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):13l6-1328.

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.