the following conditions exist:

- The minimum required horizontal setback distances associated with infrastructure site features (as listed in Table 10- 3) cannot be met.
- The vertical separation distance from the bottom of an unlined filtering system to the SHGT or bedrock is less than 1 foot.
- Infiltration systems designed for the 10-year storm event or greater and have a separation from the bottom of the infiltration system to the SHGT or bedrock of less than 4 feet. Infiltration practices designed for residential rooftops ≤ 1,000 square feet are exempt from this requirement.

A groundwater mounding analysis may be required at the discretion of the review authority where the 3-foot separation distance cannot be met for strictly residential uses, there is potential for surficial ponding, basement flooding or interference with subsurface sewage disposal systems or the geology surrounding the potential infiltration practice indicates potential for ground water mounding.

The groundwater mounding analysis must demonstrate that the infiltration system will accept the required design infiltration volume without causing:

- Backup into the infiltration system (i.e., the maximum elevation of the groundwater mound beneath the system is above the bottom of the filtering system)
- Breakout above the ground surface, surface waterbodies, or wetlands
- Flooding of basements or other adverse impacts to buildings or other structures
- Slope failure
- Adverse impacts to the proper operation of a subsurface sewage disposal system, including any increase in the SHGT under the leaching system.

The Hantush or other equivalent method may be used to conduct the mounding analysis. The Hantush method predicts the maximum height of the groundwater mound beneath a recharge system. It assumes unconfined groundwater flow, and that a linear relation exists between the water table elevation and water table decline rate. It results in a water table recession hydrograph depicting exponential decline. The Hantush method is available in proprietary software and free on-line calculators, including the following recommended tool:

- USGS and New Jersey Department of Environmental Protection Hantush Groundwater Mounding Spreadsheet

If the analysis indicates the groundwater mound will prevent the infiltration system from fully draining within 48 hours after the end of the storm, an iterative process should be followed to determine an alternative design that drains within the 48-hour period.

Pretreatment

Pretreatment is required prior to discharge of stormwater runoff to most Infiltration BMPs to protect the long-term integrity of the infiltration rate and prolong the life of the system. Exceptions include dry wells that receive clean roof runoff, and permeable pavement. For some infiltration systems in highly urbanized settings, pretreatment may be economically or physically impractical due to insufficient space, insufficient grades, or utility conflicts. . In these instances, a larger infiltration system or a more intensive maintenance schedule may be used in lieu of pretreatment, at the discretion of the review authority. Pretreatment can be achieved using one of the Pretreatment BMPs described in this Manual. The design of pretreatment BMPs is addressed in Chapter 13 - Structural Stormwater BMP Design Guidance.

Land Uses with Higher Potential Pollutant Loads

Infiltration of stormwater from land uses or activities with higher potential pollutant loads (LUHPPLs) can contaminate public and private groundwater supplies and surface waters via groundwater flow. As listed in Table 10- 4 infiltration of stormwater from certain LUHPPLs is not allowed, while infiltration of stormwater from other LUHPPLs may be allowed by the review authority under the following conditions:

- The entire volume of runoff to be infiltrated should be treated, prior to infiltration, using one or more of the Filtering BMPs, Stormwater Pond and Wetland BMPs, Water Quality Conveyance BMPs, or Proprietary BMPs presented in Chapter 7 - Overview of Structural Stormwater Best Management Practices.

- Treatment BMPs that precede an infiltration system may be an integral part of the infiltration BMP (e.g., a bioretention system without an underdrain) or a stand-alone treatment BMP. Stand-alone treatment BMPs that precede an infiltration system should have an impermeable liner under the bottom and along the side slopes of the treatment BMP to prevent infiltration into the underlying and adjacent soil.

The above restrictions and conditions on infiltration of stormwater from LUHPPLs applies only to stormwater discharges that meet the area or activity on the site that may generate the higher potential pollutant load.

Table 10- 4 Land Uses or Activities with Higher Potential Pollutant Loads (LUHPPLs)

Land Use/Activities	Stormwater Infiltration Systems Allowed?
Industrial facilities subject to the CT DEEP General Permit for the Discharge of Stormwater Associated with Industrial Activity[1]	Yes[2]
Vehicle salvage yards and vehicle recycling facilities	No
Vehicle fueling facilities (gas stations and other facilities with on-site vehicle fueling)	No
Vehicle service, maintenance, and equipment cleaning facilities	No
Fleet storage areas (cars, buses, trucks, public works)	Yes[2]
Public works storage areas	Yes[2]
Road salt storage facilities (if exposed to rainfall)	No
Commercial nurseries	Yes[2]
Flat metal rooftops of industrial facilities	No
Facilities with outdoor storage and loading/unloading of hazardous substances or materials, regardless of the primary land use of the facility or development	No
Facilities subject to chemical inventory reporting under Section 312 of the Superfund Amendments and Reauthorization Act of 1986 (SARA), if materials or containers are exposed to rainfall	Yes[2]
Marinas (service and maintenance)	No

Notes:

[1] Stormwater pollution prevention plans are required for these facilities. Source control practices and pollution prevention (refer to Chapter 6) are recommended for the other land uses and activities listed above.

[2] If allowed by the review authority under the conditions described in this section, special considerations to site that have subsurface contamination are essential and may severely limit the applications in vehicle salvage yards and recycling facilities.

Fill Materials

When fill materials are present or are added prior to construction of the infiltration system, a soil textural analysis (as described in Soil Evaluation Guidance) should be conducted in both the fill material and the underlying native soil below the fill layer. Stormwater infiltration is not permitted through fill materials composed of asphalt, brick, concrete, construction debris, and materials classified as solid or hazardous waste. Alternatively, the debris or waste may be removed in accordance with applicable state solid waste regulations and replaced with clean material suitable for infiltration.

Subsurface Contamination

Infiltration of stormwater in areas with or that may introduce soil or groundwater contamination such as brownfield sites and urban redevelopment areas can mobilize contaminants. Infiltration BMPs should not be used where subsurface contamination is present from prior land use due to the increased threat of pollutant migration associated with increased hydraulic loading from infiltration systems, unless contaminated soil is removed and the site is remediated, or if approved by CT DEEP on a case-by-case basis. Filtering BMPs may be used in areas with subsurface contamination if designed with an underdrain system and impermeable liner. Such systems are suitable for providing treatment but do not provide retention credit.

Aquifer Protection Areas and Other Groundwater Drinking Supply Areas

The following measures apply to stormwater infiltration systems located within Aquifer Protection Areas (and other groundwater drinking supply areas) to prevent inadvertent pollution discharges/releases to the ground, while encouraging recharge of stormwater where it does not threaten groundwater quality.

- Aboveground Infiltration BMPs such as infiltration basins or bioretention systems designed for infiltration should be used for paved surface runoff to provide an opportunity for volatilization [73]of volatile organic compounds to the extent possible before the stormwater can infiltrate into the ground.

- Subsurface Infiltration BMPs (i.e., infiltration trenches, infiltration chambers, dry wells, infiltrating catch basins) should only be used to infiltrate clean roof runoff.

- Infiltration of stormwater within public or private wellhead protection areas (see minimum horizontal setback distances for public and private wells in Table 10- 3) should be limited to clean roof runoff only.

Coastal Areas and Sea Level Rise

Rising sea levels will result in more regular coastal flooding, increased water depths will result in greater potential for wave and storm surge propagation further inland during storms, and

[73] This excludes CT DOT related projects; CT DOT policy prohibits infiltration BMPS within an aquifer protection area.

groundwater elevations will rise in areas that are directly influenced by coastal and tidal waters. Stormwater infiltration systems in these areas are vulnerable to future reductions in separation distances between the bottom of the system and the groundwater table, submerged outfalls, and storm surge inundation of infiltration systems.

The following siting and design measures can be considered to improve the long-term effectiveness of stormwater infiltration systems in coastal and tidally influenced areas that are subject to substantial future sea level rise:

- Site and design stormwater infiltration practices not only for existing site conditions (depth to seasonal high groundwater table and flood inundation areas) but also for the conditions expected over a 50-year planning horizon, which is consistent with a 50-year design life typical of structural stormwater BMPs.
- The location of the proposed infiltration system should be evaluated in conjunction with flood projection maps to understand the implications of climate change over the design life of the BMP.
- Use several smaller infiltration BMPs located throughout the site combined with non-structural practices (e.g., LID site planning and design strategies) rather than the use of a larger, single infiltration system sited close to the shoreline.
- If infiltration systems must be sited close to the shoreline due to other constraints, site infiltration systems in areas where the required depth to groundwater can be sustained in light of expected sea level rise and associated groundwater rise. The projected separation distance to future seasonal high groundwater levels should also be accounted for in the system design and groundwater mounding analysis, if required, as well as the design of other system components such as underdrains and overflow structures.
- Avoid installing infiltration BMPs in areas where they will be exposed to significant storm impacts or sand sources that could prematurely clog the infiltration system.

Connecticut Institute for Resilience and Climate Adaptation (CIRCA_ maintains information on projected sea level rise, associated groundwater rise, and flood inundation areas. Further information on the decision to include this guidance and the most relevant sea level rise information at the time of the update of this manual is available in Appendix G.

Design Infiltration Volume

The design infiltration volume is the volume of post-development stormwater runoff required to be retained on-site through the use of stormwater infiltration systems to meet the stormwater management standards and performance criteria described in Chapter 4 - Stormwater Management Standards and Performance Criteria of this Manual.

- For off-line infiltration systems designed to meet Standard 1 (Runoff Volume and Pollutant Reduction) only, the design infiltration volume is equal to the Required Retention Volume

(50% or 100% of the Water Quality Volume), as described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

- For on-line infiltration systems designed to meet Standard 1 and provide peak runoff attenuation for larger storm events (Standard 2), the design infiltration volume is equal to the Required Retention Volume plus additional runoff volume to attenuate peak runoff rates associated with the 2-year, 10-year, and potentially 100-year storms.

As required by Standard 1, the use of non-structural LID site planning and design strategies should be considered, to the Maximum Extent Practicable, prior to the consideration of other practices, including stormwater infiltration systems. Refer to Chapter 5 - Low Impact Development Site Planning and Design Strategies for impervious surface disconnection and other non-structural LID Site Planning and Design techniques that can reduce the required design infiltration volume for stormwater infiltration systems.

Sizing Methods

Infiltration systems should be sized to store the design infiltration volume. Infiltration systems can be sized by one of two methods – the "Static Method" or the "Dynamic Method" – which are described below.

Static Method

In the Static Method, infiltration systems are sized to hold the design infiltration volume and fully infiltrate this volume into the underlying soil within 48 hours after the end of the storm. This method is more conservative and generally results in larger infiltration systems since it does not account for exfiltration from the system (infiltration into underlying soils) during the storm.

- Size the infiltration system to hold the design infiltration volume. Assume the entire design infiltration volume is discharged to the infiltration system before infiltration begins. Exfiltration during the storm event is not considered in sizing or modeling infiltration systems using the Static Method.

- The static storage volume – the volume of stormwater a structural stormwater BMP can physically hold – should be equal to or greater than the design infiltration volume.

    - The static storage volume includes the volume of ponded water below the elevation associated with the maximum ponding depth (for surface infiltration systems), the volume associated with void spaces in the subsurface engineered porous media (e.g., bioretention soil, pea gravel layer, gravel/stone reservoir), and the volume within subsurface structures (chambers, pipes, tanks, etc.). It doesn't include the additional treatment volume as a result of the water that infiltrates into the underlying soil while the system is filling or stormwater that bypasses the system through inlet or outlet controls. Table 10- 5 provides equations for calculating the static storage volume for stormwater infiltration systems. Table 10- 5 also includes the corresponding equations for calculating the minimum required surface area of a stormwater infiltration system for a given design infiltration volume or static storage volume.

- A default porosity value of 0.4 should be used for stone reservoirs in the static storage volume calculation. A default porosity value of 0.3 should be used for engineered soil media and sand for bioretention systems, tree filters, and sand filters designed for infiltration. Other porosity values may be used as determined from testing of the proposed materials.

- Confirm that the bottom of the infiltration system is large enough to ensure that the infiltration system will completely drain in 48 hours or less after the end of the storm. Calculate the drain time using the following equation:

$$T_d = \left(\frac{V}{K * A}\right) * 12\ inches/foot$$

where:

T_d = drain time (hours)
V = design infiltration volume or static storage volume calculated using the equations in Table 10- 5 (cubic feet)
K = design infiltration rate (inches per hour)
A = average surface area of infiltration system (square feet)

- The design infiltration rate (K) in the drain time equation should be the infiltration rate that is representative of the most restrictive layer in the infiltration system (i.e., surface loam layer, filter media layer for bioretention and other filtering systems used for infiltration, and the underlying soils) as described in General Design Guidance.

- The infiltration rate should be assumed to be constant for the purpose of the drain time analysis.

- Only bottom surface area should be considered. No credit is allowed for sidewall (i.e., horizontal) exfiltration. The average surface area of the infiltration system between the maximum ponding depth and the bottom of the system should be used in the drain time calculation for surface infiltration systems.

- If the drain time analysis indicates the system cannot completely drain within 48 hours after the end of the storm, the bottom area of the infiltration system should be increased, or the design infiltration volume should be reduced by reducing or disconnecting impervious area.

- An underdrain can also be added to meet the drain time requirement. The volume of stormwater infiltrated versus discharged via the underdrain will depend on the infiltration rate of the underlying soils (and filter media for

Filtering BMPs and dry water quality swales). Retention credit is only allowed for the volume of stormwater infiltrated into the underlying soils, not for stormwater that bypasses the system through inlet or outlet controls. The volume of stormwater infiltrated versus discharged via the underdrain will depend on the infiltration rate of the underlying soils. Retention credit is only allowed for the volume of stormwater infiltrated into the underlying soils, not for stormwater that bypasses the system through inlet or outlet controls

Table 10- 5 Equations for Calculating the Static Storage Volume and Required Surface Area of Stormwater Infiltration Systems (Static Method)

Stormwater BMP Type and Description	Static Storage Volume Description	Equation
Infiltration Trench Provides temporary storage of runoff through surface ponding and within the void spaces of the stone-filled trench for subsequent infiltration into the underlying soils.	Ponding water storage volume and void space volume of stone	$V = (A * D_{ponding}) + (L * W * D_{stone} * n_{stone})$ V = static storage volume (cubic feet) A = average area between maximum ponding depth and the trench surface (square feet) $D_{ponding}$ = maximum ponding depth (feet) L = length (feet) W = width (feet) D_{stone} = depth of stone (feet) n_{stone} = porosity of stone (use default value of 0.4). Other porosity values may be used as determined from testing of the proposed materials. $A_{required} = \frac{V}{(D_{ponding}) + (D_{stone} * n_{stone})}$ $A_{required}$ = minimum required surface area of infiltration trench (square feet) V = design infiltration volume (cubic feet)

Stormwater BMP Type and Description	Static Storage Volume Description	Equation
Subsurface Infiltration (Chambers, Dry Wells, and Infiltrating Catch Basins Provides temporary storage of runoff using the combination of storage structures (e.g., galleys, chambers, manholes, catch basins, etc.) and void spaces within the underlying and surrounding stone that is used to backfill the system for subsequent infiltration into the underlying soils.	Water storage volume of storage structures and void space volumes of stone underlying and surrounding the storage structures	Static storage volume equations vary based on type of system. Refer to manufacturer's design guidance for calculating static storage volume for manufactured infiltration chambers and similar subsurface storage units. When calculating the stone storage capacity, subtract the storage volume of the chambers from the calculated storage volume of the stone layer before multiplying by stone porosity.
Infiltration Basin Provides temporary storage of runoff through surface ponding storage for subsequent infiltration into the underlying soils.	Ponding water storage volume	$V = A * D_{ponding}$ V = static storage volume (cubic feet) A = average area between maximum ponding depth and the basin bottom (square feet) $D_{ponding}$ = maximum ponding depth (feet) $A_{required} = \frac{V}{D_{ponding}}$ $A_{required}$ = minimum required surface area of infiltration basin (square feet) V = design infiltration volume (cubic feet)

Stormwater BMP Type and Description	Static Storage Volume Description	Equation
Permeable Pavement Provides filtering of runoff through a surface course, choker and filter course, and temporary storage of runoff within the void spaces of a subsurface stone reservoir course prior to infiltration into subsoils.	Void space volume of choker course (stone), filter course (sand), and stone reservoir.	$V = L * W * (D_{stone} * n_{stone} + D_{sand} * n_{sand})$ V = static storage volume (cubic feet) L = length (feet) W = width (feet) D_{stone} = depth of stone courses (feet) D_{sand} = depth of sand filter course (feet) n_{stone} = porosity of stone courses (use default value of 0.4) n_{sand} = porosity of sand filter course (use default value of 0.3) Other porosity values may be used as determined from testing of the proposed materials. $A_{required} = \frac{V}{D_{stone} * n_{stone} + D_{sand} * n_{sand}}$ $A_{required}$ = minimum required surface area of permeable pavement (square feet) V = design infiltration volume (cubic feet)

Stormwater BMP Type and Description	Static Storage Volume Description	Equation
Bioretention and Tree Filter (when designed for infiltration) Provides temporary storage of runoff for filtering through an engineered soil media. The storage capacity includes void spaces in the filter media and temporary ponding at the surface. After runoff has passed through the filter media, some of it is infiltrated into the underlying soils and some is collected by an underdrain overflow pipe for discharge if an underdrain is used.	Ponding water storage volume and void space volume of soil filter media and gravel/stone layers (pea gravel and stone reservoir) if underdrain system is used or if design includes a stone reservoir without an underdrain.	Static storage volume equations vary based on type and configuration of bioretention system. Refer to manufacturer's design guidance for manufactured tree filters. $V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ V = static storage volume (cubic feet) L = length of bioretention system (feet) W = average width of bioretention system between maximum ponding depth and the bottom of the system (feet) $D_{ponding}$ = maximum ponding depth (feet) D_{soil} = depth of bioretention soil layer (feet) D_{stone} = depth of underdrain gravel and/or stone reservoir layer(s) between bottom of the bioretention soil layer and native soil (feet) n_{soil} = porosity of bioretention soil (use default value of 0.3) n_{stone} = porosity of gravel/stone (use default value of 0.4) Other porosity values may be used as determined from testing of the proposed materials. $A_{required} = \frac{V}{(D_{ponding}) + (D_{soil} * n_{soil}) + (D_{stone} * n_{stone})}$ $A_{required}$ = minimum required surface area of bioretention system (square feet) V = design infiltration volume (cubic feet)

Stormwater BMP Type and Description	Static Storage Volume Description	Equation
Surface Sand Filter (when designed for infiltration) Provides filtering of runoff through a sand filter course and temporary storage of runoff through surface ponding and within void spaces of the sand and washed stone layers. After runoff has passed through the filter media, some of it is infiltrated into the underlying soils and some is collected by an underdrain overflow pipe for discharge.	Ponding volume and void space volume of sand and gravel/stone layers.	$V = (A * D_{ponding}) + (A_{bed} * D_{sand} * n_{sand}) + (A_{bed} * D_{stone} * n_{stone})$ V = static storage volume (cubic feet) A = average area between maximum ponding depth and the filter bed surface (square feet) A_{bed} = surface area of filter bed (square feet) $D_{ponding}$ = maximum ponding depth above filter bed (feet) D_{sand} = depth of sand layer (feet) D_{stone} = depth of underdrain stone layer (feet) n_{sand} = porosity of sand (use default value of 0.3) n_{stone} = porosity of stone (use default value of 0.4) Other porosity values may be used as determined from testing of the proposed materials. $A_{required} = \frac{V}{(D_{ponding}) + (D_{sand} * n_{sand}) + (D_{stone} * n_{stone})}$ $A_{required}$ = minimum required surface area of filter bed (square feet) V = design infiltration volume (cubic feet)

Stormwater BMP Type and Description	Static Storage Volume Description	Equation
Dry Water Quality Swale (when designed for infiltration) Provides temporary surface ponding storage of runoff in an open vegetated channel through permeable check dams and filtering through an engineered soil media (bioretention soil) below the bottom of the swale. After runoff has passed through the engineered soil media, some of it is infiltrated into the underlying soils and some is collected by an underdrain overflow pipe for discharge if an underdrain is used.	Water storage volume of swale and void space volume of soil filter media and gravel/stone layers (pea gravel and stone reservoir) if underdrain system is used or if design includes a stone reservoir without an underdrain.	$V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ V = static storage volume (cubic feet) L = length of swale (feet) W = average width of swale between maximum ponding depth and the bottom of the swale (feet) $D_{ponding}$ = maximum ponding depth (feet) D_{soil} = depth of bioretention soil layer (feet) D_{stone} = depth of underdrain stone/gravel layer (feet) n_{soil} = porosity of bioretention soil (use default value of 0.3) n_{stone} = porosity of gravel/stone (use default value of 0.4) Other porosity values may be used as determined from testing of the proposed materials. $A_{required} = \frac{V}{(D_{ponding}) + (D_{soil} * n_{soil}) + (D_{stone} * n_{stone})}$ $A_{required}$ = minimum required surface area of swale (square feet) V = design infiltration volume (cubic feet)

Dynamic Method

The Dynamic Method accounts for exfiltration of stormwater into the underlying soil during the time required for the infiltration system to completely fill. This method is less conservative and can result in smaller infiltration systems, especially in more permeable soils (HSG A and B soils), which can be helpful for space-constrained sites and for more cost-effective infiltration system designs overall.

- When the Dynamic Method is used, the design infiltration rate should be determined from field infiltration testing and be equal to 50% of the field measured infiltration rate, regardless of USDA soil textural class or Hydrologic Soil Group. Default infiltration rates should not be used when using the Dynamic Method for sizing infiltration BMPs.

- Calculate the required surface area of the infiltration system using the appropriate sizing equation from Table 10- 6 or a stormwater hydrologic/hydraulic routing model (e.g., HydroCAD or similar software).

- Confirm that the bottom of the infiltration system is large enough such that the infiltration system will completely drain in 48 hours or less after the end of the storm. Use the drain time equation presented above for the Static Method or a stormwater hydrologic/hydraulic routing model (e.g., HydroCAD or similar software).

    - The drain time should be based on the design infiltration rate (see General Design Guidance).

    - The infiltration rate should be assumed to be constant for the purpose of the drain time analysis.

    - Only the bottom surface area should be considered. No credit is allowed for sidewall (i.e., horizontal) exfiltration. The average surface area of the infiltration system between the maximum ponding depth and the bottom of the system should be used in the drain time calculation for surface infiltration systems.

    - If the drain time analysis indicates the system cannot completely drain within 48 hours after the end of the storm, the bottom area of the infiltration system should be increased, or the design infiltration volume should be reduced by reducing or disconnecting impervious area.

    - An underdrain can also be added to meet the drain time requirement.

Table 10- 6 Equations for Calculating the Required Surface Area of Stormwater Infiltration Systems (Dynamic Method)

Stormwater BMP Type and Description	Equation
Infiltration Trench Provides temporary storage of runoff through surface ponding and within the void spaces of the stone-filled trench for subsequent infiltration into the underlying soils.	$$A_{required} = \frac{V}{(D_{ponding}) + (D_{stone} * n_{stone}) + (K * T/12)}$$ $A_{required}$ = minimum required surface area of infiltration trench (square feet) V = design infiltration volume (cubic feet) $D_{ponding}$ = maximum ponding depth (feet) D_{stone} = depth of stone (feet) n_{stone} = porosity of stone (use default value of 0.4) K = design infiltration rate (inches per hour) (50% of the slowest observed field infiltration rate or 0.5 inches per hour if grass/loam surface is used, whichever value is lower) T = time to fill trench (hours) (assumed to be 2 hours for design purposes)
Subsurface Infiltration (Chambers, Dry Wells, and Infiltrating Catch Basins) Provides temporary storage of runoff using the combination of storage structures (e.g., galleys, chambers, manholes, catch basins, etc.) and void spaces within the underlying and surrounding stone that is used to backfill the system for subsequent infiltration into the underlying soils.	Required surface area equations vary based on type of system. Refer to manufacturer's design guidance for calculating required surface area for manufactured infiltration chambers and similar subsurface storage units.

Stormwater BMP Type and Description	Equation
Infiltration Basin Provides temporary storage of runoff through surface ponding for subsequent infiltration into the underlying soils.	$A_{required} = \frac{V}{(D_{ponding}) + (K * T/12)}$ $A_{required}$ = minimum required surface area of infiltration basin (square feet) V = design infiltration volume (cubic feet) $D_{ponding}$ = maximum depth of ponding (feet) K = design infiltration rate (inches per hour) (50% of the slowest observed field infiltration rate or 0.5 inches per hour if grass/loam surface is used, whichever value is lower) T = time to fill basin (hours) (assumed to be 2 hours for design purposes)
Permeable Pavement Provides filtering of runoff through a surface course, choker and filter course, and temporary storage of runoff within the void spaces of a subsurface stone reservoir course prior to infiltration into subsoils.	$A_{required} = \frac{V}{(D_{stone} * n_{stone} + D_{sand} * n_{sand}) + (K * T/12)}$ $Arequired$ = minimum required surface area of permeable pavement (square feet) V = design infiltration volume (cubic feet) D_{stone} = depth of stone courses (feet) D_{sand} = depth of sand filter course (feet) n_{stone} = porosity of stone courses (use default value of 0.4) n_{sand} = porosity of sand filter course (use default value of 0.3) K = design infiltration rate (inches per hour) (50% of the slowest observed field infiltration rate) T = time to fill system (hours) (assumed to be 2 hours for design purposes)
Bioretention and Tree Filter **(when designed for infiltration)**	Required surface area equations vary based on type and configuration of bioretention system. Refer to manufacturer's design guidance for manufactured tree filters.

Stormwater BMP Type and Description	Equation
Provides temporary storage of runoff for filtering through an engineered soil media. The storage capacity includes void spaces in the filter media and temporary ponding at the surface. After runoff has passed through the filter media, some of it is infiltrated into the underlying soils and some is collected by an underdrain system for discharge.	$$A_{required} = \frac{V}{(D_{ponding}) + (D_{soil} * n_{soil}) + (D_{stone} * n_{stone}) + (K * T/12)}$$ $A_{required}$ = minimum required surface area of bioretention system (square feet) V = design infiltration volume (cubic feet) $D_{ponding}$ = maximum ponding depth (feet) D_{soil} = depth of bioretention soil layer (feet) D_{stone} = depth of underdrain gravel and/or stone reservoir layer(s) between bottom of the bioretention soil layer and native soil (feet) n_{soil} = porosity of bioretention soil (use default value of 0.3) n_{stone} = porosity of gravel/stone (use default value of 0.4) Other porosity values may be used as determined from testing of the proposed materials. K = design infiltration rate (inches per hour) (50% of the slowest observed field infiltration rate or 0.5 inches per hour for the bioretention soil media, whichever value is lower) T = time to fill bioretention system (hours) (assumed to be 2 hours for design purposes)

Stormwater BMP Type and Description	Equation
Surface Sand Filter (when designed for infiltration) Provides filtering of runoff through a sand filter course and temporary storage of runoff through surface ponding and within void spaces of the sand layer and underdrain stone layer. After runoff has passed through the filter media, some of it is infiltrated into the underlying soils and some is collected by an underdrain system for discharge.	$A_{required} = \frac{V * D_{sand}}{[(K)(D_{ponding} + D_{sand} + D_{stone})(T)]}$ $A_{required}$ = minimum required surface area of filter bed (square feet) V = design infiltration volume (cubic feet) K = design infiltration rate (ft/day) (50% of the slowest observed field infiltration rate, 3.5 ft/day for the sand filter media, or 1.0 ft/day if a loam/grass surface is used, whichever value is lowest) D_{sand} = depth of sand layer (feet) D_{stone} = depth of underdrain stone layer (feet) $D_{ponding}$ = depth of ponding above filter bed (feet) T = maximum filter bed drain time (days), use 2 days (48 hours)
Dry Water Quality Swale (when designed for infiltration) Provides temporary surface ponding storage of runoff in an open vegetated channel through permeable check dams and filtering through an engineered soil media (bioretention soil) below the bottom of the swale. After runoff has passed through the engineered soil media, some of it is infiltrated into the underlying soils and some is collected by an underdrain system for discharge.	$A_{required} = \frac{V * D_{soil}}{[(K)(D_{ponding} + D_{soil} + D_{stone})(T)]}$ $A_{required}$ = minimum required surface area of swale (square feet) V = design infiltration volume (cubic feet) K = design infiltration rate (ft/day) (50% of the slowest observed field infiltration rate or 1.0 ft/day for the engineered soil media, whichever value is lower) D_{soil} = depth of bioretention soil layer (feet) D_{stone} = depth of underdrain stone/gravel layer (feet) $D_{ponding}$ = depth of ponding above swale surface (feet) T = maximum filter bed drain time (days), use 2 days (48 hours)

Underdrained Systems

An underdrain should be included for infiltration systems in HSG C and D soils. Underdrains may also be used with some Infiltration BMPs and Filtering BMPs, regardless of soil type, to account for potential infiltration failure due to clogging, groundwater mounding, and periods of hydraulic over-loading due to excessive rainfall.

When underdrains are used, the infiltration system may not fully infiltrate the design infiltration volume since some water may discharge via the underdrain rather than through exfiltration into the underlying soil.

- Perforated underdrain pipes should be placed at the top of the underlying gravel/stone storage reservoir or sump. This type of "raised" underdrain design, which acts as an overflow for the internal gravel/stone storage reservoir, encourages infiltration of stormwater into the underlying soil before discharging via the underdrain. Chapter 13 - Structural Stormwater BMP Design Guidance provides additional guidance on the design of underdrain systems for various types of BMPs.

- A raised underdrain may be used to create a submerged internal water storage zone within some infiltration systems, such as a bioretention system designed for partial infiltration, which can enhance the removal of nitrogen.

- A stormwater hydrologic/hydraulic routing model (e.g., HydroCAD or similar software) should be used to calculate the volume of runoff infiltrated versus discharged through the underdrain. Only stormwater runoff that is infiltrated into the underlying soil can be credited toward the Required Retention Volume. Retention credit is not allowed for stormwater that is discharged through the underdrain or bypasses the system through inlet or outlet controls

Impermeable Liner

An underdrain system and impermeable liner are required for use with Filtering BMPs, dry water quality swales, and permeable pavement in the following situations:

- When receiving runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs)
- In locations with subsurface contamination
- Where the required vertical separation to the SHGT cannot be met
- In locations with unacceptable horizontal setbacks for infiltration.

Such systems are suitable for providing treatment but do not provide retention credit. The impermeable liner should be installed under the bottom and along the side slopes of the BMP to prevent infiltration into the underlying and adjacent soil. The liner should consist of a 30 mil (minimum) HDPE or PVC liner.

Alternative liner systems that may be used with the approval of the review authority include:

- 6 to 12 inches of Low Permeability Fill consisting of clay soil (minimum 15% passing the #200 sieve and a minimum hydraulic conductivity of 1 x 10-5 centimeter per second (cm/sec)
- Bentonite
- A watertight concrete structure.

The impermeable liner should extend from the top of the freeboard to beneath the bottom of the practice and should cover the entire bottom of the excavation. The liner should be sufficiently anchored along the upper edge to prevent slipping and should not extend to the surface where it would be visible.

If designing a lined system in a location where the SHGT is located at or above the bottom of the liner or closed bottom of the system, complete a buoyancy analysis to ensure buoyancy of the system will not be an issue.

Chapter 11 – Proprietary Stormwater BMPs

Introduction

> **What's New in this Chapter?**
> - Describes uses and limitations of proprietary stormwater BMPs
> - Identifies recommended third-party BMP performance verification programs for use in Connecticut
> - Provides general design criteria and maintenance requirements for proprietary BMPs

Proprietary stormwater Best Management Practices (BMPs) are manufactured systems that use proprietary settling, filtration, absorption/adsorption, vortex principles, vegetation, and other processes to remove pollutants from stormwater runoff. Proprietary BMPs are commonly used as pretreatment for other BMPs (see Chapter 13) or as treatment systems in retrofit applications where physical site constraints limit the use of other retention and/or treatment BMPs. Common types of proprietary BMPs include hydrodynamic separators, media filtration devices, and catch basin inserts. This category of stormwater BMPs also includes new and emerging technologies that are continually coming onto the market.

Underground storage and infiltration systems are not considered Proprietary BMPs since treatment typically occurs in the soil below the structure, not in the structure itself. Chapter 13 - Structural Stormwater BMP Design Guidance provides design guidance for underground storage and infiltration systems.

Uses and Limitations of Proprietary BMPs

Proprietary BMPs can be used for the following applications:

- **Pretreatment.** Proprietary BMPs may provide pretreatment for stormwater before discharging to another structural stormwater BMP. Chapter 13 - Structural Stormwater BMP Design Guidance provides design guidance for proprietary BMPs when used as pretreatment. Proprietary BMPs should meet all of the following criteria to qualify as acceptable for pretreatment:
    - Remove a minimum of 50% TSS, based on pollutant concentrations or loads, as verified by a recommended independent third-party stormwater BMP performance verification program (refer to the Third-Party Performance Verification section for recommended programs)
    - Be designed per the manufacturer's recommendations

- Be designed as off-line systems or have an internal bypass to avoid large flows and resuspension of pollutants
- If designed in an on-line configuration, proprietary pretreatment devices should be designed in accordance with the manufacturer's recommendations and any applicable use limitations upon which the third-party performance certification are based.

➢ **Treatment.** Proprietary BMPs may be used as stand-alone treatment systems to provide additional stormwater treatment (without retention) credit toward Standard 1 – Runoff Volume and Pollutant Reduction (Chapter 4 - Stormwater Management Standards and Performance Criteria). Proprietary BMPs cannot be used to meet the retention requirements of Standard 1 since they do not provide infiltration or runoff reduction. Proprietary BMPs should meet all of the following criteria to qualify as acceptable for treatment:

- Remove a minimum of 80% TSS, based on pollutant concentrations or loads, as verified by a recommended independent third-party stormwater BMP performance verification program (refer to the Third-Party Performance Verification section for recommended programs)
- Be designed per the manufacturer's recommendations
- Be sized to treat runoff associated with the Water Quality Volume (WQV) or associated peak flow rate (Water Quality Flow or WQF)
- Be designed as off-line systems or have an internal bypass to avoid flows in excess of the WQF and resuspension of pollutants
- If designed in an on-line configuration, proprietary pretreatment devices should be designed in accordance with the manufacturer's recommendations and any applicable use limitations upon which the third-party performance certification are based.

Third-Party Performance Verification

For proprietary stormwater BMPs to be considered acceptable for use as pretreatment or treatment, the project proponent should demonstrate that the system pollutant removal performance has been verified by a recommended independent third-party stormwater BMP performance verification program. The following third-party BMP performance verification programs are recommended for proprietary BMPs used in Connecticut. These programs have been active and robust in laboratory and/or field testing of various stormwater products and practices for over a decade.

➢ **New Jersey Corporation for Advanced Technology Stormwater Technologies (NJCAT).** NJCAT is a public-private partnership that was created to help bring innovative energy and environmental technologies to market. NJCAT administers the proprietary stormwater BMP verification/certification process created by New Jersey Department of Environmental Protection (NJDEP). NJCAT works with manufacturers of proprietary devices to develop quality assurance plans and conduct performance testing. NJCAT also works with independent reviewers to evaluate the results to ensure accuracy and protocol compliance. Once data has been reviewed, deemed accurate and in compliance with the protocols, NJCAT then issues a final verification report that is posted in their on-line verification database. The reports posted in the NJCAT verification database may be used as documentation of pollutant removal performance for proprietary stormwater BMPs in Connecticut, regardless of certification by NJDEP for compliance with the New Jersey stormwater requirements.

NJCAT Verification Database

- **Technology Assessment Protocol – Ecology (TAPE), Emerging Stormwater Treatment Technologies, Department of Ecology, Washington State.** TAPE is the Washington State Department of Ecology’s process for evaluating and approving emerging stormwater treatment BMPs. The TAPE program provides a rigorous evaluation protocol and peer-reviewed regulatory certification process that is recognized by many jurisdictions in the United States. TAPE evaluations must be conducted in the field, at a site in the Pacific Northwest or at an Ecology approved Stormwater Technology Evaluation Facility, which includes the University of New Hampshire Stormwater Center. Proprietary BMPs that are certified by TAPE for General Use Level Designation (GULD) for pretreatment (50% TSS removal) and/or basic treatment (80% TSS removal) are suitable for pretreatment and treatment, respectively, in Connecticut. GULD certification designates technologies whose evaluation report demonstrates confidently it can achieve Ecology's performance goals.

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- **Other Equivalent Programs.** Other equivalent independent, third-party stormwater BMP performance verification programs, at the discretion of the review authority. Such programs may include a future national testing and verification program for proprietary stormwater BMPs (Stormwater Testing and Evaluation for Products and Practices or “STEPP”), which is being led by the National Municipal Stormwater Alliance (NMSA).

  Stormwater Testing and Evaluation for Products and Practices (STEPP)

A proprietary stormwater BMP is presumed to achieve the assigned pollutant removal efficiency provided the conditions under which it is proposed to be used are similar to those in the performance testing. Key considerations in making this evaluation include:

- Design flow rate or runoff volume
- Particle size distribution

- Pollutant loading
- On-line versus off-line configuration
- Tailwater effects
- Maintenance

General Design Criteria

The following are general design criteria for proprietary stormwater BMPs, in addition to the design criteria specified by the device manufacturer and any design criteria and/or use limitations upon which the third-party performance certification is based.

- The proprietary BMP should be designed and installed with the same configuration utilized during the performance verification testing.
- Locate proprietary BMPs to be accessible for maintenance and/or emergency removal of oil or chemical spills.
- Designs for hydrodynamic separators may not include grate inlets directly into the unit unless they were specifically tested with this type of inlet.
- Proprietary BMPs subject to vehicular loading should be designed for at least HS-20 traffic loading at the surface.
- All joints and connections should be watertight.
- The manhole cover, or other approved permanent marker, should clearly indicate that the BMP is a pollutant-trapping device.
- Proprietary BMPs should be designed to safely convey overflows to downgradient drainage systems, including overflow structures designed to provide safe, stable discharge of stormwater runoff in the event of an overflow.
- Any connection to downgradient stormwater management facilities should include access points such as inspections ports and manholes for visual inspection and maintenance, as appropriate, to prevent blockage of flow and ensure operation as intended.
- Tailwater effects should be considered based upon the manufacturer's recommendations.

Maintenance of Proprietary BMPs

Proprietary devices should be inspected and maintained regularly for continued effectiveness as pretreatment or treatment systems. The following minimum maintenance guidelines are recommended for proprietary stormwater BMPs.

- Maintain proprietary BMPs in accordance with the manufacturer's guidelines.

- Perform inspections of proprietary devices a minimum of 2 times per year – in late Spring after snowmelt and in late Fall after leaf fall and before the first snowfall.

- During inspections, examined the device for standing water. If standing water is present in the device, and standing water is not a component of the design, take corrective action and revise the maintenance plan to prevent similar failures in the future.

- Clean proprietary BMPs when pollutant removal capacity is reduced by 50% or more, or when the pollutant storage capacity is reduced by 50% or more.

- Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment using a vacuum truck or other catch basin cleaning equipment.

- The Operation and Maintenance (O&M) Plan should indicate the maximum allowable level of oil, sediment, and debris accumulation. These levels should be monitored during inspections to ensure that removal of these materials is performed when necessary.

- Dispose of material removed from the device in accordance with CT DEEP guidelines (see Chapter 6 - Source Control Practices and Pollution Prevention) and other state and federal requirements by a properly licensed contractor.

Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for additional design considerations to facilitate and reduce maintenance and for general inspection and maintenance requirements. Maintenance provisions for proprietary stormwater BMPs should be included in the required O&M Plan and Stormwater Management Plan (see Chapter 12 – Stormwater Management Plan).