CONNECTICUT DEPARTMENT OF ENERGY & ENVIRONMENTAL PROTECTION

Connecticut Stormwater Quality Manual

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THIS REVISION REPLACES THE VERSION TITLED 2004 STORMWATER QUALITY MANUAL

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Chapter 1 – Introduction

Adoption of this Manual

This manual will be used for guidance immediately upon its effective date. Any design that has completed preliminary design phase (approximately 50% of full design), however, as of the effective date will not be subject to this updated guidance. If this is the status of your project, you must immediately communicate this to the appropriate review authority. However, all projects received or permitted after one year from publication must comply with the updated Manuals. Any reference in DEEP General Permits for adherence to the guidelines, criteria, recommendations and/or requirements specified in the Manual shall be considered to have adopted these dates and criteria.

Any references in municipal regulations shall at least meet the dates above, but, if they so choose may adopt an earlier date of compliance with the updated guidance.

Purpose of the Manual

The Connecticut Stormwater Quality Manual (Manual) provides guidance on the measures necessary to protect the waters of Connecticut from the adverse impacts of stormwater runoff. States like Connecticut, which are National Pollutant Discharge Elimination System (NPDES) authorized, are required to address stormwater pollution from three potential sources: construction activities, municipal separate storm sewer systems (MS4s), and industrial activities. While the NPDES permits are the driver for the requirements, this Manual provides guidance for operators of these sources to evaluate and select the best stormwater design options to meet the requirements in these various permits. The guidance provided in this Manual is applicable to post-construction stormwater controls for new development, redevelopment, and upgrades to existing development (i.e., retrofits).

What's New in this Chapter?

- Summary of major revisions to the Manual and where to find information on future updates
- Updates to the organization and use of the Manual
- Updates to the applicability and regulatory basis of the Manual
- Updated descriptions of federal, state, and local regulatory stormwater programs as they relate to the Manual (moved to the Manual appendices)

The Manual emphasizes the use of source controls and pollution prevention, non-structural Low Impact Development (LID) site planning and design strategies, and structural stormwater Best Management Practices (BMPs). Related topics such as construction-phase soil erosion and sediment control and storm drainage system design are integral components of a comprehensive stormwater management strategy. These topics, which are included in the

Manual as secondary considerations, are addressed in detail in other related state-wide design manuals. Specifically, construction-phase soil erosion and sediment control guidance is provided in the Connecticut Guidelines for Soil Erosion and Sediment Control.

The Manual does not address agricultural[1] nonpoint source runoff. However, many of the LID and structural stormwater BMPs contained in this manual should be considered for existing and new agricultural uses, in addition to other agricultural conservation practices, to address water quality concerns.

Revisions to the Manual

Summary of 2023 Revisions

The practice of stormwater management, the scientific understanding of water quality impacts of stormwater runoff, and the state and federal regulatory environment have evolved substantially since the original Connecticut Stormwater Quality Manual was released in 2004 and then the LID Appendix in 2011. The primary objectives of the 2023 revisions to the Manual were to:

- Incorporate updated information on structural stormwater BMPs based on the current understanding of BMP selection, design, construction, and performance.
- Resolve conflicts and improve consistency between the Connecticut Stormwater Quality Manual and the Connecticut Guidelines for Soil Erosion and Sediment Control for more effective integration of construction-phase and post-construction stormwater management.
- Update the Manual for consistency with the CT DEEP stormwater general permit programs, in particular the post-construction stormwater management requirements of the General Permit for the Discharge of Stormwater from Small Municipal Separate Storm Sewer Systems (MS4 General Permit), the General Permit for the Discharge of Stormwater from Department of Transportation Separate Storm Sewer Systems (CTDOT MS4 General Permit), and the General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities (Construction Stormwater General Permit).
- Incorporate climate change and resilience considerations for stormwater management design and implementation.
- Enhance the usability of the Manual from the perspective of project designers and reviewers.

[1] The Natural Resource Conservation provides additional information specific to agriculture and stormwater control: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/?cid=nrcs144p2_027171

The 2023 revisions to the Connecticut Stormwater Quality Manual were made in conjunction with revisions to the Connecticut Guidelines for Soil Erosion and Sediment Control. This parallel process was initiated to ensure these two documents provided consistent and complementary guidance.

The 2023 version of the Connecticut Stormwater Quality Manual incorporates revisions that include but are not limited to:

- Update and streamlining of the stormwater management standards and performance criteria (Chapter 4 - Stormwater Management Standards and Performance Criteria) for consistency with the post-construction stormwater retention and treatment requirements of the CT DEEP stormwater general permits, including incorporation of permit concepts such as on-site retention of runoff and disconnection of Directly Connected Impervious Area (DCIA). The updated manual also includes a process for demonstrating compliance with the stormwater management standards and performance criteria, incorporating use of the EPA stormwater BMP performance curves for demonstrating compliance with pollutant-specific pollutant load reduction targets when retention of the applicable water quality volume is not achievable.

- Consistent with the CT DEEP stormwater general permits and stormwater management approaches adopted by other states within EPA Region 1, greater emphasis on retention of stormwater as the preferred strategy for reducing stormwater pollutant loads (pollutant concentrations and volumes) and for restoring and maintaining pre-development site hydrology with respect to groundwater recharge and the volume, flow rate, duration, and temperature of runoff.

- Development of a new chapter (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) on the design of stormwater infiltration systems, which is the primary means of achieving the retention standard. This section provides updated guidance on site suitability, soil evaluation methods, sizing methods, and other design requirements for stormwater infiltration systems.

- Update and consolidation of the LID section of the 2004 Manual and the 2011 LID Appendix into a new chapter (Chapter 5 - Low Impact Development Site Planning and Design Strategies) on LID site planning and design strategies. The updated chapter provides additional guidance on the LID site planning and design process, LID hydrologic analysis, and criteria/credits for reducing DCIA through simple disconnection and other non-structural site planning and design techniques.

- Recategorization of structural stormwater BMPs based on function, replacing the previous "Primary and Secondary Treatment Practices" terminology and framework from the 2004 Manual.

- Update of design storm precipitation to incorporate available precipitation-frequency data for Connecticut for more resilient stormwater management designs. This includes updates

to design storm precipitation for stormwater quantity control (NOAA Atlas 14) and an updated water quality design storm (90th percentile 24-hour rainfall) based on updated rainfall data for Connecticut as of the development of this Manual.

- Incorporation of other climate resilience considerations including sea level rise and coastal considerations in the selection and design of stormwater BMPs in coastal areas, as well as design considerations for mitigating the potential negative impacts of climate change on stream temperatures and nutrient loads.

- Updated structural stormwater BMP selection criteria and matrices, as well as a new stormwater BMP selection flowchart to guide designers and reviewers in the selection of appropriate structural stormwater BMPs for a given project and site (Chapter 8 - Selection Considerations for Stormwater BMPs).

- An updated section on stormwater retrofits (Chapter 9 - Stormwater Retrofits), reflecting the importance of retrofits to the success of municipal stormwater management programs in achieving the DCIA disconnection goals of the CT DEEP MS4 General Permit. The updated stormwater retrofit guidance in the Manual also incorporates and/or references information from a regional stormwater retrofit manual that has been developed for New England.

- Updated section on the appropriate use of proprietary stormwater BMPs (Chapter 11 - Proprietary Stormwater BMPs), as well as new or emerging technologies, including criteria for evaluating the use of such systems and recommended third-party performance programs.

- Updated design guidance for specific types of structural stormwater BMPs with a focus on practices that are most used to meet the retention and treatment standards in the revised Manual (Chapter 13 - Structural Stormwater BMP Design Guidance).

- Greater emphasis on integrating construction and post-construction phase stormwater management, particularly how construction activities should be integrated with LID site planning and design strategies or can impact the effectiveness of post-construction stormwater controls such as infiltration systems.

Updates and Future Revisions

Technical information regarding updates to the Manual will be available at:

http://www.ct.gov/deep/stormwaterqualitymanual

Future versions of the Manual will reflect the technical updates found on the website. Notices regarding future revisions of the Manual will also be posted at this website.

Applicability and Regulatory Basis of the Manual

The Manual itself has no independent regulatory authority. Rather, it establishes guidelines that are implemented through a framework of existing laws and regulations. Many municipalities have incorporated the Manual by reference into municipal planning, subdivision, and inland wetlands regulations. The CT DEEP MS4 General Permit specifically requires municipalities to update their local regulations to incorporate post-construction stormwater management requirements that meet or exceed the guidance contained in the Connecticut Stormwater Quality Manual. Similarly, state agencies have incorporated the Manual by reference into state regulatory and permit programs including the CT DEEP stormwater general permits.

The Manual is therefore applicable to all new development, redevelopment, and other land disturbance activity in the State of Connecticut, whether considered individually or collectively as part of a larger common plan, which triggers a local, state, or federal regulatory requirement to address post-construction stormwater management. This includes projects and activities undertaken by private entities, municipalities, or state agencies. Appendix A – Stormwater Regulation, contains a summary of local, state, and federal regulatory programs in Connecticut that require consideration of post-construction stormwater management. Linear projects have alternative standards and may take a programmatic approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT Drainage Manual, the CTDOT MS4 General Permit, the Construction General Permit and in the supporting materials that CTDOT has developed.

The Manual also applies to the design and implementation of stormwater retrofits, which can help municipalities meet the DCIA disconnection goals in the MS4 General Permit, as well as non-regulatory water quality improvement projects (e.g., implementation of watershed management plans or other voluntary nonpoint source management programs).

Organization and Use of the Manual

The Manual is organized into three major functional components. Part 1 (Chapters 1 through 3) contains background information on the Manual and its use, the stormwater-related impacts of land development, and approaches for preventing and mitigating stormwater impacts. Part 2 (Chapters 4 through 13) provides design guidance and is organized around the recommended stormwater management planning and design process. The Manual appendices contain supplemental information on the planning, design, and implementation of stormwater management measures.

Part 1 – Background

- Chapter 1 - Introduction describes the Manual's purpose, current and future revisions, users and organization, and applicability and regulatory basis.
- Chapter 2 - Stormwater Impacts describes stormwater runoff and its impacts on watershed hydrology, water quality, and ecology. Chapter 2 also introduces the concept of

impervious cover and the importance of disconnecting Directly Connected Impervious Area (DCIA). Climate change impacts on stormwater quality and quantity are also discussed.

- Chapter 3 - Preventing and Mitigating Stormwater Impacts, presents an overview of approaches for preventing and mitigating stormwater impacts through LID site planning and design, source controls and pollution prevention, construction soil erosion and sedimentation controls, and post-construction stormwater management.

Part 2 – Design

- Chapter 4 - Stormwater Management Standards and Performance Criteria, describes updated stormwater management standards and performance criteria for new development, redevelopment, and retrofit projects. This chapter also provides updated design storm precipitation for stormwater quantity control and the water quality design storm, as well as a process for demonstrating compliance with the stormwater management standards and performance criteria.

- Chapter 5 - Low Impact Development Site Planning and Design Strategies, addresses non-structural Low Impact Development (LID) site planning and design strategies that can be used to reduce or disconnect impervious surfaces and retain and infiltrate stormwater on-site, thereby eliminating or reducing the need for structural stormwater BMPs. Chapter 5 integrates information from the 2011 LID Appendix and provides additional guidance on the LID site planning and design process, hydrologic analysis, and criteria/credits for reducing DCIA through simple disconnection and other non-structural site planning and design techniques.

- Chapter 6 - Source Control Practices and Pollution Prevention, addresses source control and pollution prevention practices, which are operational practices to limit the generation of stormwater pollutants at their source. This chapter has been abbreviated to provide website links to current information on common source control and pollution prevention practices.

- Chapter 7 - Overview of Structural Stormwater Best Management Practices, introduces functional categories of structural stormwater Best Management Practices (BMPs) that can be used after consideration and use of LID site planning and design techniques to meet the stormwater management standards and performance criteria described in Chapter 4.

- Chapter 8 - Selection Considerations for Stormwater BMPs, provides guidance on selecting appropriate structural stormwater BMPs for a development site based on the requirements and needs of the site. This chapter includes an updated selection process and selection factors.

- Chapter 9 - Stormwater Retrofits, describes techniques for retrofitting existing developed sites to improve or enhance the water quality mitigation functions of the sites. Chapter 9

also discusses the conditions for which stormwater retrofits are appropriate and the potential benefits of stormwater retrofits. This updated chapter discusses the role of stormwater retrofits in meeting DCIA disconnection goals for municipal stormwater management programs.

- Chapter 10 - General Design Guidance for Stormwater Infiltration Systems, addresses the design of stormwater infiltration systems, including updated guidance on site suitability, soil evaluation methods, sizing methods, and other general design requirements for stormwater infiltration systems.

- Chapter 11 - Proprietary Stormwater BMPs, provides guidance on the appropriate use of proprietary stormwater BMPs, as well as new or emerging technologies, including criteria for evaluating the use of such systems and recommended third-party performance programs and testing criteria

- Chapter 12 – Stormwater Management Plan, describes how to prepare a stormwater management plan for review by local and state regulatory agencies. The chapter includes a recommended plan format and contents, and a completeness checklist for use by the plan preparer and reviewer.

- Chapter 13 - Structural Stormwater BMP Design Guidance, provides detailed technical design guidance for each of the structural stormwater BMPs. This chapter includes guidance on the selection, design, construction, and maintenance of these practices, as well as summary information on selection and sizing criteria addressed in previous chapters.

Chapter 2 – Stormwater Impacts

Stormwater and Land Development Impacts

What's New in this Chapter?

- Advances in scientific understanding of the water quality impacts of stormwater runoff
- Concepts of Directly Connected Impervious Area (DCIA) and DCIA disconnection from the CT DEEP MS4 General Permit
- Discussion of climate change impacts and stormwater management

Stormwater is from rain or snowmelt that runs off land surfaces such as rooftops, streets, highways, parking lots, and lawns. Along the way, the stormwater may pick up and transport contaminants. These contaminants might include motor oils, gasoline, antifreeze, and brake dust (commonly found on pavements), deposition from atmospheric sources, fertilizers and pesticides (found on landscaped areas), heavy metals and pathogens (commonly found on roofs)[2] and soil sediments (from farms and construction sites). Stormwater eventually flows into a local stream, river or lake, or into a storm drain and continues through storm pipes until it is discharged into a local waterbody. Stormwater that seeps into the ground receives some treatment by natural soil processes and eventually replenishes groundwater aquifers and surface waters such as lakes, streams, and oceans.

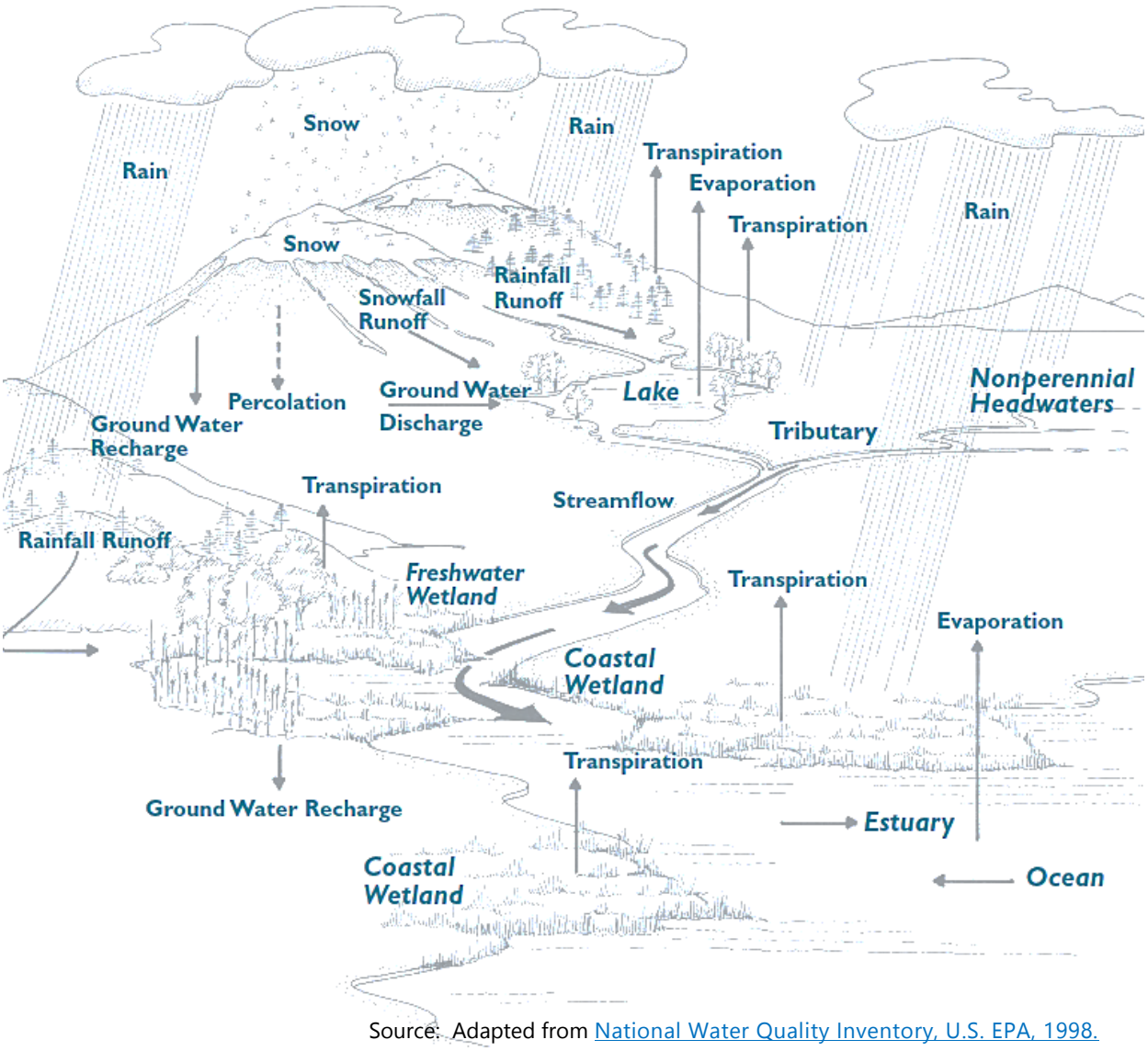
Stormwater is one component of the hydrologic cycle, which is the distribution and movement of water between the earth's atmosphere, land, and water bodies (Figure 2-1). While stormwater itself is a natural process, the development of the landscape with impervious surfaces such as buildings, roads, and parking lots, as well as storm sewer systems and other man-made features, alters the stormwater flow and composition, and even other parts of the hydrologic cycle, which can adversely impact water quality and aquatic habitat of a site or watershed. Even conversion of natural vegetation (wooded areas and meadows) to lawn can significantly alter the infiltration and water holding capacity of native soils by eliminating vegetation with deep root systems and compacting soils during construction. In addition, natural pollutant removal mechanisms provided by on-site vegetation and soils have less opportunity to remove pollutants from stormwater runoff in developed areas. This transformation increases the amount of stormwater runoff from a site, decreases infiltration and groundwater recharge, and alters natural drainage patterns.

Stormwater runoff can be considered both a point source and a nonpoint source of pollution. Stormwater runoff that flows into a conveyance system and is discharged through a pipe, ditch, channel, or other structure is considered a point source discharge under EPA's National Pollutant Discharge Elimination System (NPDES) permit program, as administered by CT DEEP.

[2] Lye DJ. Rooftop runoff as a source of contamination: a review. Sci Total Environ. 2009 Oct 15;407(21):5429-34. doi: 10.1016/j.scitotenv.2009.07.011. Epub 2009 Jul 31. PMID: 19647287.

Stormwater runoff that flows over the land surface and is not concentrated in a defined channel is considered a type of nonpoint source pollution. In most cases stormwater runoff begins as a nonpoint source (i.e., sheet flow) and becomes a point source discharge (i.e., shallow concentrated flow or flow conveyed by a gutter, ditch, drainpipe, etc.).

Figure 2-1. Hydrologic Cycle



Source: Adapted from National Water Quality Inventory, U.S. EPA, 1998.

The stormwater-related impacts of land development on rivers, streams, and other receiving waters can be grouped into four categories, which are described further in the following sections:

1. Hydrologic Impacts
2. Stream Channel and Floodplain Impacts
3. Water Quality Impacts
4. Habitat and Ecological Impacts

Hydrologic Impacts

Development can dramatically alter the hydrologic regime of a site or watershed as a result of increases in impervious surfaces. The impacts of development on hydrology may include:

- Increased runoff volume
- Increased peak discharges
- Decreased runoff travel time
- Reduced groundwater recharge
- Reduced stream baseflow
- Increased frequency of bankfull and overbank flow
- Increased flow velocity during storms
- Increased frequency and duration of high stream flow

Figure 2-2 depicts typical pre-development and post-development streamflow hydrographs for a developed watershed.

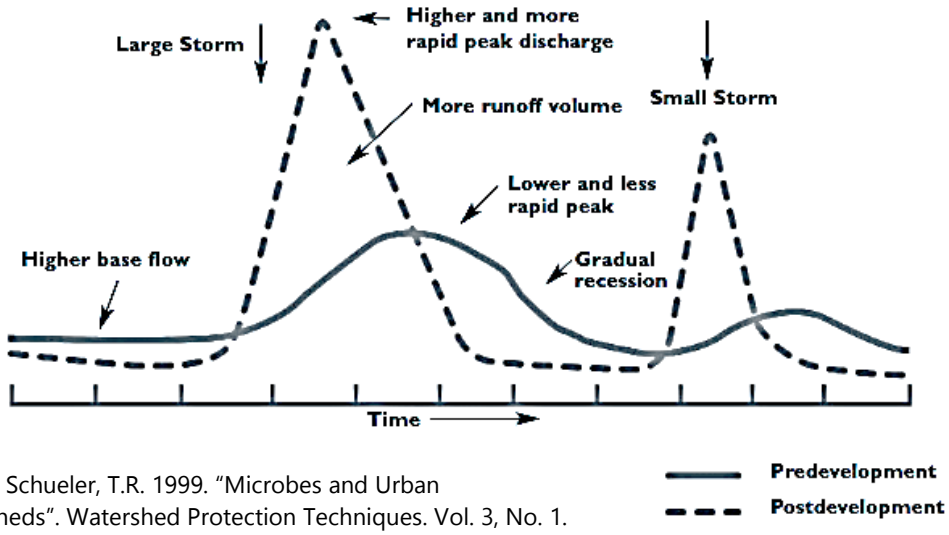
Stream Channel and Floodplain Impacts

Stream channels in developed areas respond to and adjust to the altered hydrologic regime that accompanies urbanization. The severity and extent of stream adjustment is a function of the degree of watershed imperviousness.[3] The impacts of development on stream channels and floodplains may include:

- Channel scour, widening, and downcutting
- Streambank erosion and increased sediment loads
- Shifting bars of coarse sediment
- Burying of stream substrate and increase in embeddedness
- Loss of pool/riffle structure and sequence
- Man-made stream enclosure or channelization
- Floodplain expansion

[3] Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE). 1998. Urban Runoff Quality Management (WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87).

Figure 2-2. Changes in Stream Hydrology as a Result of Land Development



Source: Schueler, T.R. 1999. "Microbes and Urban Watersheds". Watershed Protection Techniques. Vol. 3, No. 1.

Water Quality Impacts

Land development and urbanization of the landscape increases the discharge of pollutants in stormwater runoff. Development introduces new sources of stormwater pollutants and provides impervious surfaces that accumulate pollutants between storms. Structural stormwater collection and conveyance systems allow stormwater pollutants to quickly wash off during storm or snowmelt events and discharge to downstream receiving waters. By contrast, most undeveloped areas have better depression storage and pervious surfaces. Natural processes, such as infiltration, interception, depression storage, filtration by vegetation, and evaporation, can reduce the quantity of stormwater runoff and remove pollutants. Impervious areas decrease the natural stormwater purification functions of watersheds and increase the potential for water quality impacts in receiving waters.

In Connecticut, stormwater is a major source of pollution to surface waters throughout the State. This pollution can limit the use of impacted waterbodies, which may include primary contact recreation, such as swimming and boating, and the ability to support healthy aquatic life. Stormwater runoff is also a contributor to excessive nutrient enrichment in lakes and ponds, as well as a continued threat to estuarine waters and Long Island Sound.[4] In urban communities with combined storm and sanitary sewer systems, stormwater runoff also contributes to combined sewer overflows (CSOs), which can have significant surface water quality and public health impacts during and after storm events.

Waterbodies in Connecticut that are impacted by pollutants may be determined to be impaired (i.e., not meeting water quality standards for certain uses) as a result of stormwater or other

[4] United States Environmental Protection Agency (EPA). 2001. National Water Quality Inventory: 1998 Report to Congress. EPA620-R-01-005. Office of Water, Washington, D.C.

related stressors related to urbanization. Impaired waters are identified in the Connecticut Integrated Water Quality Report, which is updated by CT DEEP approximately every two years. This information is also available through an interactive map viewer maintained by UConn at: https://nemo.uconn.edu/ms4/tools/ms4map.html.

Stormwater runoff from developed areas can also degrade groundwater quality if stormwater with high pollutant loads is directed into the soil without adequate treatment. Certain land uses and activities, sometimes referred to as stormwater "hotspots" (e.g., commercial parking lots, vehicle service and maintenance facilities, and industrial rooftops), are known to produce higher loads of pollutants such as metals and toxic chemicals. Soluble pollutants can migrate into groundwater and potentially contaminate wells in groundwater supply aquifer areas.

Table 2-1 lists the principal pollutants found in stormwater runoff, typical pollutant sources, related impacts to receiving waters, and factors that promote pollutant removal. Table 2-1 also identifies those pollutants that commonly occur in a dissolved or soluble form, which has important implications for the selection and design of stormwater management practices described later in this Manual. Chapter 3 - Preventing and Mitigating Stormwater Impacts contains additional information on pollutant removal mechanisms for various stormwater pollutants.

Table 2-1. Summary of Stormwater Pollutants

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
Excess Nutrients - Nitrogen, Phosphorus (soluble)	Animal waste, fertilizers, failing septic systems, landfills, atmospheric deposition, erosion and sedimentation, illicit sanitary connections	Algal growth, nuisance plants, ammonia toxicity, reduced clarity, oxygen deficit (hypoxia), pollutant recycling from sediments, decrease in submerged aquatic vegetation (SAV)	Phosphorus: High soil exchangeable aluminum and/or iron content, vegetation, presence of carbon in the filtration medium and aquatic plants Nitrogen: Alternating aerobic and anaerobic conditions, low levels of toxicants, near neutral pH (7)
Sediments - Suspended, Dissolved, Deposited, Sorbed Pollutants	Construction sites, streambank erosion, wash off from impervious surfaces, winter sand application	Increased turbidity, lower dissolved oxygen, deposition of sediments, aquatic habitat alteration, sediment and benthic toxicity	Lowering turbulence, increasing residence time
Pathogens - Bacteria, Viruses	Animal waste, failing septic systems, illicit sanitary connections	Human health risk via drinking water supplies, contaminated swimming beaches, and contaminated shellfish consumption	High light (ultraviolet radiation), increasing residence time, filtration by media/soil filtration, disinfection
Organic Materials - Biochemical Oxygen Demand, Chemical Oxygen Demand	Leaves, grass clippings, brush, failing septic systems	Lower dissolved oxygen, odors, fish kills, algal growth, reduced clarity	Aerobic conditions, high light, high soil organic content, low levels of toxicants, near neutral pH (7)

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
Hydrocarbons - Oil and Grease	Industrial processes; commercial processes; automobile wear, emissions, and fluid leaks; improper oil disposal	Toxicity of water column and sediments, bioaccumulation in food chain organisms	Lowering turbulence, increasing residence time, physical separation or capture techniques
Metals - Copper, Lead, Zinc, Mercury, Chromium, Aluminum (soluble)	Industrial processes, normal wear of automobile brake linings and tires, automobile emissions and fluid leaks, metal roofs	Toxicity of water column and sediments, bioaccumulation in food chain organisms	High soil organic content, high soil cation exchange capacity, near neutral pH (7)
Synthetic Organic Chemicals - Pesticides, VOCs, SVOCs, PCBs, PAHs, PFAS, other contaminants of emerging concern (soluble)	Residential, commercial, and industrial application of herbicides, insecticides, fungicides, rodenticides; industrial processes; commercial processes; food packaging, commercial household products, industry (PFAS); residues of tire wear most often in urban runoff (6-PPD Quinone)[5]	Toxicity of water column and sediments, bioaccumulation in food chain organisms, health effects of drinking water contamination (PFAS)	Aerobic conditions, high light, high soil organic content, low levels of toxicants, near neutral pH (7), high temperature and air movement for volatilization of VOCs; treatability for PFAS and 6-PPD Quinone in stormwater is an evolving area of research.

[5]Markus Brinkmann, David Montgomery, Summer Selinger, Justin G. P. Miller, Eric Stock, Alper James Alcaraz, Jonathan K. Challis, Lynn Weber, David Janz, Markus Hecker, Steve Wiseman. Acute Toxicity of the Tire Rubber-Derived Chemical 6PPD-quinone to Four Fishes of Commercial, Cultural, and Ecological Importance. Environmental Science & Technology Letters, 2022; DOI: 10.1021/acs.estlett.2c00050

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
Deicing Constituents - Sodium, Calcium, Potassium, Chloride, Ethylene Glycol, Other Pollutants (soluble)	Road salting and uncovered salt storage. Snowmelt runoff from snow piles in parking lots and roads during the spring snowmelt season or during winter rain on snow events.	Toxicity of water column and sediments, contamination of drinking water, harmful to salt intolerant plants. Concentrated loadings of other pollutants as a result of snowmelt.	Aerobic conditions, high light, high soil organic content, low levels of toxicants, near neutral pH (7)
Trash and Debris	Litter washed through storm drain network	Degradation of aesthetics, threat to wildlife, potential clogging of storm drainage system	Lowering turbulence, physical straining/capture
Freshwater Impacts	Stormwater discharges to tidal wetlands and estuarine environments	Dilution of the high marsh salinity and encouragement of the invasion of brackish or upland wetland species such as *Phragmites*	Stormwater retention and volume reduction
Thermal Impacts	Runoff with elevated temperatures from contact with impervious surfaces (pavement)	Adverse impacts to aquatic organisms that require cold and cool water conditions	Retention/infiltration of runoff, use of vegetation and trees for shading of impervious surfaces, increased pool depths in stormwater ponds/wetlands

Stormwater Pollutant	Potential Sources	Receiving Water Impacts	Removal Promoted By[1]
[1]Factors that promote removal of most stormwater pollutants include: ○ Increasing hydraulic residence time ○ Lowering turbulence ○ Flow through fine, dense herbaceous plants ○ Filtration through medium-fine textured soil ○ Presence of carbon in the filtration medium			

Table above is developed from a compilation of sources.[6, 7, 8, 9, 10, 11]

[6] Ali, W.; Takaijudin, H.; Yusof, K.W.; Osman, M.; Abdurrasheed, A.S. The Common Approaches of Nitrogen Removal in Bioretention System. Sustainability 2021, 13, 2575. https://doi.org/ 10.3390/su13052575

[7] Watershed Management Institute, Inc. 1997. Operation, Maintenance, and Management of Stormwater Management Systems. In cooperation with U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

[8] Metropolitan Council. 2001. Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates, prepared by Barr Engineering Company, St. Paul, Minnesota

[9] Ismail W. Almanassra, Viktor Kochkodan, Gordon Mckay, Muataz Ali Atieh, Tareq Al-Ansari, Review of phosphate removal from water by carbonaceous sorbents, Journal of Environmental Management, Volume 287, 2021, 112245, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2021.112245.

[10] Bettina Seiwert, Maolida Nihemaiti, Mareva Troussier, Steffen Weyrauch, Thorsten Reemtsma, Abiotic oxidative transformation of 6-PPD and 6-PPD quinone from tires and occurrence of their products in snow from urban roads and in municipal wastewater, Water Research, Volume 212, 2022, 118122, ISSN 0043-1354, https://doi.org/10.1016/j.watres.2022.118122.

[11] Connecticut Department of Environmental Protection (DEP). 1995. Assessment of Nonpoint Sources of Pollution in Urbanized Watersheds: A Guidance Document for Municipal Officials, DEP Bulletin #22. Bureau of Water Management, Planning and Standards Division, Hartford, Connecticut.

Excess Nutrients

Urban stormwater runoff typically contains elevated concentrations of nitrogen and phosphorus that are mostly derived from lawn fertilizer, detergents, animal waste, atmospheric deposition, organic matter, and improperly installed or failing septic systems. Nutrient concentrations in urban runoff are like those found in secondary wastewater effluents (American Public Works Association and Texas Natural Resource Conservation Commission). Elevated nutrient concentrations in stormwater runoff can result in excessive growth of vegetation or algae in streams, lakes, reservoirs, and estuaries, a process known as accelerated eutrophication. Phosphorus is typically the growth-limiting nutrient in freshwater systems, while nitrogen is growth-limiting in estuarine and marine systems. This means that in marine waters algal growth usually responds to the level of nitrogen in the water, and in fresh waters algal growth is usually stimulated by the level of available or soluble phosphorus.[12]

Nutrients are a major source of degradation in many of Connecticut's water bodies. Excessive nitrogen loadings have led to hypoxia, a condition of low dissolved oxygen, in Long Island Sound. A Total Maximum Daily Load (TMDL) for nitrogen has been developed for Long Island Sound, which will restrict nitrogen loadings from point and non-point sources throughout Connecticut. Phosphorus in runoff has impacted the quality of many of Connecticut's lakes and ponds, which are susceptible to eutrophication from phosphorus loadings. Nutrients are also detrimental to submerged aquatic vegetation (SAV). Nutrient enrichment can favor the growth of epiphytes (small plants that grow attached to other things, such as blades of eelgrass) and increase amounts of phytoplankton and zooplankton in the water column, thereby decreasing available light. Excess nutrients can also favor the growth of macroalgae, which can dominate and displace eelgrass beds and dramatically change the food web.[13]

Sediment

Sediment loading to waterbodies occurs from washed off particles that are deposited on impervious surfaces such as roads and parking lots (through winter sand application or vehicle tracking), soil erosion associated with construction activities, and streambank erosion. Although some erosion and sedimentation is natural, excessive sediment loads can be detrimental to aquatic life including phytoplankton, algae, benthic invertebrates, and fish by interfering with photosynthesis, respiration, growth, and reproduction. Solids can either remain in suspension or settle to the bottom of the water body. Suspended solids can make the water cloudy or turbid, detract from the aesthetic and recreational value of a water body, and harm SAV, finfish, and

[12] Connecticut Department of Environmental Protection (DEP). 1995. Assessment of Nonpoint Sources of Pollution in Urbanized Watersheds: A Guidance Document for Municipal Officials, DEP Bulletin #22. Bureau of Water Management, Planning and Standards Division, Hartford, Connecticut.

[13] Deegan, L., A. A. Wright, S. G. Ayvazian, J. T. Finn, H. Golden, R. R. Merson, and J. Harrison. 2002. Nitrogen loading alters seagrass ecosystem structure and support of higher trophic levels. Aquatic Conservation. 12(2): p. 193-212. March-April, 2002.

shellfish. Sediment transported in stormwater runoff can be deposited in a stream or other water body or wetland and can adversely impact fish and wildlife habitat by smothering bottom dwelling aquatic life (including increasing spawning failure)[14] and changing the bottom substrate. Sediment deposition in water bodies can result in the loss of deep-water habitat and can affect navigation, often necessitating dredging. Sediment, particularly finer particles, can also transport pollutants such as nutrients, toxics, organics, metals, and hydrocarbons. Pathogens, often measured with the surrogate fecal indicator bacteria (FIB), are known to attach to, and thereby transport with, sediment in stormwater. Sediment accumulation in stormwater BMPs has been noted to function as a reservoir to these microorganisms.[15]

Additionally, sediment accumulation can degrade or inhibit the effectiveness of stormwater BMPs and thereby, contribute to water quality impacts indirectly as well (see the Maintenance sections of Infiltration Trenches, Underground Infiltration Systems, Dry Water Quality Swales, Wet Water Quality Swales, and Underground Detentions). Each of these contributing factors that complicate or compound the impact of sediment on water quality further demonstrate the importance of BMP maintenance and ensuring preventative measures to control erosion are taken when disturbing sediment/soil (see the Soil Erosion and Sediment Control Guidelines).

Pathogens

Pathogens are bacteria, protozoa, and viruses that can cause disease in humans. The presence of FIB such as fecal coliform, Escherichia coli, and Enterococci are indicators of the potential presence of pathogenic organisms and potential risk to human health.[16] Fecal indicator bacteria levels in stormwater runoff routinely exceed public health standards for water contact during recreation and shell fishing. Sources of fecal indicator bacteria and pathogens in stormwater runoff include animal waste from pets, wildlife, and waterfowl; combined sewer overflows; failing septic systems; and illegal sanitary sewer cross-connections. High levels of fecal indicator bacteria in stormwater have commonly led to the closure of beaches and shell fishing beds along coastal areas of Connecticut.

Organic Materials

Oxygen-demanding organic substances such as grass clippings, leaves, animal waste, and street litter are commonly found in stormwater. The decomposition of such substances in waterbodies can deplete oxygen from the water, thereby causing similar effects to those caused by nutrient

[14] Krzysztof Kukuła, Aneta Bylak, Synergistic impacts of sediment generation and hydrotechnical structures related to forestry on stream fish communities, Science of The Total Environment, Volume 737, 2020, 139751, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.139751.

[15] Urban Water Resources Research Council, Pathogens in Wet Weather Flows Technical Committee, Environmental and Water Resources Institute, American Society of Civil Engineers 2014 https://www.asce-pgh.org/Resources/EWRI/Pathogens%20Paper%20August%202014.pdf

[16] Connecticut Department of Environmental Protection (DEP). 1995. Assessment of Nonpoint Sources of Pollution in Urbanized Watersheds: A Guidance Document for Municipal Officials, DEP Bulletin #22. Bureau of Water Management, Planning and Standards Division, Hartford, Connecticut.

loading. Organic matter is of primary concern in waterbodies where oxygen is not easily replenished, such as slower moving streams, lakes, and estuaries. An additional concern for unfiltered water supplies is the formation of trihalomethane (THM), a carcinogenic disinfection byproduct generated by the mixing of chlorine with water high in organic carbon.[17]

Hydrocarbons

Stormwater runoff from developed areas contains a wide array of hydrocarbon compounds, some of which are toxic to aquatic organisms at low concentrations.[18] Vehicles are the primary sources of hydrocarbons in stormwater runoff. Source areas with higher concentrations of hydrocarbons in stormwater runoff include roads, parking lots, gas stations, vehicle service stations, residential parking areas, and bulk petroleum storage facilities.

Metals

Metals such as copper, lead, zinc, mercury, and cadmium are commonly found in stormwater runoff. Chromium and nickel are also frequently present.[19] The primary sources of these metals in stormwater runoff are vehicular exhaust residue, fossil fuel combustion, corrosion of galvanized and chrome-plated products, roof runoff, stormwater runoff from industrial sites, and the application of deicing agents. Architectural copper associated with building roofs, flashing, gutters, and downspouts has been shown to be a source of copper in stormwater runoff in Connecticut and other areas of the country.[20,21] Marinas have also been identified as a source of copper and, therefore, present aquatic toxicity to inland and marine waters.[22] Washing or sandblasting of boat hulls to remove salt and barnacles also removes some of the bottom paint, which contains copper and zinc additives to protect hulls from deterioration.

In Connecticut, discharge of metals to surface waters is of particular concern. Metals can be toxic to aquatic organisms, can bioaccumulate, and have the potential to contaminate drinking water supplies. Many major rivers in Connecticut have copper levels that exceed Connecticut's Copper Water Quality Criteria. Although metals generally attach themselves to the solids in stormwater runoff or receiving waters, studies have demonstrated that dissolved metals, particularly copper

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[17] New York State Department of Environmental Conservation (NYDEC). 2001. New York State Stormwater Management Design Manual. Prepared by Center for Watershed Protection. Albany, New York.

[18] Woodward-Clyde Consultants. 1990. Urban targeting and BMP Selection: An Information and Guidance Manual for State NPS Program Staff Engineers and Managers, Final Report.

[19] United States Environmental Protection Agency (EPA). 1983. Results of the Nationwide Urban Runoff Program, Volume 1, Final Report. Water Planning Division. Washington, D.C. NTIS No. PB 84-185 552.

[20] Barron, T. 2000. Architectural Uses of Copper: An Evaluation of Stormwater Pollution Loads and Best Management Practices. Prepared for the Palo Alto Regional Water Quality Control Plant.

[21] Tobiason, S. 2001. "Trickle Down Effect". *Industrial Wastewater.* Water Environment Federation. Vol. 9, No. 6.

[22] Sailer Environmental, Inc. 2000. Final Report on the Alternative Stormwater Sampling for CMTA Members. Prepared for Connecticut Marine Trades Association.

and zinc, are the primary toxicants in stormwater runoff from industrial facilities throughout Connecticut.[23, 24] Additionally, stormwater runoff can contribute to elevated metals in aquatic sediments by combining with road salts which then mobilize metals.[25] Many metals can become bioavailable where the bottom sediment is anaerobic (without oxygen) such as in a lake or estuary. Metal accumulation in sediments has resulted in impaired aquatic habitat and more difficult maintenance dredging operations in estuaries because of the special handling requirements for contaminated sediments.

Synthetic Organic Chemicals

Synthetic organic chemicals can also be present at low concentrations in urban stormwater. Pesticides, phenols, polychlorinated biphenyls (PCBs), and polynuclear or polycyclic aromatic hydrocarbons (PAHs) are the compounds most frequently found in stormwater runoff. Such chemicals can exert varying degrees of toxicity on aquatic organisms and can bioaccumulate in fish and shellfish. Toxic organic pollutants are most found in stormwater runoff from industrial areas. Pesticides are commonly found in runoff from urban lawns and rights-of-way.[26] A review of monitoring data on stormwater runoff quality from industrial facilities has shown that PAHs are the most common organic toxicants found in roof runoff, parking area runoff, and vehicle service area runoff.[27] Emerging contaminants such as per- and polyfluoroalkyl substances (PFAS), which is a group of man-made chemicals that have been manufactured and used in a variety of industries since the 1940s, are an increasing concern for public health in both drinking water supplies and in stormwater runoff.

Deicing Constituents

Salting of roads, parking lots, driveways, and sidewalks during winter months and snowmelt during the early spring result in the discharge of sodium, chloride, and other deicing compounds to surface waters via stormwater runoff. Excessive amounts of sodium and chloride may have harmful effects on water, soil, and vegetation, and can also accelerate corrosion of metal surfaces. Drinking water supplies, particularly groundwater wells, may be contaminated by runoff from roadways where deicing compounds have been applied or from highway facilities where salt mixes are improperly stored. In addition, sufficient concentrations of chlorides may prove toxic to certain aquatic species. Excess sodium in drinking water can lead to health

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[23] Mas, D.M.L., Curtis, M.D., and E.V. Mas. 2001. "Investigation of Toxicity Relationships in Industrial Stormwater Discharges", presented at New England Water Environment Association 2001 Annual Conference, Boston, MA.

[24] New England Bioassay, Inc. 2001. Final Report on Stormwater Toxicity Identification Evaluations (TIE) at Industrial Sites. Prepared for the Connecticut Department of Environmental Protection.

[25] https://stormwater.pca.state.mn.us/index.php/Environmental_impacts_of_road_salt_and_other_de-icing_chemicals

[26] New York State Department of Environmental Conservation (NYDEC). 2001. New York State Stormwater Management Design Manual. Prepared by Center for Watershed Protection. Albany, New York.

[27] Pitt, R., Field, R., Lalor, M., and M. Brown. 1995. "Urban Stormwater Toxic Pollutants: Assessment, Sources, and Treatability". Water Environment Research. Vol. 67, No. 3.

problems in individuals on low sodium diets. Other deicing compounds may contain nitrogen, phosphorus, and oxygen demanding substances. Antifreeze from automobiles is a source of phosphates, chromium, copper, nickel, and cadmium.

Other pollutants such as sediment, nutrients, and hydrocarbons are released from the snowpack during the spring snowmelt season and during winter rain-on-snow events. The pollutant loading during snowmelt can be significant and can vary considerably during the melt event.[28] For example, a majority of the hydrocarbon load from snowmelt occurs during the last 10 percent of the event and towards the end of the snowmelt season.[29] Similarly, PAHs, which are hydrophobic materials, remain in the snowpack until the end of the snowmelt season, resulting in highly concentrated loadings.[30]

Trash and Debris

Trash and debris are washed off the land surface by stormwater runoff and can accumulate in storm drainage systems and receiving waters. Litter detracts from the aesthetic value of waterbodies and can harm aquatic life either directly (by being mistaken for food) or indirectly (by habitat modification). Sources of trash and debris in urban stormwater runoff include residential yard waste, commercial parking lots, street refuse, combined sewers, illegal dumping, and industrial refuse.

Impacts of Freshwater Discharges

Discharge of freshwater, including stormwater, into brackish and tidal wetlands can alter the salinity and hydroperiod of these environments, which can encourage the invasion of brackish or freshwater wetland species such as Phragmites australis (common reed).

Thermal Impacts

Impervious surfaces may increase temperatures of stormwater runoff and receiving waters. Roads and other impervious surfaces heated by sunlight may transport thermal energy to a stream during storm events. Direct exposure of sunlight to shallow ponds and impoundments, as well as unshaded streams, may further elevate water temperatures. Elevated water temperatures can exceed fish and invertebrate tolerance limits, reducing survival and lowering resistance to disease. Coldwater fish such as trout may be eliminated, or the habitat may become marginally supportive of cold-water species. Elevated water temperatures also contribute to decreased oxygen levels in water bodies and dissolution of solutes.

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[28] New York State Department of Environmental Conservation (NYDEC). 2001. New York State Stormwater Management Design Manual. Prepared by Center for Watershed Protection. Albany, New York.

[29] Oberts, G. 1994. "Influence of Snowmelt Dynamics on Stormwater Runoff Quality". Watershed Protection Techniques. Vol. 1, No. 2.

[30] Metropolitan Council. 2001. Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates, prepared by Barr Engineering Company, St. Paul, Minnesota.

Additionally, increasing temperatures may compound the issues around harmful algal blooms. As noted by EPA, warming water temperatures may favor harmful algal blooms in several ways:[31]

- Toxic blue-green algae prefer warmer water.
- Warmer temperatures prevent water from mixing, allowing algae to grow thicker and faster.
- Warmer water is easier for small organisms to move through and allows algae to float to the surface faster.
- Algal blooms absorb sunlight, making water even warmer and promoting more blooms.

Habitat and Ecological Impacts

Changes in hydrology, stream morphology, and water quality that accompany the development process can also impact stream habitat and ecology. A large body of research has demonstrated the relationship between urbanization and impacts to aquatic habitat and organisms. Habitat and ecological impacts may include:

- A shift from external (leaf matter) to internal (algal organic matter) stream production
- Reduction in the diversity, richness, and abundance of the stream community (aquatic insects, fish, amphibians)
- Destruction of freshwater wetlands, riparian buffers, and springs
- Creation of barriers to fish migration

Impacts on Other Receiving Environments

Most of the research on the ecological impacts of urbanization has focused on streams. However, urban stormwater runoff has also been shown to adversely impact other types of receiving environments such as wetlands, lakes, and estuaries. Development alters the physical, geochemical, and biological characteristics of wetland systems. Lakes, ponds, wetlands, estuaries and SAV are impacted through deposition of sediment and particulate pollutant loads. Additionally, increased nutrient loads accelerate eutrophication and lower light penetration impacting the living organisms of these waterbodies. Estuaries also experience more extreme salinity swings caused by increased runoff and reduced baseflow. Table 2- 2 summarizes the effects of land development and urbanization on these receiving environments.

[31] https://www.epa.gov/nutrientpollution/climate-change-and-harmful-algal-blooms

Table 2- 2 Effects of Land Development and Urbanization on Other Receiving Environments

Receiving Environment	Impacts
Wetlands	➢ Changes in hydrology and hydrogeology ➢ Increased nutrient and other contaminant loads ➢ Compaction and destruction of wetland soil ➢ Changes in wetland vegetation ➢ Changes in or loss of habitat ➢ Changes in the community (diversity, richness, and abundance) of organisms ➢ Loss of biota ➢ Permanent loss of wetlands
Lakes and Ponds	➢ Impacts to biota on the lake bottom due to sedimentation ➢ Contamination of lake sediments ➢ Water column turbidity ➢ Aesthetic impairment due to floatables and trash ➢ Increased algal blooms and depleted oxygen levels due to nutrient enrichment, resulting in an aquatic environment with decreased diversity ➢ Contaminated drinking water supplies
Estuaries	➢ Sedimentation in estuarial streams and SAV beds ➢ Altered hydroperiod of brackish and tidal wetlands, which results from larger, more frequent pulses of fresh water and longer exposure to saline waters because of reduced baseflow ➢ Hypoxia ➢ Turbidity ➢ Bioaccumulation ➢ Loss of SAV due to nutrient enrichment ➢ Scour of tidal wetlands and SAV ➢ Short-term salinity swings in small estuaries caused by the increased volume of runoff which can impact key reproduction areas for aquatic organisms

Source: Adapted from WEF and ASCE, 1998.

Impervious Cover

Impervious cover is any impervious surface in the landscape that cannot effectively absorb and infiltrate rainfall. For the purpose of this Manual, impervious surfaces include, but are not limited to roads, parking lots, driveways, roofs, sidewalks, patios (i.e., solid or open-joint patios or decks with an underlying impervious surface), water surfaces of manmade impoundments (i.e., stormwater ponds and swimming pools) only if they are hydraulically connected to a storm drainage system, receiving waterbody, or wetland; compacted gravel surfaces and highly compacted soils. These surfaces disrupt the natural hydrologic cycle, increasing surface runoff and decreasing infiltration of rainfall into the soil.

Impervious cover is widely considered a key environmental indicator. A large body of scientific literature has shown that groundwater recharge, stream base flow, and water quality measurably change and can decrease as impervious cover increases. Studies have shown a direct relationship between the intensity of development, as indicated by the amount of impervious cover, and the degree of damage in a watershed. [32, 33, 34, 35, 36, 37, 38] Research nationwide has shown that when impervious cover in a watershed reaches approximately 10 percent, ecological stress becomes clearly apparent. Beyond 25 percent, stream stability is reduced, habitat is lost, water quality becomes degraded, and biological diversity decreases.[39] Figure 2-3 illustrates this effect.

Studies indicate that as the amount of impervious cover in a watershed exceeds 12 percent, unacceptable impacts to aquatic life can be predicted to occur in surface waters. The Connecticut Watershed Response Plan for Impervious Cover set a target of 11 percent impervious cover or less to be applied in Connecticut based on the observed water quality

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[32] Schueler T. R. Kumble P. A. Heraty M. A. Metropolitan Washington Council of Governments & United States. (1992). A current assessment of urban best management practices: techniques for reducing non-point source pollution in the coastal zone. Metropolitan Washington Council of Governments.

[33] Schueler, T.R. 1994. "The Importance of Imperviousness". Watershed Protection Techniques. Vol. 1, No. 3.

[34] Schueler, T.R. 1995. Site Planning for Urban Stream Protection. Metropolitan Washington Council of Governments. Washington, D.C.

[35] Booth, D.B. and L.E. Reinelt. 1993. "Consequences of Urbanization on Aquatic Systems - Measured Effects, Degradation Thresholds, and Corrective Strategies", in Proceedings of the Watershed '93 Conference. Alexandria, Virginia.

[36] Arnold, C.L., Jr., and C.J. Gibbons. 1996. "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator". Journal of the American Planning Association. Vol. 62, No. 2.

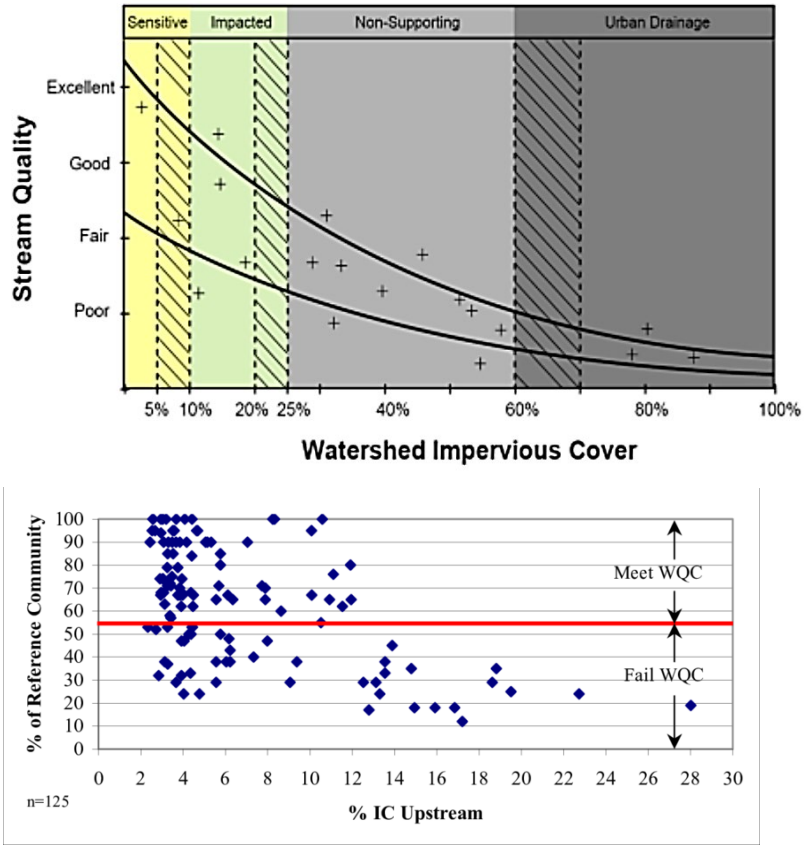
[37] Brant, T.R. 1999. "Community Perceptions of Water Quality and Management Measures in the Naamans Creek Watershed". Master's Thesis for the Degree of Master of Marine Policy

[38] Shaver, E.J. and J.R. Maxted. 1996. "Technical Note 72 Habitat and Biological Monitoring Reveals Headwater Stream Impairment in Delaware's Piedmont". Watershed Protection Techniques. Vol. 2, No. 2.

[39] Natural Resources Defense Council (NRDC). 1999. Stormwater Strategies: Community Responses to Runoff Pollution.

impairments at 12 percent IC and an application of a 1 percent margin of safety. Stormwater runoff has been identified as a probable contributing cause to the impairment. Municipalities and other stakeholders should therefore aim to mitigate stormwater impacts in areas with IC greater than 11 percent to reduce the amount of stormwater pollution reaching surface waters, to improve water quality.

Figure 2-3. Relationship Between Watershed Impervious Cover and Stream Health



National impervious cover model (top) and scatterplot of percent impervious cover and reference macroinvertebrate communities in Connecticut (bottom).

Image sources: Center for Watershed Protection[40] (top) and Chris Bellucci/CT DEEP (bottom).

[40] Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. March 2003.

Impervious Area and Directly Connected Impervious Area

Impervious area (IA) includes any impervious surface in a drainage area or watershed. 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 "Effective Impervious Area" or, for this manual, "Directly Connected Impervious Area (DCIA)". DCIA is considered a better predictor of watershed/ecosystem health than IA because it only 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. The following types of impervious areas are considered disconnected:

- Impervious areas that drain as sheet flow onto and over an adjacent pervious area that, due to its size, slope, vegetation, and underlying soil characteristics, can retain the appropriate portion of the Water Quality Volume, as defined in Chapter 4. This non-structural LID site planning and design technique is called "simple disconnection," which is described further in Chapter 5 – Low Impact Development Site Planning and Design Strategies.
- Impervious areas that discharge runoff through structural stormwater BMPs designed to retain the appropriate portion of the Water Quality Volume.
- Isolated impervious areas that are not hydraulically connected to a storm drainage system, receiving waterbody, or wetland.
- Swimming pools or man-made impoundments, unless hydraulically connected to a storm drainage system, receiving waterbody, or wetland.
- The surface area of natural waterbodies (e.g., wetlands, ponds, lakes, streams, rivers).

The CT DEEP MS4 General Permit requires regulated municipalities to track and disconnect DCIA using simple disconnection and structural stormwater BMPs for redevelopment projects and retrofits, or by converting impervious surfaces to pervious surfaces. The existing DCIA of a site is also an important factor in determining the portion of the Water Quality Volume that must be retained, also referred to as the "Required Retention Volume" (see Chapter 4).

Stormwater Management and Climate Change Impacts

Water resources in Connecticut are affected by climate stressors, including increasing temperatures, changing precipitation patterns, extreme events (storms, floods, and drought), and rising sea levels. These changing conditions have implications for stormwater management as local and state decision makers look to implement appropriate maintenance plans, improve existing infrastructure, and build new stormwater systems that are more resilient to changes in

the quantity and quality of stormwater runoff.[41] See Appendix G for additional details regarding climate change and stormwater impacts in Connecticut, including the basis for the approach selected to incorporate climate change considerations into this Manual.

This Manual incorporates climate change and resilience considerations for stormwater management design and implementation, including:

- Preserving pre-development site hydrology using LID site planning and design strategies (Chapter 5 – Low Impact Development Site Planning and Design Strategies) and structural stormwater BMPs (Chapters 7-13)
- Discussion of updated design storm precipitation for stormwater quantity and quality control (Chapter 4)
- Sea level rise and other considerations for stormwater BMP siting and design in coastal areas (Chapter 4, Chapter 8, and Chapter 10)
- Design considerations for mitigating the potential negative impacts of climate change on stream temperatures and nutrient loads (Chapter 4 and Chapter 8).

It is important to consider future conditions when designing and implementing stormwater BMPs (including long-term maintenance) to ensure the longevity of the investment. Appendix G contains additional resources that may be of use when evaluating climate change considerations for resilient stormwater management design and implementation, including long-term maintenance.

[41] EPA, 2021, https://www.epa.gov/arc-x/climate-adaptation-and-stormwater-runoff

Chapter 3 – Preventing and Mitigating Stormwater Impacts

Introduction

What's New in this Chapter?

- Streamlined stormwater management framework and elements
- Recategorized structural stormwater BMPs based on function

Managing the stormwater impacts of land development requires the selective use of non-structural and structural stormwater control measures. Low Impact Development (LID) site planning and design is a critical and effective element of a successful stormwater management approach because it addresses the root causes of both stormwater quality and quantity problems by helping to preserve pre-development site hydrology and pollutant loads. Source controls and pollution prevention, as well as construction erosion and sedimentation controls, are also key elements for preventing or mitigating stormwater quality problems. These preventive measures can reduce the size and scope of structural stormwater Best Management Practices (BMPs). However, it is also recognized that structural stormwater BMPs, in combination with LID and other non-structural measures, are often necessary to fully meet stormwater quality and quantity control objectives.

This Manual addresses stormwater quality and quantity using LID site planning and design strategies, source controls, and structural stormwater BMPs. Construction-phase soil erosion and sedimentation controls, storm drainage facilities (catch basins, manholes, storm sewers, etc.), and flood mitigation/control are addressed as secondary topics as they relate to stormwater quality for more detailed guidance refer to the Soil Erosion and Sediment Control Guidelines. Other statewide design guidance documents, as well as local ordinances and requirements, should be consulted for more information on these topics.

Guiding Stormwater Management Principles

A comprehensive stormwater management strategy should prevent or mitigate stormwater runoff problems and protect beneficial uses of receiving waters in a cost-effective manner. The stormwater management measures described in this Manual are designed to accomplish this objective by adhering to the following guiding principles:

- Preserve pre-development site hydrology (i.e., runoff, infiltration, interception, evapotranspiration, groundwater recharge, and stream baseflow).
- Provide minimum average annual reductions in post-development pollutant loads for sediment, floatables, nutrients, and other pollutants.

- Preserve and protect wetlands, stream buffers, natural drainage systems and other natural features that provide water quality and quantity benefits.
- Manage runoff velocity and volume in a manner that maintains or improves the physical and biological character of existing drainage systems and prevents increases in downstream flooding/streambank erosion.
- Prevent pollutants from entering receiving waters and wetlands in amounts that exceed the systems' natural ability to assimilate the pollutants and provide the desired functions.
- Seek multi-objective benefits (i.e., flood control, water quality, recreation, aesthetics, habitat) from stormwater control measures.

LID Site Planning and Design

LID site planning and design focuses on measures that counteract the impacts of development. LID includes the use of both non-structural site planning and design techniques, which are addressed in Chapter 5, and the use of distributed, small-scale structural stormwater BMPs, which are practices referred to as Green Infrastructure (GI), see Structural Stormwater BMPs in this Chapter for the overview of GI.

LID site planning and design techniques have three general approaches: avoid, reduce, and manage the impacts of development. All of these approaches are designed to address the root causes of stormwater problems by helping to maintain pre-development hydrology and the pollutant removal functions of a site. LID approaches integrate stormwater management from the beginning of the site design process. Often these non-structural site design strategies can reduce the scope of or eliminate the need for more costly structural stormwater BMPs. This Manual emphasizes the use of LID site planning and design techniques early in the site development process and prior to the consideration of structural measures. LID site planning and design practices are addressed in Chapter 5 – Low Impact Development Site Planning and Design Strategies of this Manual.

Source Control Practices and Pollution Prevention

Source controls and pollution prevention are operational practices that can reduce the types and concentrations of pollutants in stormwater runoff by limiting the generation of pollutants at their source. The guiding principle behind these techniques is to minimize contact of stormwater with potential pollutants, thereby reducing pollutant loads and the size and cost of stormwater treatment. This Manual emphasizes the use of source control practices and pollution prevention, in conjunction with LID site planning and design, to reduce the need for and scope of structural stormwater BMPs. A variety of common source control practices that can be implemented at residential, municipal, institutional, commercial, and industrial sites are addressed in Chapter 6 – Source Control Practices and Pollution Prevention of this Manual, which includes references and links to existing available information sources on each topic.

Construction of Soil Erosion and Sedimentation Controls

As described in Chapter 1, soil erosion and sedimentation control is addressed through the Soil Erosion and Sediment Control Act (Section 22a-325 through 22a-335, inclusive) as well as related local and state permitting requirements. The primary goal of the Act is to reduce soil erosion from stormwater runoff and nonpoint sediment pollution from land that is being developed. Measures for controlling soil erosion and sedimentation during construction are described in a site-specific Soil Erosion and Sediment Control (SESC) Plan. The post-construction stormwater management standards addressed in Chapter 4 of this Manual include the development and implementation of an SESC Plan. Erosion and sedimentation control measures should be designed in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control Guidelines (as amended) and applicable local and state permit requirements.

Structural Stormwater BMPs

Structural stormwater Best Management Practices (BMPs) are stormwater management systems used to reduce the discharge of pollutants and the volume of runoff from developed sites to maintain pre-development hydrology, pollutant loads, and groundwater recharge. Structural stormwater BMPs can be designed to collect, store, treat, infiltrate, and evapotranspire stormwater runoff.

Structural stormwater BMPs that primarily rely on vegetation and soils to mimic natural processes and manage rainwater close to where it falls are also commonly referred to as "Green Infrastructure (GI)." Structural stormwater BMPs are one element of a comprehensive stormwater management approach and should be selected and designed only after consideration of LID site planning and design strategies and in combination with operational source control practices and pollution prevention. Note that GI can also be applied as a form of LID, especially at a watershed scale.

Stormwater quality and quantity controls are related and complementary elements of an effective stormwater management strategy. Structural stormwater BMPs are typically designed for small, frequent storms to achieve stormwater quality objectives (i.e., smaller than a one-year return frequency storm), in contrast to drainage and flood control facilities, which are typically designed for the two-year and larger storms. Stormwater BMPs can also be designed for stormwater quantity control by reducing post-development runoff volumes and peak flows.

This Manual includes the following major categories and types of structural stormwater BMPs that are recommended for use in Connecticut, based on their primary function:

- Pretreatment BMPs
- Infiltration BMPs
- Filtering BMPs
- Stormwater Pond and Wetland BMPs
- Water Quality Conveyance BMPs
- Stormwater Reuse BMPs

- Proprietary BMPs
- Other BMPs and BMP Accessories

Chapters 7 through 13 address the selection, design, construction, and maintenance of structural stormwater BMPs for new development, redevelopment, and retrofitting of existing developed areas.

This Manual addresses the topics of storm drainage design and flood control as they relate to stormwater quality management. Storm drainage facilities (catch basins, manholes, storm sewers, etc.) and stormwater BMPs used primarily for flood control should be designed in accordance with the Connecticut Department of Transportation Drainage Manual as well as applicable local and state design and permitting requirements, including flood management requirements.

Chapter 4 – Stormwater Management Standards and Performance Criteria

Introduction

This chapter presents stormwater management standards and performance criteria for land development projects in Connecticut. The standards and performance criteria apply to all new development, redevelopment, retrofits, and other land disturbance activities, whether considered individually or collectively as part of a larger common plan, which are subject to local, state, or federal regulatory requirements to address post-construction stormwater management.

What's New in this Chapter?

- Updated stormwater management standards and performance criteria
- Consistency with stormwater retention and treatment requirements in the CT DEEP stormwater general permits
- Updated design storm precipitation for stormwater quality and quantity control
- Use of EPA stormwater BMP performance curves and pollutant-specific load reduction targets

Project proponents are required to meet and demonstrate compliance with the management standards and performance criteria using non-structural Low Impact Development (LID) site planning and design techniques and structural stormwater Best Management Practices (BMPs), in addition to operational source controls and pollution prevention. The management standards and performance criteria are intended to help preserve pre-development site hydrology and pollutant loads to the maximum extent possible to protect water quality, maintain groundwater recharge, and prevent flooding.

The performance criteria address the full spectrum of storm flows and their associated water quality and quantity impacts. These range from smaller more frequent storms that are responsible for a majority of the annual runoff volume and pollutant loads, to larger less frequent events that can cause flooding. Given the observed and anticipated future increases in precipitation as a result of climate change, the performance criteria include updated design storm precipitation amounts and intensities for more resilient stormwater management designs.

The management standards and performance criteria presented in this Manual are intended to be consistent with the post-construction stormwater management requirements of the CT DEEP stormwater general permits, as well as local requirements within municipal planning, zoning, and stormwater ordinances and regulations. Some differences may exist between the standards and performance criteria in this Manual and local requirements. For example a local Inland Wetlands and Watercourses authority may require to maintain certain flow levels with respect to a downstream wetland, shallow water body, vernal pool, or small watercourse, etc. Where local requirements are less stringent than noted in this Manual, the intent of this Manual is to provide recommended guidance based on the most relevant science at the time of its publication.

Table 4-1 summarizes the stormwater management standards and performance criteria, which are described in more detail in the following sections.

KEY TERM:

Maximum Extent Achievable (MEA)

This term is meant to indicate the site design has incorporated that element as completely as possible for the given site parameters. The justification and documentation of achieving this extent is described further in each of the sub sections below.

Maximum Extent Achievable (MEA) - LID Site Planning and Design

Maximum Extent Achievable (MEA) – Stormwater Treatment

Maximum Extent Achievable (MEA) – Stormwater Retention

***Note:** The term MEA is used, but not specifically defined, in the current MS4 General Permit. The concepts described here are synonymous with the term Maximum Extent Practicable (MEP) of the MS4 General Permit.

Table 4-1. Stormwater Management Standards and Performance Criteria Summary

Stormwater Management Standard	Performance Criteria
Standard 1 – Runoff Volume and Pollutant Reduction Preserve pre-development hydrology and pollutant loads to protect water quality and maintain groundwater recharge.	**LID Site Planning and Design (non-structural)** Consider the use of non-structural LID site planning and design strategies, to the maximum extent achievable, prior to the consideration of other practices, including structural stormwater BMPs. 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 post-development impervious area and stormwater runoff volumes. **Stormwater Retention and Treatment (structural)** After application of non-structural LID site planning and design techniques, use structural stormwater BMPs to retain and/or treat the remaining post-development stormwater runoff volume: ➢ Retention: Retain on-site the following post-development stormwater runoff volume for the site (Required Retention Volume) to the Maximum Extent Achievable using structural stormwater BMPs: Required Retention Volume (RRV): ○ 100% of the site's Water Quality Volume (WQV) ▪ All new development ▪ Redevelopment or retrofit of sites that are currently developed with existing DCIA[42] of less than 40% ▪ Any new stormwater discharges located within 500 feet of tidal wetlands ○ 50% of the site's WQV ▪ Redevelopment or retrofit of sites that are currently developed with existing DCIA of 40% or more ➢ Additional Treatment without Retention: If the post-development stormwater runoff volume retained on-site does not meet the Required Retention Volume for the site, provide stormwater treatment without retention to the Maximum Extent Achievable for the volume above that which can be retained, up to 100% of the site's WQV. The additional stormwater treatment should be provided using structural stormwater BMPs to achieve annual average pollutant load reduction targets for sediment, floatables, and nutrients, per Table 4-3. Refer to Chapters 7 through 13 for selection and design of structural stormwater BMPs for meeting the Stormwater Retention and Treatment requirements.

[42] Note DCIA is not equivalent to the impervious area, see the distinction noted in Chapter 2.

Stormwater Management Standard	Performance Criteria
Standard 2 – Stormwater Runoff Quantity Control[43] Do not exceed pre-development peak flow rates and manage the volume and timing of runoff to prevent downstream flooding, channel erosion, and other adverse impacts, and safely convey flows into, through, and from structural stormwater BMPs.	**Peak Runoff Attenuation for Site Development / Redevelopment** Control the 2-year, 24-hour post-development peak flow rate to 50% of the 2-year, 24-hour pre-development peak flow rate for each point at which stormwater discharges from a site using structural stormwater BMPs. Control the 10-year, 24-hour post-development peak flow rate to the 10-year, 24-hour pre-development peak flow rate for each point at which stormwater discharges from a site using structural stormwater BMPs. Potentially control the 100-year, 24-hour post-development peak flow rate to the 100-year, 24-hour pre-development peak flow rate for each point at which stormwater discharges from a site using structural stormwater BMPs, as required by the review authority. Demonstrate that any increased volume or change in timing of stormwater runoff will not result in adverse effects such as increased flooding downstream of the site or at other off-site locations, as required by the review authority. **Conveyance Protection** Design the conveyance system leading to, from, and through structural stormwater BMPs based on the post-development peak flow rate associated with the 10-year, 24-hour or larger magnitude design storm. **Emergency Outlet Sizing** Size the emergency outlet of stormwater quantity control structures to safely pass the post-development peak runoff from the 100-year, 24-hour or larger magnitude design storm in a controlled manner without eroding the outlet and downstream drainage systems. Refer to Chapters 7 through 13 for selection and design of structural stormwater BMPs for meeting the Stormwater Runoff Quantity Control requirements.

[43] Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

Stormwater Management Standard	Performance Criteria
Standard 3 – Construction Soil Erosion and Sediment Control Design, install, and maintain effective soil erosion and sedimentation control measures during construction and land disturbance activities. Consideration for final site stabilization should also be included during the development of a SESC Plan.	Develop and implement a Soil Erosion and Sediment Control (SESC) Plan in accordance with local and/or state regulatory requirements, the Connecticut Guidelines for Soil Erosion and Sediment Control Guidelines (as amended), and the requirements of the CT DEEP Construction Stormwater General Permit.
Standard 4 – Post-Construction Operation and Maintenance Perform long-term maintenance of structural stormwater management systems to ensure that they continue to function as designed and implement operational source control and pollution prevention measures.	Develop and implement a long-term Operation and Maintenance (O&M) Plan, which identifies required inspection and maintenance activities for structural stormwater BMPs. Operational source control and pollution prevention practices (see Chapter 6 - Source Control Practices and Pollution Prevention) should be included in the O&M Plan. Refer to Chapter 7 – Overview of Structural Stormwater Best Management Practices for general maintenance guidelines for stormwater BMPs, Chapter 13 – Structural Stormwater BMP Design Guidance for recommended maintenance for specific stormwater BMPs, and Appendix B for BMP-specific maintenance inspection checklists.

Stormwater Management Standard	Performance Criteria
Standard 5 – Stormwater Management Plan Document how the proposed stormwater management measures meet the stormwater management standards, performance criteria, and design guidelines.	Prepare a Stormwater Management Plan (see Chapter 12 – Stormwater Management Plan) to document how the proposed stormwater management measures for a specific land development project or activity meet the stormwater management standards, performance criteria, and design guidelines contained in the Connecticut Stormwater Quality Manual, as well as other local, state, and federal stormwater requirements.

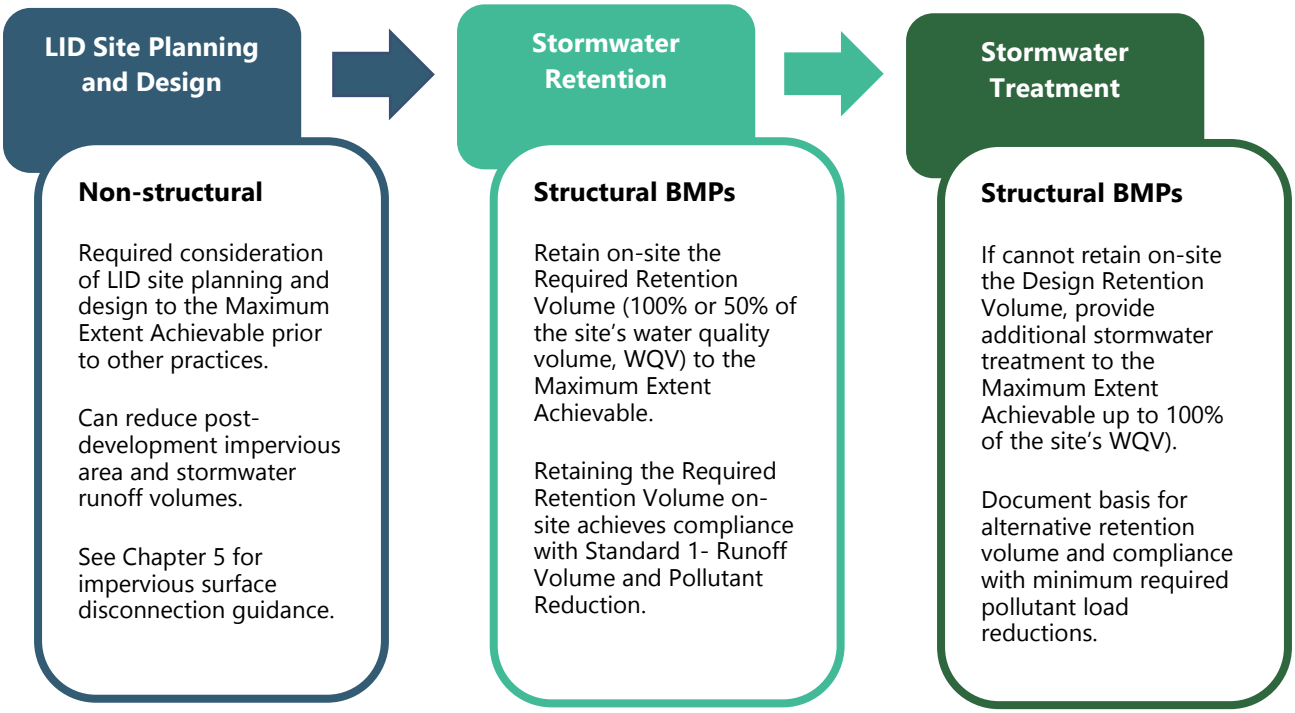
Note: Consult local and state regulations for additional stormwater management requirements. The above standards and criteria are recommended where local or state regulations are less stringent.

Standard 1 – Runoff Volume and Pollutant Reduction

Standard 1 (Runoff Volume and Pollutant Reduction) is intended to preserve pre-development hydrology (runoff duration, rate, and volume) and pollutant loads to protect water quality and maintain groundwater recharge by retaining and/or treating stormwater runoff from smaller, more frequent storms.

Standard 1 requires consideration of non-structural LID site planning and design techniques to reduce and disconnect post-development impervious areas on a site prior to consideration of structural stormwater BMPs. Once LID site planning and design techniques have been applied, structural stormwater BMPs should be used to retain on-site the required post-development stormwater runoff volume (i.e., retention volume) primarily through stormwater infiltration or reuse. If the retention volume for the site cannot be fully retained on-site, additional stormwater BMPs should be used to treat the volume above that which can be retained. Figure 4-1 illustrates schematically the major elements of and general process for complying with Standard 1.

Figure 4-1. Runoff Volume and Pollutant Reduction (Standard 1) Elements and Process



LID Site Planning and Design (non-structural)

Consider the use of non-structural LID site planning and design strategies, to the **MEA** (see the text box below for the definition) prior to the consideration of other practices, including structural stormwater BMPs, consistent with the CT DEEP stormwater general permits. The objective of this is to ensure that non-structural LID site planning and design techniques are considered at an early stage in the planning process and integrated into the project design.

Refer to Chapter 5 - Low Impact Development Site Planning and Design Strategies for performance criteria and design guidance for impervious area disconnection and other non-structural LID site planning and design strategies that can reduce post-development impervious area and stormwater runoff volumes.

Maximum Extent Achievable (MEA) – LID

For demonstrating "maximum extent achievable" regarding the LID Site Planning and Design requirement, a project proponent should demonstrate the following:

1. All reasonable efforts have been made to incorporate the use of LID site planning and design strategies in accordance with current local, state, and federal regulations,
2. A complete evaluation of all possible LID site planning and design strategies has been performed based on consideration of site characteristic, water quality, and other factors, and
3. The highest practicable use of LID site planning and design strategies is incorporated into the project.

The Stormwater Management Plan (Chapter 12 – Stormwater Management Plan) should include:

- LID Site Planning and Design Opportunities and Constraints Plan
- Completed LID Site Planning and Design Checklist documenting the non-structural LID strategies selected for the project and why other non-structural LID strategies could not be incorporated into the project.

Note: These LID principles are requirements of the CT DEEP Construction General Permit and are highly recommended for other categories of stormwater management.

Stormwater Retention and Treatment (structural)

After application of non-structural LID site planning and design strategies to the MEA, select and design structural stormwater BMPs in accordance with this Manual to manage the remaining post-development stormwater runoff volume from the site through on-site retention and treatment.

Stormwater Retention

Retain on-site the applicable post-development stormwater runoff volume **for the site**, referred to as the "Required Retention Volume," using structural stormwater BMPs. The Required Retention Volume is equal to 100% or 50% of the site's Water Quality Volume (WQV) depending on the type of project or activity (new development, redevelopment, or retrofit) and the existing Directly Connected Impervious Area (DCIA) of the site, consistent with the post-construction stormwater management provisions of the CT DEEP stormwater general permits. Refer to Table 4-2 for determining the appropriate Required Retention Volume for a given land development project or activity.

Table 4-2. Required Retention Volume Determination

Type of Project or Activity	Required Retention Volume (RRV)[1]	Additional Treatment Volume Required[1]	
		If Volume Retained Meets or Exceeds RRV	If Volume Retained Does Not Meet RRV
➢ New development[2] ➢ Redevelopment[3] or retrofit of sites that are currently developed with existing DCIA[4] of less than 40% ➢ Any new stormwater discharges located within 500 feet of tidal wetlands, which are not fresh-tidal wetlands, to avoid dilution of the high marsh salinity and encouragement of the invasion of brackish or upland wetland species	100% of site's WQV	None	(100% of site's WQV) – (Volume Retained)
➢ Redevelopment or retrofit of sites that are currently developed with existing DCIA[4] of 40% or more	50% of site's WQV	None	(100% of site's WQV) – (Volume Retained)

[1] Provide stormwater retention or additional treatment without retention to the Maximum Extent Achievable as defined in the CT DEEP stormwater general permits and described in this section.

[2] "New Development" means any construction or disturbance of a parcel of land that is currently in a natural vegetated state and does not contain alteration by man-made activities.

[3] "Redevelopment" means any construction activity (including, but not limited to, clearing and grubbing, grading, excavation, and dewatering) within existing drainage infrastructure or at an existing site to modify, expand, or add onto existing buildings, structures, grounds, or infrastructure.

[4] For the purpose of determining the Required Retention Volume, existing DCIA should be calculated based on the existing (pre-development) conditions of the overall project site.

- "Retention" means to hold post-development runoff on-site using structural stormwater BMPs or non-structural LID site planning and design strategies. In addition, it means there shall be no subsequent point source discharge to the drainage system or surface waters, including bypass of the stormwater BMP through inlet or outlet controls, **of any portion of** the Required Retention Volume. Retention practices reduce post-development runoff volumes and therefore are also called "runoff reduction" practices.

- Table 8-1. Stormwater Management Suitability in Chapter 8 identifies stormwater BMPs and their suitability for meeting the stormwater retention performance criterion. In general, Infiltration BMPs and Stormwater Reuse BMPs are considered suitable retention practices. Infiltration BMPs are preferred for meeting the stormwater retention performance criteria because they also recharge groundwater. Filtering BMPs (bioretention systems, tree filters, and surface sand filters) can provide retention of stormwater when designed specifically for infiltration. Dry water quality swales and green roofs are also suitable for providing stormwater retention.

- Retention practices should be sized to meet or exceed the applicable Required Retention Volume and should be designed, installed, and maintained consistent with the guidelines contained in this Manual to preserve pre-development hydrology and to achieve minimum average annual pollutant load reductions for sediment, floatables, and nutrients.

- In cases where the Required Retention Volume cannot be fully[44] retained on-site, retain stormwater runoff on-site to the "Maximum Extent Achievable" (see text box for demonstrating this) and provide additional stormwater treatment without retention as summarized in Table 4-2. Required Retention Volume Determination and described in the following section.

The Standard 1 stormwater retention requirements can be met at each individual discharge point along the boundary of the development site or internal to the site (i.e., design point) such as abutting properties, roadways, wetlands and watercourses, and receiving storm drainage systems.[45] I Or the Standard 1 retention requirement may also be demonstrated sitewide or for multiple design points.

[44] Fully means for the site. This can be address through multiple LID strategies, and structural BMPs in series or separately at several discharge points. The element that is important here is the RRV for the entire site.

[45] Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

- Appendix C presents calculation methods for designing retention and treatment stormwater BMPs and demonstrating compliance with the Standard 1 retention requirements by demonstrating individual BMPs.
- Pretreatment is necessary for most BMPs and should be provided as necessary (see Table 8-1. Stormwater Management Suitability) guidelines in Chapter 13 – Structural Stormwater BMP Design Guidance.

Maximum Extent Achievable (MEA) – Stormwater Retention*

For the Stormwater Retention requirement, MEA means maximum extent achievable using control measures that are technologically available and economically practicable and achievable considering best industry practice. To demonstrate compliance with the MEA standard for stormwater retention, a project proponent should:

- **Documentation:** Submit documentation for review and approval by the review authority describing site constraints (e.g., brownfields, capped landfills, bedrock, elevated groundwater, etc.) that would prevent on-site retention of the full Design Retention Volume. The documentation should include:
    - An explanation of site limitations
    - A description of the stormwater retention practices implemented
    - An explanation of why this constitutes the Maximum Extent Achievable
    - An alternative retention volume (i.e., the volume that can be retained on-site when the Required Retention Volume cannot be fully retained)
    - A description of the measures used to provide additional stormwater treatment without retention for sediment, floatables, and nutrients above the alternative volume up to the site's WQV
    - Analysis demonstrating that the average annual pollutant load reductions achieved by the proposed stormwater treatment measures meet or exceed minimum required reductions for sediment, floatables, and nutrients. The analysis should use the EPA stormwater BMP performance curves.

AND

- **Offsite Retention Mitigation:** Propose a stormwater retrofit project on another site within the same CT DEEP Subregional Basin or USGS HUC12 watershed (and preferably the same municipality) as the project site, provided the municipality has an offsite mitigation program in place. 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. The fee should be based on an estimate of the cost necessary to implement the retrofit to achieve a similar amount of retention to the amount by which the actual amount of retention fails to achieve the required retention volume for the site. Offsite mitigation is allowed for new development and redevelopment.

***Note:** The term MEA is used, but not specifically defined, in the current MS4 General Permit. The concepts described here are synonymous with the term Maximum Extent Practicable (MEP) of the MS4 General Permit.

- In the case of linear projects that do not involve impervious surfaces (e.g., electrical transmission rights-of-way or natural gas pipelines), stormwater retention is not required if the post-development runoff characteristics do not differ significantly from pre-development conditions.

- In the case of linear redevelopment projects (e.g., roadway reconstruction or widening) for the developed portion of the right of way:

    - For projects that may be unable to retain the Required Retention Volume (50% of the site's WQV), the alternate retention volume and additional treatment measures (see below) may also be applied, OR
    - For projects that will not increase the DCIA within a given CT DEEP Local Basin, the project proponent should implement the additional stormwater treatment measures (see below) but is not required to retain the Required Retention Volume (50% of the site's WQV).
    - For projects that are adding DCIA but unable to meet the retention requirements, the project proponent should prioritize the removal of the pollutant of concern if discharging to an impaired waterbody. If the project is not discharging to an impaired waterbody, the project proponent should prioritize the removal of TSS.

Stormwater Treatment

If the post-development stormwater runoff volume retained on-site does not meet the Required Retention Volume (100% or 50% of the site's WQV) for the site, provide stormwater treatment without retention for the post-development runoff volume above that which can be retained (the "alternate retention volume") up to 100% of the site's WQV (refer to Table 4-2. Required Retention Volume Determination).

Table 8-1. Stormwater Management Suitability identifies stormwater BMPs that can be used to provide stormwater treatment without retention. Treatment practices should be sized for the appropriate WQV or Water Quality Flow (WQF) and should be designed, installed, and maintained consistent with the guidelines contained in this Manual to achieve minimum average annual pollutant load reductions for sediment, floatables, and nutrients.

- Pretreatment is required for most stormwater BMPs and should be provided, as necessary (Table 8-1. Stormwater Management Suitability), in accordance with the design guidelines in Chapter 13 - Structural Stormwater BMP Design Guidance.

- When necessary, meeting Standard 1 through a combination of stormwater retention and treatment may require a treatment train approach – the use of multiple stormwater BMPs in series (e.g., an infiltration BMP sized for a portion of the required retention volume, followed by a treatment BMP to treat the remaining volume **up to** the site's full WQV).

- In cases where the stormwater treatment requirement cannot be fully achieved on-site, provide stormwater treatment to the "Maximum Extent Achievable" (see text box for definition).

Maximum Extent Achievable (MEA) – Stormwater Treatment*

For the Stormwater Treatment requirement, "MEA" means maximum extent achievable using control measures that are technologically available and economically practicable and achievable considering best industry practice. To demonstrate compliance with the MEA standard for stormwater treatment, a project proponent should:

- **Documentation:** Submit documentation for review and approval by the review authority describing site constraints that would prevent on-site treatment of the required treatment volume. The documentation should include:
  - An explanation of site limitations
  - A description of the stormwater treatment practices implemented and an alternative treatment volume (i.e., the volume that can be treated on-site when the required treatment volume cannot be achieved)

AND

- **Offsite Treatment Mitigation:** Propose a stormwater retrofit project on another site within the same CT DEEP Subregional Basin or USGS HUC12 watershed (and preferably the same municipality) as the project site, provided the municipality has an offsite mitigation program in place. 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. The fee should be based on an estimate of the cost necessary to implement the retrofit to achieve a similar amount of treatment to the amount by which the actual amount of treatment fails to achieve the required treatment volume for the site. Offsite mitigation is allowed for new development and redevelopment.

***Note:** The term MEA is used, but not specifically defined, in the current MS4 General Permit. The concepts described here are synonymous with the term Maximum Extent Practicable (MEP) of the MS4 General Permit.

Water Quality Volume

Updated Water Quality Volume

The Water Quality Volume (WQV) concept is based on the "first flush" principle, which assumes that most pollutants in stormwater runoff are conveyed in the initial portion of a storm event. As such, the WQV is the volume of runoff generated by the water quality storm. The water quality storm is defined as the 90th percentile rainfall event (accounting for 90 percent of all 24-hour storms on an average annual basis). The runoff volume associated with the 90th percentile rainfall depth roughly corresponds to the volume of runoff that is infiltrated in a natural condition and thus should be managed on-site to restore and maintain pre-development hydrology for duration, rate, and volume of stormwater flows.[46]

Prior to this update, the water quality storm was defined as the 1-inch storm. This version of the Manual replaces the previous 1-inch water quality storm with an updated 90th percentile rainfall depth of 1.3 inches. Specifically, this represents the average of 90th percentile rainfall depths calculated for several locations throughout Connecticut using daily precipitation observations over an approximately 40-year period of record (1980-2021) and the procedure cited in EPA technical guidance (see Appendix G for further information).

Water Quality Volume Calculation

As described above, the WQV is a key factor in determining the Required Retention Volume and any additional treatment requirements. The WQV is the volume of stormwater runoff from a given storm event that must be retained and/or treated to remove most of the post-development stormwater pollutant load on an average annual basis and to help maintain pre-development site hydrology in terms of duration, rate, and volume of stormwater flows including groundwater recharge. The WQV is calculated using the following equation:

$$WQV = \frac{(P)(R)(A)}{12}$$

where:

WQV = water quality volume (cubic feet)
P = 1.3 inches (90th percentile rainfall event)
R = volumetric runoff coefficient = $0.05+0.009(I)$
I = post- development impervious area (percent) after application of non-structural LID site planning and design strategies and before application of structural stormwater BMPs
A = post-development total drainage area of site or design point (square feet)

[46] USEPA. Section 438 Technical Guidance December 2009. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. EPA 841-B-09-001. December 2009. www.epa.gov/owow/nps/lid/section438.

- For the WQV calculation, impervious area (*I*) should be measured from the post-development site plan and includes all directly connected impervious surfaces (DCIA as defined in this Manual) within boundaries of the site or for the drainage area of the each design point.

- Impervious areas that drain as sheet flow onto and over an adjacent pervious area that, due to its size, slope, vegetation, and underlying soil characteristics, meets the criteria for "simple disconnection criteria for "impervious area (simple) disconnection" can be subtracted from the post development impervious area term in the WQV equation. This provides further incentive to use simple disconnection and other non-structural LID site planning and design strategies to reduce the need for and size of structural stormwater BMPs to meet the retention and treatment performance criterion.

Water Quality Flow

The Water Quality Flow (WQF) is the peak flow rate associated with the water quality storm or WQV, as described above. Although most of the structural stormwater BMPs in this Manual should be sized based on a design volume (Required Retention Volume and any additional treatment volume), some BMPs such as grass channels and proprietary treatment/pretreatment BMPs should be designed based on peak flow rate. In this approach, the stormwater BMP (including inlet structure) must have a flow rate capacity equal to or greater than the design WQF in order to prevent bypass and treat the associated design WQV for the site. Flow diversion structures (also called flow splitters) are typically used to bypass flows in excess of the design WQF for off-line stormwater BMPs.

The design WQF is calculated based on the design WQV for the site using a modified NRCS Runoff Curve Number for small storm events. The procedure is based on the approach described in Claytor and Schueler, 1996.[47] The Inlet and Outlet Controls section of Chapter 13 - Structural Stormwater BMP Design Guidance provides design guidance for flow diversion structures.

Demonstrating Compliance with Standard 1

Stormwater management systems should be designed to achieve the average annual pollutant load reductions from directly connected impervious area for sediment (Total Suspended Solids) and nutrients (Total Phosphorus and Total Nitrogen) shown in Table 4. 3.

Achieving these minimum required load reductions for sediment and nutrients is assumed to provide adequate reductions of other stormwater pollutants including floatable materials. However, it is important to note that if the full retention goal (i.e., Required Retention Volume) is

[47] Claytor, R.A. and T. R. Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Silver Spring, Maryland.

met, then it is assumed pollutant reduction is also achieved and individual pollutant calculations are not necessary.

Table 4. 3 Minimum Average Annual Pollutant Load Reductions When Evaluating BMP Selection and Sizing (Only needed when additional stormwater treatment is needed[1])

Water Quality Parameter	New Development	Redevelopment/Retrofits
Total Suspended Solids (TSS)	90%	80%
Total Phosphorus (TP)	60%	50%
Total Nitrogen (TN)	40%	30%

[1] Pollutant load reduction percentages are calculated based on average annual loading and not based on any individual storm event. Load reductions based on post-construction stormwater management standards contained in the EPA Massachusetts MS4 General Permit.

- A proposed stormwater management system meets or exceeds these average annual pollutant load reductions when the Required Retention Volume is retained on-site using suitable stormwater retention practices (refer to Figure 8- 1).[48]

- If the stormwater runoff volume retained on-site does not meet the Required Retention Volume (100% or 50% of the site's WQV), and therefore additional stormwater treatment is required, the project proponent should document that the proposed stormwater management system meets or exceeds the minimum required average annual pollutant load reductions through the use of EPA Region 1 stormwater BMP performance curves (see the following section).

Stormwater BMP Performance Curves

EPA Region 1 developed performance curves to help quantify the pollutant reduction benefits of structural stormwater BMPs. The 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 curves were developed using EPA's Stormwater Management Model and long-term rainfall data from Boston, Massachusetts to simulate rainfall-runoff and pollutant loading and removal during rain events in New England. The models were calibrated and tested with performance data from stormwater controls evaluated by the University of New Hampshire Stormwater Center. The 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. Curves have been developed for TSS, TP, TN, Zinc, fecal indicator bacteria (*E. coli* and Enterococcus), and runoff reduction. Multiple curves have been developed for stormwater

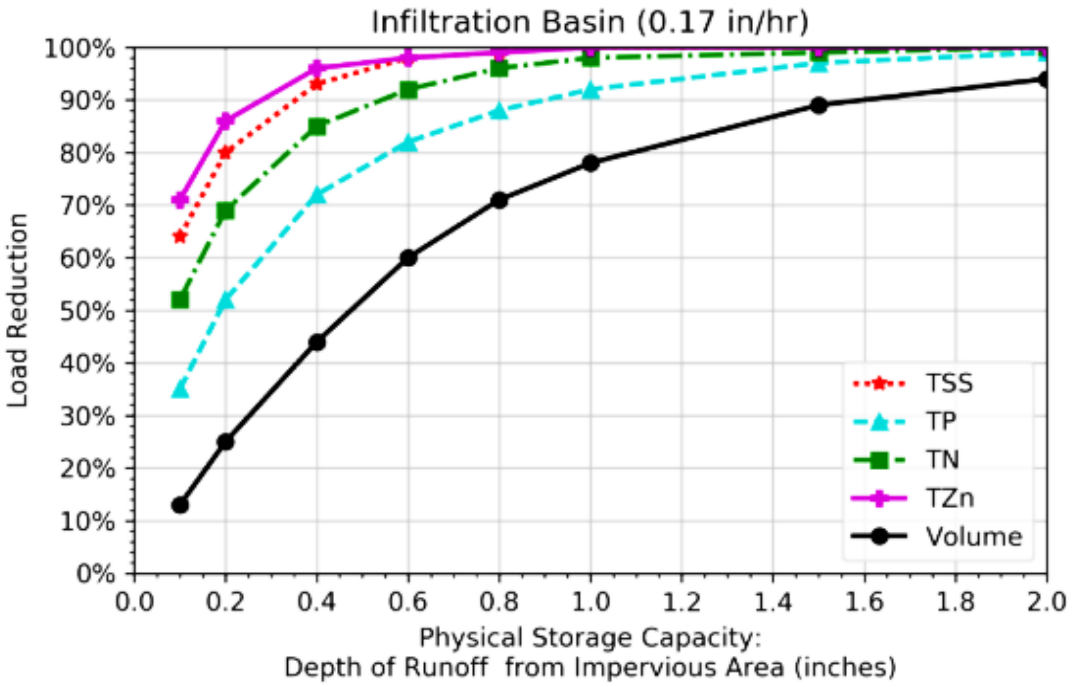
[48] On-site retention of the Required Retention Volume (100% or 50% of the site's WQV) using stormwater BMPs designed in accordance with the guidelines in this Manual is assumed to achieve average annual pollutant load reductions that exceed the minimum required values in Table 4-3 based on EPA Region 1 stormwater BMP performance curves.

infiltration BMPs to represent various soil conditions, land uses and infiltration rates. 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.

Figure 4- 2 shows a typical set of BMP performance curves for an infiltration basin in Type B soils. In this example, an infiltration basin designed with a physical storage volume equivalent to the runoff volume created by the first 1 inch of runoff of precipitation over the contributing impervious area will result in average annual load reductions of approximately 100% for TSS, 92% for TP, and 98% for TN. The curves also demonstrate that:

- Structural stormwater BMPs sized to store less than 1 inch of runoff from the impervious area 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.
- Structural stormwater BMPs provide diminishing pollutant reduction benefits above a certain size (the "knee" in the curve), although on-site retention of stormwater volumes **up to** the Required Retention Volume (100% or 50% of the site's WQV) is important to maintain pre-development hydrology (i.e., volume, rate, and temperature of runoff) and groundwater recharge.

Figure 4- 2 Example Stormwater BMP Performance Curves for Infiltration Basin in Type B Soils



Source: University of New Hampshire Stormwater Center

Use of Performance Curves to Demonstrate Compliance with Minimum Required Pollutant Load Reductions for Individual BMPs

When the Required Retention Volume cannot be retained on-site, and therefore additional stormwater treatment is required, the stormwater BMP performance curves should be used to document that the proposed stormwater management system meets or exceeds the minimum required pollutant load reductions listed in Table 4. 3. The following procedure should be used:

1. Calculate the runoff depth from the impervious area BMP can statically store the following equation:

$$Depth\ of\ Runoff\ from\ Impervious\ Area\ (inches) = \frac{V}{DCIA} * 12\frac{inches}{foot}$$

where:

V = BMP static storage volume (cubic feet)
$DCIA$ = post-development Directly Connected Impervious Area (square feet) draining to the BMP after application of non-structural LID site planning and design strategies

- The static storage volume is the volume of stormwater a structural stormwater BMP can physically hold. It includes the BMP's permanent storage volume (ponding above the surface, voids in subsurface engineered media, and subsurface structures such as chambers or tanks) but does not include the volume associated with peak rate attenuation control (volume above the primary outlet). It also 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.

- 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.

2. With the calculated Depth of Runoff from Impervious Area, use the appropriate stormwater BMP performance curves in Appendix C to obtain the average annual pollutant load reduction percentages of the BMP for TSS, TP, and TN.

3. If the pollutant load reduction percentages provided by the BMP meet or exceed the minimum required pollutant load reductions in Table 4. 3 (for all three pollutants), then the proposed stormwater management system meets the pollutant reduction performance criteria.
4. If the pollutant load reduction percentages provided by the BMP are less than the minimum required pollutant load reductions in Table 4. 3 (for any of the three pollutants), then the proposed stormwater management system does not meet the

pollutant reduction performance criteria, and the system should be increased in size to achieve the minimum required pollutant load reduction(s) or another BMP should be selected. In this situation, the curves should be used in "reverse" to determine the required Depth of Runoff from Impervious Area and required static storage volume to achieve the target pollutant load reduction.

5. When multiple stormwater BMPs are used in series to provide treatment or a combination of retention and treatment, the BMP performance curves should be used to calculate the individual average annual pollutant load reduction percentages for each BMP in the treatment train. The overall average annual pollutant load reductions for the entire treatment train should be calculated using one of the following approaches:

   - Use the equation below for two treatment BMPs in series when both BMPs treat the same water as it flows from one BMP to the next:

$$R = (A + B) - \frac{(A \times B)}{100}$$

     where:

     R = total pollutant load reduction (%)
     A = pollutant load reduction of first or upstream BMP (%)
     B = pollutant load reduction of second or downstream BMP (%)

   - For more BMPs in series when all of the BMPs treat the same water as it flows from one BMP to the next, calculate the total pollutant load reduction percentage by successively applying the pollutant load reductions of each individual BMP to the load entering from the upstream BMP. For example:

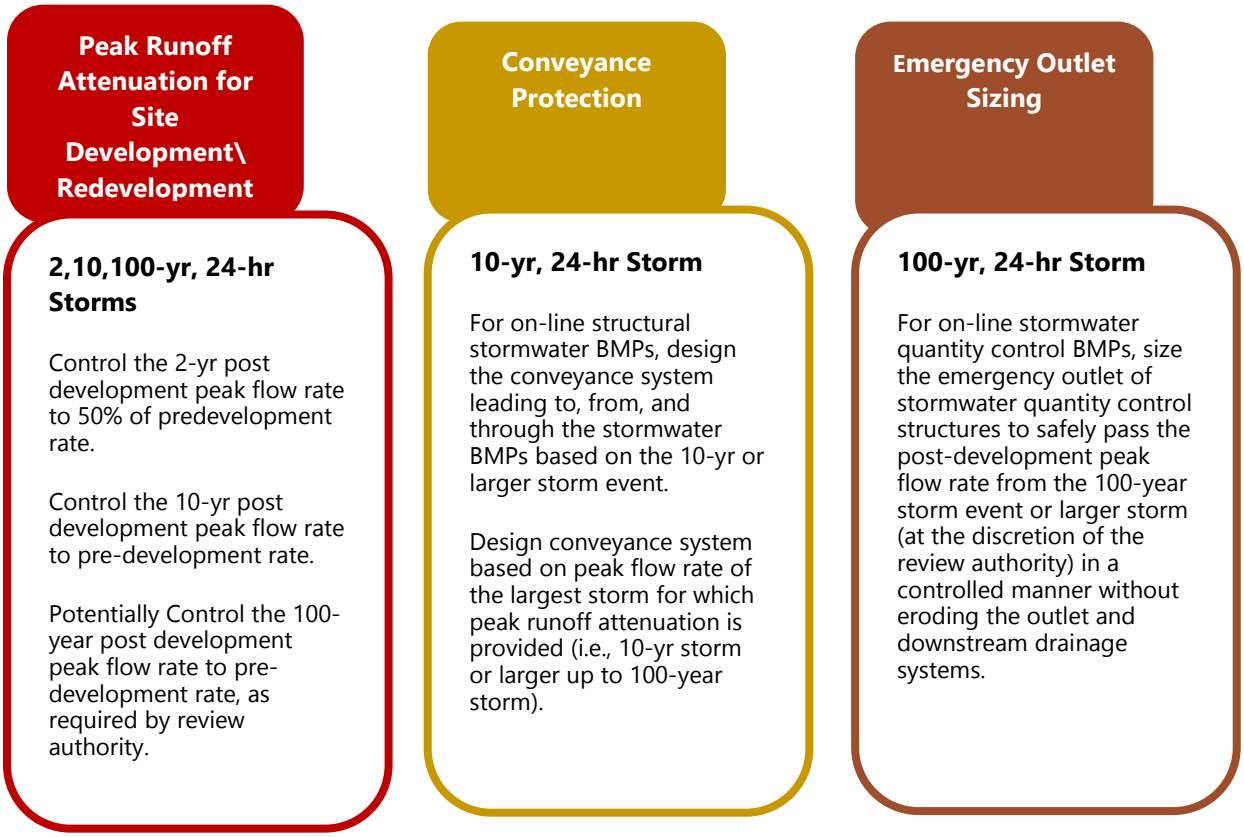
     - Initial TSS Load Upstream of BMP 1 = 1.0
     - TSS Load Removed by BMP 1 = 1.0 x 60% Removal Rate = 0.6
     - Remaining TSS Load Downstream of BMP 1 = 1.0 – 0.6 = 0.4
     - TSS Load Removed by BMP 2 = 0.4 x 50% Removal Rate = 0.2
     - Final TSS Load Downstream of BMP 2 = 0.4 – 0.2 = 0.2
     - Total TSS Removal Rate = 1.0 – 0.2 = 0.8 or 80%

   - When the upstream BMP bypasses without treatment a portion of the Required Retention Volume to a downstream BMP (i.e., the two BMPs do not treat the same water), obtain the pollutant load reductions for each individual BMP from the performance curves based on their respective static storage volumes. Then calculate the overall pollutant load reduction efficiency of the treatment train as the weighted average of the load reductions of the individual BMPs, weighted by the respective static storage volumes.

Standard 2 – Stormwater Runoff Quantity Control

The objective of Standard 2 (Stormwater Runoff Quantity Control) is to maintain pre-development peak runoff rates and manage the volume and timing of runoff to prevent downstream flooding, channel erosion, and other adverse impacts resulting from development. The associated performance criteria address relatively frequent events that cause channel erosion and larger events that result in bankfull and overbank flooding. The stormwater runoff quantity control standard also addresses the design of stormwater conveyance systems associated with stormwater BMPs to safely manage flows during larger storms. Figure 4- 3 illustrates schematically the major elements of Standard 2.

Figure 4- 3 Stormwater Runoff Quantity Control (Standard 2) Elements



The Standard 2 stormwater quantity control criteria should be met at each individual discharge point along the boundary of the development site or internal to the site (i.e., design point) such as abutting properties, roadways, wetlands and watercourses, and receiving storm drainage systems.

Linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the

CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

Stormwater Quantity Control Design Storms

Stormwater quantity controls are designed to manage peak rates of runoff from storm events of various sizes, which are also called "design storms." Stormwater quantity control design storms are defined in terms of rainfall depth and duration, recurrence interval (i.e., the likelihood or probability of the occurrence of a certain size storm event), and rainfall distribution (i.e., how rain falls during a storm event).

Updated Stormwater Quantity Control Design Storm Rainfall

NOAA Atlas 14 (and subsequent generations of NOAA precipitation-frequency products) replaces Technical Paper No. 40 (TP-40) as the definitive source of design rainfall in Connecticut. The version of NOAA Atlas 14 for the northeastern United States, including Connecticut, was released in 2015 and revised in 2019. NOAA Atlas 14 contains precipitation frequency estimates for selected durations and frequencies with associated lower and upper bounds of the 90% confidence interval (5% lower and 95% upper confidence limits). NOAA Atlas 14 is a significant improvement over the TP-40 precipitation estimates since it includes more observation locations, more sophisticated statistical analysis methods, a much longer period of record, and more recent precipitation data, thereby accounting for observed increases in extreme precipitation as the climate has become warmer and wetter. NOAA Atlas 14 has also been adopted by CT DEEP as the source of design storm precipitation in the Construction Stormwater General Permit and in the CTDOT Transportation MS4 Permit. CTDOT has incorporated the use of NOAA Atlas 14 precipitation frequency estimates in the CTDOT Drainage Manual. The NOAA Atlas 14 results are published online through the Precipitation Frequency Data Server.

Stormwater runoff quantity control design storms in Connecticut should be based on:

- **Rainfall Depth and Duration:** 24-hour precipitation depth with a specified recurrence interval as defined by the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (or latest generation of this product at the time of the site planning) precipitation frequency estimates,[49] or equivalent regional or state rainfall probability information developed from NOAA Atlas 14. Designs should be based on, at a minimum, the 50th percentile (median) NOAA Atlas 14 precipitation depth, which is the primary value reported by the online Precipitation Frequency Data Server (PFDS). The review authority

[49] NOAA Atlas 14 Volume 10 Version 3, Precipitation-Frequency Atlas of the United States, Northeastern States. NOAA, National Weather Service, 2015, revised 2019. https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

may require at their discretion the use of greater 24-hour precipitation depths such as the upper bound of the 90% confidence interval (also reported by the PFDS) to account for larger and more intense observed storm events.

- NOAA Atlas 14 (or latest generation of this product at the time of the site planning) precipitation frequency estimates should be selected for the project site based on the site address, latitude/longitude coordinates, or by clicking on the approximate center of the site.
- "Precipitation depth" and "Partial duration" time series type should be selected from the dropdown menus.
- Select precipitation depths from the storm duration row labeled "24-hour" (see Figure 4- 4).
- County-wide average 24-hour precipitation depths derived from NOAA Atlas 14 (or latest generation of this product at the time of the site planning) may also be used, provided that the county-wide average values are representative of the project site and the values are based on the latest version of NOAA Atlas 14. Such values have been incorporated as standard options in hydrologic analysis software such as HydroCAD. However, site-specific precipitation estimates obtained from the NOAA Atlas 14 Precipitation Frequency Data Server are preferred.

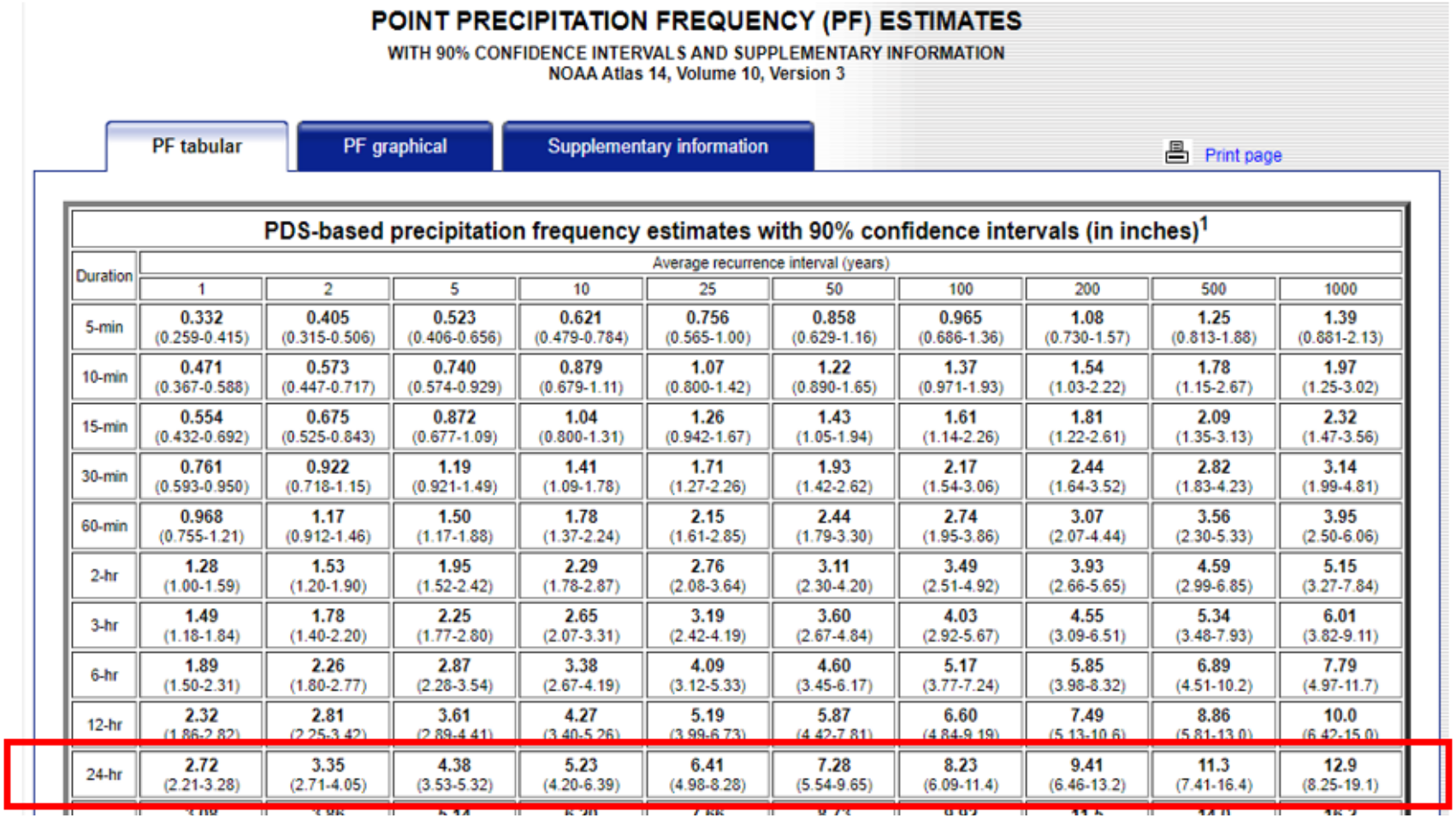
- **Rainfall Distribution:** Natural Resources Conservation Service (NRCS) Type D regional rainfall distribution, which is derived from the NOAA Atlas 14 rainfall data (referred to as "NOAA_D" rainfall distribution). Other equivalent regional rainfall distributions specifically developed for use in Connecticut, or a site-specific rainfall distribution based on NOAA Atlas 14 data, may be used for design purposes at the discretion of the review authority.[50]

[50] USDA Natural Resources Conservation Service. 2018. Connecticut Instruction 210-397 – Using NOAA Atlas 14, Volume 10 Extreme Precipitation Data with WinTR-55 in Connecticut, January 24, 2018. file:///F:/P2020/0636/A11/Background%20Documents/Climate%20Change%20and%20Precipitation/Win%20TR-20%20Rainfall%20Distributions/CT_INSTRUCTION_210-397-WinTR-55_NOAA.pdf

Updated Rainfall Distribution

The NOAA_D rainfall distribution replaces the NRCS Type III regional distribution, which has historically been used in Connecticut and other Atlantic coastal areas, as well as the Northeast Regional Climate Center (NRCC) regional rainfall distributions developed in 2015. In 2018, Connecticut NRCS began recommending the use of the NOAA_D regional rainfall distribution throughout Connecticut. The NRCS NOAA_D rainfall distribution is available as a standard rainfall distribution in hydrologic analysis software such as WinTR-55. In HydroCAD, the NRCC_D distribution is available as a pre-defined rainfall distribution for Connecticut, while NOAA_D is not. NOAA_D may be created as a user-defined rainfall distribution in HydroCAD. The NOAA_D rainfall distribution is available online in text format.

Figure 4- 4 24-hour Design Storm Rainfall Depths from NOAA Atlas 14 Precipitation Frequency Data Server



POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 10, Version 3

PF tabular | PF graphical | Supplementary information | Print page

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.332 (0.259-0.415)	0.405 (0.315-0.506)	0.523 (0.406-0.656)	0.621 (0.479-0.784)	0.756 (0.565-1.00)	0.858 (0.629-1.16)	0.965 (0.686-1.36)	1.08 (0.730-1.57)	1.25 (0.813-1.88)	1.39 (0.881-2.13)
10-min	0.471 (0.367-0.588)	0.573 (0.447-0.717)	0.740 (0.574-0.929)	0.879 (0.679-1.11)	1.07 (0.800-1.42)	1.22 (0.890-1.65)	1.37 (0.971-1.93)	1.54 (1.03-2.22)	1.78 (1.15-2.67)	1.97 (1.25-3.02)
15-min	0.554 (0.432-0.692)	0.675 (0.525-0.843)	0.872 (0.677-1.09)	1.04 (0.800-1.31)	1.26 (0.942-1.67)	1.43 (1.05-1.94)	1.61 (1.14-2.26)	1.81 (1.22-2.61)	2.09 (1.35-3.13)	2.32 (1.47-3.56)
30-min	0.761 (0.593-0.950)	0.922 (0.718-1.15)	1.19 (0.921-1.49)	1.41 (1.09-1.78)	1.71 (1.27-2.26)	1.93 (1.42-2.62)	2.17 (1.54-3.06)	2.44 (1.64-3.52)	2.82 (1.83-4.23)	3.14 (1.99-4.81)
60-min	0.968 (0.755-1.21)	1.17 (0.912-1.46)	1.50 (1.17-1.88)	1.78 (1.37-2.24)	2.15 (1.61-2.85)	2.44 (1.79-3.30)	2.74 (1.95-3.86)	3.07 (2.07-4.44)	3.56 (2.30-5.33)	3.95 (2.50-6.06)
2-hr	1.28 (1.00-1.59)	1.53 (1.20-1.90)	1.95 (1.52-2.42)	2.29 (1.78-2.87)	2.76 (2.08-3.64)	3.11 (2.30-4.20)	3.49 (2.51-4.92)	3.93 (2.66-5.65)	4.59 (2.99-6.85)	5.15 (3.27-7.84)
3-hr	1.49 (1.18-1.84)	1.78 (1.40-2.20)	2.25 (1.77-2.80)	2.65 (2.07-3.31)	3.19 (2.42-4.19)	3.60 (2.67-4.84)	4.03 (2.92-5.67)	4.55 (3.09-6.51)	5.34 (3.48-7.93)	6.01 (3.82-9.11)
6-hr	1.89 (1.50-2.31)	2.26 (1.80-2.77)	2.87 (2.28-3.54)	3.38 (2.67-4.19)	4.09 (3.12-5.33)	4.60 (3.45-6.17)	5.17 (3.77-7.24)	5.85 (3.98-8.32)	6.89 (4.51-10.2)	7.79 (4.97-11.7)
12-hr	2.32 (1.86-2.82)	2.81 (2.25-3.42)	3.61 (2.89-4.41)	4.27 (3.40-5.26)	5.19 (3.99-6.73)	5.87 (4.42-7.81)	6.60 (4.84-9.19)	7.49 (5.13-10.6)	8.86 (5.81-13.0)	10.0 (6.42-15.0)
24-hr	2.72 (2.21-3.28)	3.35 (2.71-4.05)	4.38 (3.53-5.32)	5.23 (4.20-6.39)	6.41 (4.98-8.28)	7.28 (5.54-9.65)	8.23 (6.09-11.4)	9.41 (6.46-13.2)	11.3 (7.41-16.4)	12.9 (8.25-19.1)

While precipitation frequency estimates published in NOAA Atlas 14 reflect observed increases in extreme precipitation over the last several decades, NOAA Atlas 14 does not account for anticipated future increases in extreme precipitation due to projected climate change. The NOAA Atlas 14 analysis methods assume stationarity in both the historical data used in making the estimates and in future conditions. This assumption may not be appropriate under changing (i.e., non-stationary) climatic conditions. NOAA is working with several research universities to develop precipitation frequency estimates that account for non-stationary climate assumptions and factor in climate projections; however, that product was not available as of the revision date of this Manual and is therefore not specifically addressed in this Manual. To account for the best science, including current and projected future rainfall, this Manual recommends the inclusion of the most recent generation of NOAA Atlas precipitation frequency products at the time of the site planning.

Peak Runoff Attenuation for Site Development and Redevelopment

Select and design stormwater BMPs (structural or non-structural measures) in accordance with the appropriate permits and the guidance contained in this Manual to control stormwater runoff quantity impacts, including flooding and erosive flows. The peak runoff attenuation criterion is intended to address increases in peak flow rates associated with a range of design storms, including events that result in bankfull flow conditions (typically the 2-year storm, which controls the form of the stream channel) and larger storms that cause overbank flooding.

- Through hydrologic and hydraulic analysis, calculate pre-development and post-development peak flow rates for the 2-year, 10-year, and potentially the 100-year 24-hour storms for each point at which stormwater discharges from a site (i.e., design point).

The following criteria should be met for each design point using structural stormwater BMPs:

- Control the 2-year, 24-hour post-development peak flow rate to 50% of the 2-year, 24-hour pre-development peak flow rate.
- Control the 10-year, 24-hour post-development peak flow rate to the 10-year, 24-hour pre-development peak flow rate.

The following criteria may be required at the discretion of the review authority:

- Potentially control the 100-year, 24-hour post-development peak flow rate to the 100-year, 24-hour pre-development peak flow rate.
- Demonstrate that any increase in volume or change in timing of stormwater runoff (for any design storm event) will not result in adverse effects such as increased flooding downstream of the site or at other off-site locations. Delaying the release of stormwater using detention/storage BMPs to attenuate peak flow rates, combined with upstream peak discharge (i.e., coincident peak flows), can also result in increases in peak flows at critical downstream locations such as road culverts and areas prone to flooding and is most pronounced for detention structures in the middle to lower third of a watershed.

The review authority may waive compliance with one or more of the peak runoff attenuation requirements under the following circumstances:

- Peak runoff attenuation may be waived for the 2-year, 24-hour storm event for sites having less than 1 acre of DCIA because the size of the orifice or weir required for extended detention becomes too small (approximately 1 inch in diameter) to effectively operate without clogging.

- Peak runoff attenuation may be waived for the 2-year, 10-year, and 100-year 24-hour storm events for sites that discharge stormwater directly into a large river (fourth order or greater), lake, or tidal waters where the development area is less than 5 percent of the watershed area upstream of the development site. If the stormwater runoff from a site will flow over or past another property, or discharge to a storm sewer or other conveyance, before reaching any of the above waterbodies, the project proponent should demonstrate compliance with the peak runoff attenuation performance criterion.

- When a downstream analysis indicates that peak discharge control would not be beneficial or would exacerbate peak flows in downstream areas through coincident peak flows.

The review authority, at its discretion, may require the project proponent to evaluate pre- and post-development peak runoff rates and provide peak runoff attenuation for other design storms including more intense, shorter-duration storms to reflect potential changes in rainfall characteristics due to climate change or other factors.

Stormwater Retention and Adjusted Runoff Curve Number

Retention or infiltration of the water quality design storm to meet the runoff volume and pollutant reduction requirements of Standard 1 may also reduce the peak rate of runoff for stormwater runoff quantity control design storms. A reduced NRCS runoff curve number (CN) may be used in peak flow rate calculations when stormwater is retained on-site through infiltration or reuse, either using impervious area (simple) disconnection (see Chapter 5 - Low Impact Development Site Planning and Design Strategies) or a stormwater infiltration system designed to fully infiltrate the Required Retention Volume (100% or 50% of the site's WQV).

For impervious area disconnection, the disconnected impervious area should be assigned a CN corresponding to the type of vegetation used for the qualifying pervious area (e.g., grass/lawn, brush or forest) in fair condition.

For stormwater infiltration systems, an adjusted CN for the area draining to the infiltration system should be determined for each design storm using the following method:

- Calculate the volume of stormwater retained by the infiltration system (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems and BMP-specific design guidance in Chapter 13).

- Calculate the stormwater runoff volume for the water quality storm and the 2-, 10-, and 100-year, 24-hour storms as described in this chapter.
- Subtract the volume of stormwater retained by the infiltration system from the stormwater runoff volume for the various storm events. The result is the runoff volume that will be discharged from the infiltration system during each storm event.
- Convert the volume of stormwater discharged from the infiltration system to an equivalent discharge depth (in inches) by dividing the volume discharged by the area draining to the infiltration system.
- Using the calculated discharge depth described above and the precipitation for each design storm event, calculate the adjusted CN values using the equation or graphical solution (Figure 2-1 from TR-55) presented in Appendix D of this Manual (i.e., Graphical Peak Discharge Method).

Once the adjusted CN values are determined, also calculate the time of concentration and either follow the remaining steps in the Graphical Peak Discharge Method in Appendix D or use a stormwater hydrologic/hydraulic routing model based on the NRCS Curve Number method (e.g., HydroCAD or similar software) to calculate peak discharge rates for each design storm event.

Downstream Analysis for Site Development and Redevelopment

A downstream hydrologic and hydraulic analysis may be required, at the discretion of the review authority, to demonstrate that increased volume or change in timing of stormwater runoff (for any design storm event) will not increase flooding downstream of the site or at other off-site locations. A downstream analysis may also be required when existing conditions are already causing known drainage or flooding conditions or existing channel erosion at or downstream of the project site or at other off-site locations.

The downstream analysis should include the following elements:

- Routing calculations should proceed downstream to a confluence point where the site drainage area represents 10 percent of the total drainage area above the point (i.e., the "10 percent rule").
- Calculation of peak flows, velocities, and hydraulic effects at critical downstream locations (stream confluences, culverts, other channel constrictions, and flood-prone areas) to the confluence point where the 10 percent rule applies.
- The analysis should use an appropriate hydrograph routing method, such as routing employed by TR-20, to route the pre- and post-development runoff hydrographs from the project site to the downstream critical locations.

- The analysis should include the analysis of impacts of existing land uses and projected land uses assuming full development under existing zoning and land use ordinances in the drainage area.

- A downstream analysis is not required if a project proponent can demonstrate through hydrologic and hydraulic analysis that, for stormwater leaving the site, the post-development runoff hydrograph does not exceed the pre-development hydrograph at any point in time for the same design storm event. This typically requires on-site retention/infiltration of stormwater to maintain or reduce pre-development runoff volumes and peak flow rates.

If flow rates and velocities at critical downstream locations increase by less than 5% from the pre-developed condition, and no existing structures are adversely impacted including exceedance of freeboard clearances and allowable flow velocities, then no additional analysis is necessary. Otherwise, the project proponent should redesign the stormwater quantity controls on the site and/or propose corrective actions to the impacted downstream areas.

Conveyance Protection

For structural stormwater BMPs designed in an "on-line" configuration, design the conveyance system leading to, from, and through structural stormwater BMPs based on the 10-year, 24-hour. At a minimum. On-line stormwater BMPs should be designed based on the peak flow rate of the largest storm for which peak runoff attenuation is provided (i.e., 10-yr, 24-hour storm event or larger up to the 100-year, 24-hour storm). This criterion is designed to prevent erosive flows within internal and external conveyance systems associated with stormwater BMPs such as channels, ditches, berms, overflow channels, and outfalls.

The review authority may also require the use of larger magnitude design storms for conveyance systems associated with stormwater BMPs, including stormwater drainage systems upstream or downstream of the BMPs. Such drainage systems should be designed in accordance with the Connecticut Department of Transportation Drainage Manual as well as applicable local and state design and permitting requirements.

Off-line stormwater BMPs (i.e., designed to manage and convey peak flows up to the water quality storm and bypass higher flows) should be designed with a bypass or overflow for flows larger than the water quality storm.

Emergency Outlet Sizing

Size the emergency outlet of stormwater quantity control BMPs to safely pass the post-development peak flow from the 100-year, 24-hour storm event (or larger storm events at the discretion of the review authority) in a controlled manner without eroding the outlet and downstream drainage systems. Emergency outlets constructed in natural ground are generally preferable to constructed embankments. This requirement is only applicable to stormwater management facilities that are designed in an "on-line" configuration and for the purpose of providing stormwater quantity control.

Standard 3 – Construction of Soil Erosion and Sediment Control

Effective soil erosion and sedimentation control measures should be designed, installed, and maintained during construction and land disturbance activities. Project proponents must develop and implement a Soil Erosion and Sediment Control (SESC) Plan in accordance with local and/or state regulatory requirements, the Connecticut Guidelines for Soil Erosion and Sediment Control, as amended (Guidelines), and the requirements of the CTDEEP General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities. The SESC Plan documents how the proposed activities are consistent with the performance criteria in the Guidelines. The SESC Plan should be included as part of the Stormwater Management Plan (see Chapter 12).

Standard 4 – Post-Construction Operation and Maintenance

Ongoing maintenance is critical to ensure that structural stormwater BMPs continue to function as designed. Project proponents must develop and implement a long-term Operation and Maintenance (O&M) Plan, which identifies required inspection and maintenance activities for structural stormwater BMPs.

The O&M Plan should include, at a minimum, detailed inspection and maintenance tasks, schedules, responsible parties, and financing provisions. Operational source control and pollution prevention measures for the site (see Chapter 6 - Source Control Practices and Pollution Prevention) should also be described in the O&M Plan. The O&M Plan should be included as part of the Stormwater Management Plan (see Standard 5).

Standard 5 – Stormwater Management Plan

A Stormwater Management Plan is required to document how the proposed stormwater management measures for a specific land development project or activity meet the stormwater management standards, performance criteria, and design guidelines contained in the Connecticut Stormwater Quality Manual, as well as other local, state, and federal stormwater requirements. Refer to Chapter 12 for more information on developing a Stormwater Management Plan.

Chapter 5 – Low Impact Development Site Planning and Design Strategies

Introduction

This chapter addresses the use of Low Impact Development (LID) site planning and design strategies to reduce stormwater runoff volumes and pollutant discharges. LID site planning and design is a non-structural approach for avoiding or reducing the impacts of development on natural site hydrology, which can minimize the need for structural stormwater Best Management Practices (BMPs).

What's New in this Chapter?

- Replaces and integrates the 2011 Low Impact Development Appendix into the revised Manual
- Streamlines content to focus on non-structural LID site planning and design strategies (Chapters 7 through 13 address structural LID measures)
- Provides design guidance for impervious area (simple) disconnection
- Incorporates LID credits to help quantify the benefits and incentivize the use of certain non-structural site planning and design techniques for meeting the runoff volume and pollutant reduction standard in Chapter 4 - Stormwater Management Standards and Performance Criteria

Stormwater Management Standard 1, as described in Chapter 4 - Stormwater Management Standards and Performance Criteria of this Manual, requires project proponents to consider the use of LID site planning and design strategies, to the Maximum Extent Practicable, to reduce and disconnect post-development impervious areas on a site prior to consideration of structural stormwater BMPs. Once LID site planning and design techniques have been considered and applied appropriately, structural stormwater BMPs should be used to retain on-site or treat the remaining required post-development stormwater runoff volume. This approach incorporates LID as the industry standard for all sites and encourages the integration of non-structural LID techniques early in the site planning and design process, consistent with the CT DEEP stormwater general permits.

This chapter provides guidance on the use of LID site planning and design strategies, including LID credits for common impervious area reduction and disconnection techniques, to help project proponents use these measures to meet the runoff volume and pollutant reduction requirements of Standard 1. Local development regulations and ordinances often dictate the extent to which these strategies can be applied for a particular project. Therefore, communities may need to revise their local land use regulations and ordinances to allow the use of these strategies. This chapter also provides guidance to communities for revising local land use regulations to enable and encourage the use of LID site planning and design strategies.

What is LID?

Low Impact Development (LID) is a site design and stormwater management strategy that maintains, mimics, or replicates pre-development hydrology through the use of numerous site design principles and small-scale structural stormwater practices distributed throughout a site to manage runoff volume and water quality at the source. LID includes the use of both non-structural site planning and design techniques, which are addressed in this chapter, and the use of distributed, small-scale structural stormwater BMPs, which are addressed in Chapter 13 - Structural Stormwater BMP Design Guidance and other sections of this Manual.

The fundamental objective of LID is to *avoid*, *reduce*, and *manage* the adverse impacts of development or redevelopment sites while still enabling the intended use of the site and enhancing the development relative to conventional development. The over-arching goals of LID and associated principles for achieving these goals are as follows:[51]

1. **Avoid Impacts**
    a. Protect as much undisturbed open space as possible to maintain pre-development hydrology and allow precipitation to naturally infiltrate into the ground.
    b. Maximize the protection of natural drainage areas, streams, surface waters, wetlands, and jurisdictional wetland buffers.
    c. Minimize land disturbance, including clearing and grading, and avoid areas susceptible to erosion and sediment loss.
    d. Minimize soil compaction and restore soils that were compacted due to construction activities or prior development
    e. Preserve the natural water cycle.
2. **Reduce Impacts**
    a. Provide low-maintenance, native vegetation that encourages water retention and minimizes the use of lawns, fertilizers, and pesticides.
    b. Minimize new impervious surfaces.
    c. Match as closely as possible the pre-development or natural site runoff characteristics in terms of volume and timing of runoff (mimic the natural water cycle).
3. **Manage Impacts at the Source**
    a. Break up or disconnect the flow of runoff from impervious surfaces by directing it to adjacent pervious, vegetated surfaces (disconnect).
    b. Infiltrate precipitation as close as possible to the point it reaches the ground using multiple, small-scale structural stormwater BMPs distributed throughout a site (decentralize and distribute).

[51] Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). 2011. Rhode Island Low Impact Development Site Planning and Design Guidance Manual.

c. Utilize less complex, non-structural methods for stormwater management that are lower cost and lower maintenance than conventional structural controls.
d. Provide source controls to prevent or minimize the use or exposure of pollutants into stormwater runoff at the site in order to prevent or minimize the release of those pollutants into stormwater runoff.

Benefits of LID

LID provides a number of benefits and advantages over traditional development and stormwater management approaches. Some of these benefits and advantages include:

Reduced consumption of land for stormwater management. LID practices rely upon the natural capacity of undisturbed land to absorb precipitation thus reducing the need for structural stormwater controls that often require significant land area. When structural controls are still needed, they are typically small, close to the source of runoff, and can be integrated into the areas of the site that are typically not used for stormwater management.

Reduced development costs. Traditional stormwater management can require substantial land clearing, earthwork, structural drainage systems, and structural stormwater controls. LID approaches involve more compact design with less land clearing and earthwork, less impervious area, and the use of natural flow paths and vegetated conveyances instead of catch basins and pipes. This results in reduced reliance on drainage infrastructure, smaller stormwater controls, and reduced need for excavation and construction materials, which translates into cost savings to developers.

Increased property values. In addition to reduced development costs, sites that employ LID can have increased property values by improving the quality of building lots and increasing their marketability (e.g., greater sense of community cohesion and character, more attractive landscape, and more open space for conservation and recreation).

More aesthetically pleasing development. Traditional stormwater management tends to incorporate the use of large, unnatural looking practices such as detention ponds that take up valuable space on a site. When neglected, these practices may present safety and mosquito concerns. LID can result in a more aesthetically pleasing and naturally attractive landscape.

Reduced maintenance. Most LID site planning and design techniques require little or no maintenance. LID structural practices generally require less maintenance and similar or lower maintenance costs that traditional drainage systems. Much of the maintenance that is required can be accomplished by the average landowner or contracted landscape maintenance companies.

Preserved site hydrology. LID management mimics natural site hydrology and relies on the ability of undisturbed land to retain and absorb runoff from impervious surface. Runoff that is absorbed recharges groundwater and stream baseflow and does not need to be managed or controlled by a structural stormwater practice.

Reduced pollutant loads and improved water quality. LID approaches reduce the loading of sediments, nutrients, and pathogens to streams and other waterbodies because. Landscapes that utilize LID practices minimize discharge and often retain all runoff from events smaller than the 2-year, 24-hour design storm. The runoff volume reduction benefits of LID result in significantly reduced pollutants loadings compared to structural stormwater BMPs that rely on pollutant removal through treatment alone.

Preservation of natural systems. LID preserves large portions of contiguous land in an undisturbed, natural state, which preserves the chemical, biological, and ecological integrity of natural systems.

Enhanced climate and community resilience. Improved land use strategies contribute to community resiliency and can help mitigate impacts from climate change. For example, LID can help avoid or reduce increases in runoff volumes and peak flows to existing urban infrastructure that is, in many cases, already undersized due to past development and vulnerable to more intense and frequent storms. Maintaining existing site vegetation, minimizing and disconnecting impervious surfaces, and using small-scale controls that rely on vegetation can also provide shading and cooling of runoff from impervious surfaces, mitigating increased temperatures.

LID Site Planning and Design Techniques

The remainder of this chapter focuses on non-structural LID site planning and design techniques, which should be applied to the MEA (see Standard 1 in Chapter 4 - Stormwater Management Standards and Performance Criteria) prior to consideration of structural stormwater BMPs. Once LID site planning and design techniques have been considered and applied appropriately, structural stormwater BMPs should be used to manage the remaining required post-development stormwater runoff volume (see Chapter 13 - Structural Stormwater BMP Design Guidance and other sections of this Manual).

Table 5- 1 summarizes and categorizes LID site planning and design techniques according to the three broad objectives described previously – avoiding, reducing, and managing impacts. The following sections describe each technique. Applications of these techniques and related LID site planning and design credits are described in later sections of this chapter.

Table 5- 1 LID Site Planning and Design Techniques

LID Objective	Site Planning and Design Technique
Avoid Impacts	➢ Minimizing Soil Compaction ➢ Minimizing Site Disturbance ➢ Protecting Sensitive Natural Areas ➢ Preserving Vegetated Buffers ➢ Avoiding Disturbance of Steep Slopes ➢ Siting on Permeable and Erodible Soils ➢ Protecting Natural Flow Pathways ➢ Conservation and Compact Development
Reduce Impacts	➢ Reducing Impervious Surfaces ○ Local Roads ○ Cul-de-sacs ○ Sidewalks ○ Driveways ○ Buildings ○ Parking Lots ➢ Preserving Pre-development Time of Concentration ➢ Use of Low Maintenance Landscaping
Manage Impacts at the Source	➢ Disconnecting Impervious Surfaces (DCIA reduction) ○ Impervious Area (Simple) Disconnection ▪ Building Roof Runoff ▪ Road, Driveway, and Parking Lot Runoff ▪ Stormwater Runoff from Solar Arrays ○ Disconnection Using Structural Stormwater BMPs ➢ Conversion of Impervious Areas to Pervious Areas ➢ Source Controls

Avoid Impacts

Minimizing Soil Compaction

Healthy soils, which have not been compacted, perform numerous valuable stormwater functions, including:

- Effectively cycling nutrients
- Minimizing runoff and erosion
- Maximizing infiltration of stormwater and water-holding capacity

- Absorbing and filtering excess nutrients, sediments, and pollutants to protect surface and groundwater
- Providing a healthy root environment
- Creating habitat for microbes, plants, and animals
- Reducing the resources needed to care for turf and landscape plantings.

When soils are overly compacted, the soil pores are destroyed and permeability is drastically reduced. In fact, the runoff response of vegetated areas with highly compacted soils closely resembles that of impervious areas, especially during large storm events.[52]

Minimizing soil compaction is the practice of protecting and minimizing damage to existing soil quality caused by the land development process. Minimizing soil compaction is not only important for drainage of a site and the successful use of other LID site planning and design techniques and structural stormwater BMPs, but also for minimizing impacts to established vegetation. Heavy equipment used within the drip line of a tree can cause soil compaction, resulting in the death of tree roots. Damage done to a tree's root system may take 3 to 4 years after construction to become evident in a tree's canopy. Maintaining healthy soil can significantly reduce the cost of landscaping vegetation (higher survival rate, less replanting) and landscaping maintenance.

Specific techniques to minimize soil compaction include:

- Fencing off an area during construction ("no disturbance areas") to minimize unnecessary soil disturbance and compaction. Vehicle movement, storage, or equipment/material lay-down are not to be permitted in such areas.

- Use of the smallest (lightest) equipment possible and minimizing travel over areas that will be revegetated (e.g., lawn areas) or used for infiltration of stormwater runoff from impervious surfaces such as adjacent pervious areas.

- Prohibiting the use of excavation equipment within the limits of infiltration-based structural stormwater BMPs to avoid compaction of the bottom of the infiltration system. A hydraulic excavator or backhoe loader, operating outside the limits of the infiltration system, should be used to excavate and place materials in the excavation, which should then be raked by hand.

- Restoring soils compacted as a result of construction activities or prior development. This typically requires modification of the underlying soils to restore the pre-development infiltration rate and soil porosity and improve soil quality to support vegetation. The soil 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. Amendment with 2

[52] Schueler, T.R. 1995. *Site Planning for Urban Stream Protection*. Metropolitan Washington Council of Governments, Washington, D.C

to 4 inches of topsoil or organic material may be required to improve plant establishment based on soil testing results.

Minimizing Site Disturbance

Land disturbance, including clearing and grading, can dramatically alter the pre-development hydrology of a site, exposing soils to erosion, compacting the soils by heavy equipment, and altering the natural terrain and drainage patterns. The limits of clearing and grading refer to the part of the site where development will occur. This includes impervious areas such as roads, sidewalks, and buildings, as well as pervious areas such as lawn and open drainage systems. Limiting the land area disturbed by development (i.e., development footprint) is most effectively addressed at the site planning level.

Specific techniques for minimizing site disturbance include:

- Land disturbance activities should be limited to only those areas absolutely necessary for construction purposes. The disturbance limits should reflect reasonable construction techniques and equipment needs together with the physical constraints of the development site such as slopes, soils, and natural features to be avoided (including avoiding disturbing topsoil).
- At a minimum, the 100-year floodplain, wetlands and associated buffers, areas with erodible soils, forested areas and other natural open space to be protected, and areas designated for stormwater practices should be protected from disturbance and/or compaction.
- Limits of disturbance may vary by type of development, size of lot or site, and by the specific development feature involved. For example, for sites not previously developed or graded, limit site disturbance with the following recommendations:[53]
    - 40 feet beyond the building perimeter and parking garages
    - 10 feet beyond surface walkways, patios, surface parking and utilities less than 12 inches in diameter
    - 15 feet beyond primary roadway curbs and main utility branch trenches
    - 25 feet beyond constructed areas with permeable surfaces (such as permeable paving areas, infiltration-based stormwater BMPs, and playing fields) that require additional staging areas to limit compaction in the constructed area.

[53] U.S. Green Building Council (USGBC). 2018. LEED Version 4 for Neighborhood Development. Updated July 2, 2018.

- Use of "site fingerprinting" to minimize land clearing and grading by establishing a limit on the percentage of a parcel that can be developed, ensuring that a minimum percentage of the parcel remains in a natural undisturbed state. This technique reduces clearing to the minimum area required for building and roadway footprints, construction access, and safety setbacks.

    - For example, on previously developed or graded sites, restore or protect a minimum of 50% of the site area (excluding the building footprint) or 20% of the total site area (including building footprint), whichever is greater, with native or adapted vegetation.[53]

- The limits of land disturbance (and no disturbance) should be depicted on the approved site plans and should be delineated in the field with tape, signs, or orange construction fence prior to commencing land disturbance activities. These limits should be reviewed and modified as necessary during a mandatory on-site preconstruction meeting.

- Maintain the area outside the limits of disturbance at natural grade and retain existing, mature vegetated cover.

- As described in the Connecticut Soil Erosion and Sediment Control Guidelines, implement proper construction sequencing to reduce the duration of soil exposure. Construction sequencing is a site-specific work schedule that coordinates the timing of site development related land-disturbance activities and the implementation of temporary and permanent erosion and sediment control measures during any particular phase to minimize soil erosion and sedimentation. Wherever practicable, site construction activities should be phased, with each phase having its own construction sequence and erosion and sediment control measures, to avoid the disturbance of over 5 acres at one time or 3 acres for sites that discharge directly to impaired waters consistent with the requirements of the CT DEEP Construction Stormwater General Permit.

- Existing topsoil should be stored on-site and reused during final grading to the maximum extent practicable. Stockpile areas should be clearly identified on the site plan.

- As-built topographic surveys should be required for site compliance to prevent more cut and/or fill than shown on an approved site plan.

- Existing stands of forest should be identified and protected before construction activity begins to the maximum extent possible.

- Individual large trees (i.e., trees with a Diameter at Breast Height or DBH of 24 inches or greater measured 4.5 ft from the ground surface) should be retained whenever feasible; the area within the drip line, or crown of the tree, should be fenced or roped off to protect trees and their roots from construction equipment.

- Performance bonds should be required to ensure that sites are cleared and graded according to the approved site plan and to cover the replacement cost of trees and other vegetation earmarked for preservation when damaged by construction activities (up to two years after completion of construction).

- Developments that are designed to "fit the terrain" of the site require significantly less grading and soil disturbance than those that are designed without regard for the existing topography. Road patterns should match the landform by placing roadways parallel to contour lines where possible. In doing so, natural drainageways can be constructed along street rights-of-way, thereby reducing the need for storm pipes.

Protecting Sensitive Natural Areas

Sensitive natural areas include woodlands, significant tree species, wetlands and watercourses, floodplains, and other hydrologically sensitive and naturally vegetated areas. Preserving and avoiding land disturbance activities in close proximity to these resources are important strategies for preserving predevelopment hydrology, water quality, important ecological functions, and the natural character and aesthetic value of a site.

Protecting sensitive natural areas involves delineating and defining sensitive natural areas before performing site layout and design. Once sensitive natural areas on a site are delineated, ensure that these areas and native vegetation are protected in an undisturbed state throughout the design, construction, and occupancy stages of a project.

If an area is permanently protected under a conservation easement or other legally enforceable deed restriction that ensures perpetual protection of the proposed area, the project proponent can subtract the conservation area from the total site area when calculating the applicable Water Quality Volume. The easement must clearly specify how the natural area vegetation shall be managed and boundaries will be marked. Managed turf (e.g., playgrounds, regularly maintained open areas) is not an acceptable form of vegetation management. Credits for protecting sensitive natural areas are described in the Section titled LID Site Planning and Design Credits.

Preserving Vegetated Buffers

Vegetated buffers are naturally vegetated areas between developed land and surface waterbodies and wetlands. Vegetated buffers protect water quality by providing shade for cooling, stabilizing banks, mitigating flow rates, and providing for pollutant removal by filtering runoff and promoting infiltration. Vegetated buffers also provide flood storage and wildlife habitat.

Preservation of vegetated buffers involves delineating and preserving naturally vegetated buffers and implementing measures to ensure that buffers and native vegetation are protected throughout planning, design, construction, and occupancy. General guidelines and standards for vegetated buffers include:

- A minimum buffer width of 100 feet as measured from the edge of a resource (wetland, top bank elevation of a stream, etc.) is recommended to preserve most buffer functions. Larger buffer widths (up to 300 feet or more) may be necessary for critical resources such as public drinking water supplies or based on site characteristics such as slope, soils, land use, vegetation type, and other factors.

- The minimum recommended buffer width may not be achievable on existing developed sites. The greatest buffer width that is practical should be maintained and restored and should not be reduced to less than 25 feet or below local or state regulatory requirements.

- Other environmental features important to water quality preservation and enhancement should be included within the buffer, such as the 100-year floodplain and steep slopes.

- Vegetated buffers should be protected during construction. Buffer zones and limits of disturbance should be shown on every drawing within every set of construction plans including, but not limited to, clearing and grading plans and sediment control plans. Buffer limits should be staked out in the field prior to any construction activity. Limits of disturbance should be marked with orange construction fence barriers with accompanying signs.

- The vegetative species should reflect the predevelopment, natural vegetative community present in the area. This can be achieved by either preserving the existing vegetation or managing a disturbed buffer. Disturbed areas should be either planted with native species or allowed to revert to the natural vegetation over time, with an invasive species management plan. Some selective clearing may be allowed in the outer portion of a buffer to allow for removal of dead or diseased trees, especially those that pose a safety hazard.

- Although buffers should remain in a natural vegetated state, certain uses and activity restrictions are appropriate in different zones within the buffer depending on the width and density of vegetation. The inner half of the buffer along the shoreline or bordering wetland should remain as a "no touch" zone, with uses limited to passive recreation such as limited access paths for walking and canoe launches. The outer zone may be managed for heavier foot and bicycle traffic and may be acceptable for stormwater BMPs. Specific uses or activities within the upland review area associated with state jurisdictional wetlands also may be dictated by local inland wetlands and watercourses regulations.

- Design site runoff to enter the buffer as sheet flow. Where necessary, incorporate stormwater BMPs to retain and treat concentrated stormwater inflow to the buffer.

Avoiding Disturbance of Steep Slopes

The potential for soil erosion is significantly increased on slopes of 25% (4H:1V slope) or greater. Development on steep slopes also results in a larger disturbance footprint than development on flatter slopes. Development (clearing, grading, or other soil disturbance) on slopes of 25% or greater should be avoided.

Siting on Permeable and Erodible Soils

Whenever possible, highly erodible soils should be left undisturbed and protected from disturbance during site construction. Gravel soils tend to be the least erodible. As clay and organic matter increase, soil erodibility tends to decrease. Infiltration-based structural stormwater BMPs and pervious areas used for infiltration of runoff from adjacent impervious surfaces should be located on those portions of the site with the most permeable soils.

Protecting Natural Flow Pathways

Natural drainage features such as vegetated swales and channels and natural micro-pools or depressions should be preserved or incorporated into the design of a site to take advantage of their ability to infiltrate and attenuate flows and filter pollutants. Site designs should use and/or improve natural drainage pathways whenever possible to reduce or eliminate the need for stormwater pipe networks. Natural drainage pathways should be protected from significantly increased runoff volumes and flow rates through the use of upstream stormwater BMPs that control runoff volume and flow rate. Level spreaders, erosion control matting, revegetation, outlet stabilization, and check dams can also be used to protect natural drainage features.

Conservation and Compact Development

Compact development is a site development strategy that incorporates smaller lot sizes to reduce overall impervious cover while providing more undisturbed open space and protection of water resources. The strategy relies on mixed-use development patterns, which generate less stormwater than the typical single-use suburban model. In addition to stormwater and water quality benefits, compact development also promotes livability, walkability, and transportation efficiency, including a reduction in greenhouse gas emissions. This approach is also consistent with State of Connecticut policies to promote compact, transit accessible, pedestrian-oriented, mixed use development patterns and land use.

In a residential setting, compact development is referred to as "conservation" or "open space" development. Conservation development concentrates density in one portion of the site while preserving a large percentage of the site as open space. The similar concept of "cluster zoning" was adopted by many communities in the 1980s but did not include clear rationale or objective analysis to determine what open space or natural resources were most important to protect on a site. Conservation development promotes the use of existing opportunities and constraints to shape the final site design.[54] Conservation development is most effective for reducing impervious cover when used in conjunction other LID site design strategies that reduce the impacts of development such as narrower streets and reduced parking. Conservation subdivisions have also been shown to have marketing and sales advantages, as buyers prefer

[54] Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). 2011. Rhode Island Low Impact Development Site Planning and Design Guidance Manual.

lots close to or facing protected open space. Conservation subdivisions have also been shown to appreciate faster than counterparts in conventional developments.[55]

Municipal land use regulations dictate the extent to which compact development strategies are allowed. Although many communities in Connecticut allow various forms of compact development, communities may need to re-evaluate local zoning and subdivision regulations to effectively promote the use of compact development strategies. The information sources listed at the end of this chapter provide additional information on how communities can modify local land use regulations to promote the use of compact development and related LID site planning and design techniques.

Reduce Impacts

Once a site development strategy has been selected, sensitive resource areas have been identified and preserved, and other site constraints have been avoided, the next objective of the LID site planning and design process is to reduce the impacts of land alteration. This includes minimizing the creation of new impervious surfaces, preserving the timing of site runoff to approximate pre-development conditions (i.e., slowing the flow), and the use of low maintenance LID landscaping.

Similar to avoidance of impacts, the extent to which impacts can be reduced on a site is also often dictated by local land use regulations, which have the potential to facilitate or hinder the implementation of LID site planning and design strategies. Communities should review and update their local land use regulations to reduce unnecessary creation of new impervious surfaces, remove barriers to the use of LID practices, and promote the use of low maintenance landscaping. The following sections provide strategies for communities to modify local land use regulations to reduce development impacts. Additional information on these topics can be found in the information sources listed at the end of this chapter

Reducing Impervious Surfaces

Reducing impervious surfaces includes minimizing areas associated with roads, sidewalks, driveways, buildings, and parking lots. By reducing the amount of impervious cover on a site, increases in post-development stormwater runoff are reduced while infiltration and evapotranspiration are increased. Reducing the area covered by impervious surfaces also provides greater opportunity for conservation of natural features and more space for vegetated swales, bioretention systems, and other structural stormwater BMPs.

Local Roads. Many local roads are wider than necessary. Reducing the length and width of roads can reduce the creation of new impervious surfaces. Other benefits of narrower roads

[55] Nonpoint Education for Municipal Officials (NEMO). 1999. "Conservation Subdivisions: A Better Way to Protect Water Quality, Retain Wildlife, and Preserve Rural Character". NEMO Fact Sheet #9.

include reduced clearing and grading impacts, reduced vehicle speeds (i.e., "traffic calming"), lower maintenance costs, and enhanced neighborhood character.

- Design local roads for the minimum required pavement width needed to support travel lanes; on-street parking; and emergency, maintenance, and service vehicle access. These widths should be based on future traffic volumes without compromising safety. Table 5- 2 provides recommended minimum road width standards for local roads.

Table 5- 2 Recommended Minimum Road Widths for Local Roads

Rural Local Roads (1)			
Annual Average Daily Traffic (AADT)	Type of Roadside Development		
	Open (Rural)	Moderate Density	High Density
<400	22	N/A	N/A
400 – 1,500	24	24	N/A
1,500 – 2,000	26	26	26
>2,000	28	28	28
Urban Local Roads			
On-Street Parking	Type of Area		
	Suburban	Intermediate	Built-Up
None (2)	24	24	24
One Side (3)	29	29	29
Both Sides (4)	34	34	34

Source: Adapted from CTDOT Highway Design Manual (2003 Edition including Revisions to February 2013)

Notes:

(1) Includes two travel lanes (9 to 12 feet in width) and two 2-foot shoulders.
(2) Includes two 10-foot travel lanes and two 2-foot shoulders.
(3) Includes two 10-foot travel lanes, one 2-foot shoulder, and one 7-foot parking lane.
(4) Includes two 10-foot travel lanes and two 7-foot parking lanes.
(5) Table excludes bicycle facilities, which are typically 5 feet wide.

- Consider site and road layouts that reduce overall street length. Reduce total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length. Conservation (open space) development and other compact forms of development can reduce overall street length.

- Consider elimination of curbs and the use of roadside vegetated open channels or swales as an alternative to traditional curb and gutter drainage (i.e., curbing, catch basins, and pipes), especially in low or medium density developments and slopes where roadside erosion is not a concern (typically slopes of less than 8 percent). Open vegetated channels provide the potential for infiltration and filtering runoff from impervious surfaces, as well as groundwater recharge and reduced runoff volume. In addition to the water quality benefits that open vegetated channels provide, these systems are also significantly less expensive to construct than conventional storm drain systems. The use of vegetated drainage swales in lieu of conventional storm sewers may be limited by soils, slope, and development density.

- Use curb extensions or "bumpouts" at roadway intersections or mid-block locations to reduce impervious area, manage stormwater through bioretention or other structural stormwater BMPs, provide traffic calming, and improve pedestrian safety. These practices are most applicable in medium or high-density developments.

- Use permeable pavement for on-street parking stalls, sidewalks, and crosswalks.

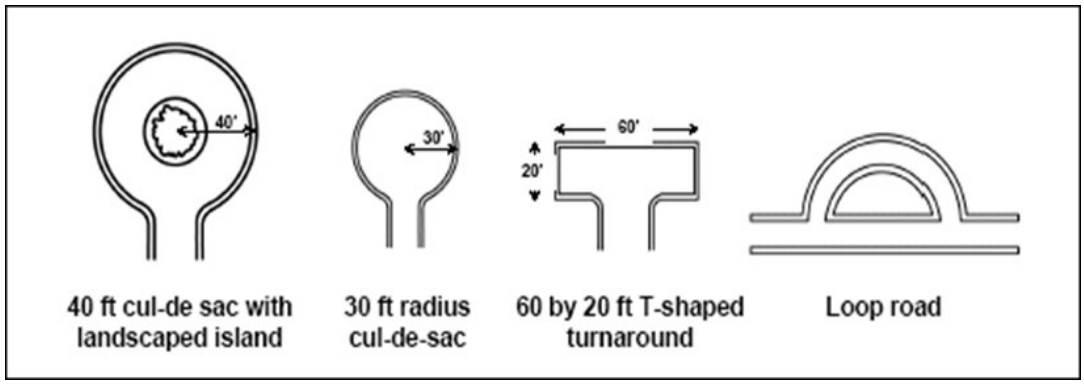
Cul-de-sacs. Cul-de-sacs are residential streets that are open at one end and have a dead-end at the other. Cul-de-sacs have a large "bulb" located at the closed end of the street to enable emergency and service vehicles to turn around without having to back up. Traditional cul-de-sacs utilize a large radius (50 to 60 feet or more), paved turnaround that can dramatically increase the imperviousness of a residential subdivision. Alternatives to this traditional design include turnaround bulbs with smaller radii and the use of a landscaped island (i.e., rain garden or bioretention area) in the center of the cul-de-sac to collect rainwater from the end of the roadway (Figure 5-1). The amount of pavement at cul-de-sac turnarounds can be reduced through the following techniques:

- Reduce the radius (and size) of the turnaround to the minimum required to accommodate emergency and maintenance vehicles, which is typically 30 to 40 feet. Consider the types of vehicles that may need to access a street. Fire trucks, service vehicles, and school buses are often cited as needing large turning radii. However, some fire trucks are designed for smaller turning radii. In addition, many newer large service vehicles are designed with a tri-axle (requiring a smaller turning radius) and school buses usually do not enter individual cul-de-sacs.

- Use a pervious center island (i.e., native vegetation or structural stormwater BMP such as an infiltration basin or bioretention system). If a cul-de-sac island is used, the cul-de-sac radius should allow for a minimum 20-foot-wide road.

- Minimize the number of cul-de-sacs and consider alternative turnaround designs such as hammerheads (T-shaped turnaround) and loop roads (jug handles).

Figure 5-1. Reduced Cul-de-Sac Radius and Alternative Turnaround Designs



Source: Adapted from Atlanta Regional Commission, 2001.[56]

Sidewalks. Subdivision codes often require sidewalks on both sides of the street, as well as a minimum sidewalk width and distance from the street, which can create excess impervious cover and stormwater runoff.

- Adopt flexible design standards that are based on safe pedestrian movement and limiting impervious cover.
- Limit sidewalks to one side of the street. A sidewalk on one side of the street may suffice in low traffic areas where safety and pedestrian access would not be significantly affected.
- Reduce sidewalk widths (3 to 4 feet), separate them from the street with a vegetated area, and grade sidewalks to drain into front lawns and away from rather than towards the street.
- Consider alternative surfaces such as permeable pavement or gravel where appropriate. Consider removing sidewalks from the roadway right-of-way and provide access to natural features or connect other destinations, such as a playground, park, or adjacent development.

Driveways. Driveways account for significant amounts of impervious cover in suburban residential development. Generally, local subdivision regulations do not contain explicit driveway design standards regarding dimensions and surface materials. Subdivision regulations also indirectly influence the length of the driveway when excessive front yard setbacks, which dictate how far houses must be from the street, are required. Overall lot imperviousness can be reduced by minimizing driveway lengths, encouraging alternative pervious surfaces, and allowing shared driveways wherever possible.

- Consider the use of shared driveways that connect two or more homes together.
- Consider minimum driveway widths of 9 feet or less (one lane) and 18 feet or less (two lanes).

[56] https://atlantaregional.org/natural-resources/water/georgia-stormwater-management-manual/

- Reduce front yard setbacks (20 to 30 feet), resulting in shorter driveways and reduced driveway imperviousness. A 20- to 30-foot-long driveway is generally adequate to meet parking needs.
- Use alternative permeable driveway surfaces (e.g., grass, gravel, permeable pavement) or the use of "two track" design for residential driveways (i.e., hard surface for vehicle tires to drive on, with grass or other permeable surface in-between and outside the tracks).

Buildings. Reducing the footprints of buildings can reduce the impervious cover in certain residential and commercial settings. Residential and commercial building footprint area can be reduced by using alternate or taller buildings while maintaining the same floor-to-area ratio.

- Minimize building footprint area and building setbacks.
- Consider the use of green roofs and the use of rain barrels and cisterns for stormwater harvesting and reuse.
- Direct roof runoff to vegetated pervious areas and structural stormwater BMPs such as rain gardens/bioretention systems, dry wells, and other infiltration or filtering systems.

Parking Lots. Parking lots account for a large percentage of impervious cover in commercial, industrial, and institutional settings. The amount of parking and associated impervious area is dictated by local land use regulations. Reducing parking ratio requirements, allowing the use of shared parking and off-site parking allowances, providing compact car spaces, minimizing stall dimensions, incorporating efficient parking aisles, use of structured parking, and using pervious materials in spillover parking areas can serve to minimize the total impervious areas associated with parking lots.

- **Parking Ratios.** The number of parking spaces at a site is determined by local parking ratios which dictate the minimum number of spaces per square foot of building space, number of dwelling units, persons, or building occupancy. Parking ratios are typically set as minimums, not maximums, thereby allowing for excess parking. Parking ratios also typically represent the minimum number of spaces needed to accommodate the highest hourly parking at the site.

    - Establish both minimum and maximum parking ratios to provide adequate parking while reducing excess impervious cover. Parking demand ratios should be based upon project-specific parking studies, where feasible. Allow additional spaces above the maximum ratio only if project-specific parking studies indicate a need for additional capacity.

    - Incorporate mechanisms into local zoning regulations that tailor parking requirements to specific development projects. Allow flexibility within the

regulations and require the developer to demonstrate the appropriate amount of parking needed.[57]

- Strategies for eliminating or reducing excess parking through parking demand ratios include but are not limited to: 1) setting minimum and maximum parking ratios (providing a range of values) based on a local parking study, 2) starting with industry standard values such as those developed by the Institute of Transportation Engineers (ITE) and the Urban Land Institute (ULI) and adjusting those values to reflect local characteristics, 3) consider using current minimum parking ratios as the new maximum requirements, and 4) eliminating minimum parking requirements for non-residential properties.

- **Shared Parking.** Shared parking is a strategy that reduces the number of parking spaces needed by allowing a parking facility to serve multiple users or destinations. This approach is most successful when the participating facilities are in close proximity to each other and have peak parking demands that occur at different times during the day or week or if they share patrons that can park at one facility and walk to multiple destinations. Parking ratios can be reduced if shared parking arrangements are in place, when multi-modal transit (e.g., mass transit, bike share, or car share programs) is provided, or when nearby on-street parking is available. Shared parking generally requires contractual agreements between two adjacent users or the use of parking management districts with multiple property owners.[58]

  A related strategy is to reserve sufficient land on the project site for projected future parking requirements (e.g., future buildout or redevelopment), but only construct a portion of the parking area at the outset of the project, maintaining the additional parking as green space and converting to parking on an as-needed basis.

- **Off-Site Parking Allowances.** Current land use regulations in many communities require new development and redevelopment projects to provide all parking on-site and do not allow off-site parking availability to be counted. Communities should increase the flexibility of parking requirements and include off-site parking allowances for certain types of development such as redevelopment sites and compact mixed-use centers given the difficulty of complying with conventional on-site parking demands in such settings. Design standards should specify a maximum distance (typical walking distance of 400-800 feet)

[57] Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). 2011. Rhode Island Low Impact Development Site Planning and Design Guidance Manual.

[58] Capitol Region Council of Governments (CRCOG). 2002. Livable Communities Toolkit: A Best Practices Manual for Metropolitan Regions, Shared Parking Fact Sheet.

and requirements for well-marked safe pedestrian travel between the site and off-site parking lot.[59]

- **Structured Parking.** Vertical parking structures can reduce impervious cover by reducing the parking footprint. In urban areas or areas where land availability is limited or land costs are high, parking garages are generally more economical to build than purchasing additional land. In such areas, communities should consider using incentives (e.g., tax credits; stormwater waivers; or density, floor area, or height bonuses) to encourage the use of multi-level, underground, and under the building parking garages.[60]

- **Parking Stall and Aisle Geometry.** Local parking codes often require standard parking stall dimensions to accommodate larger vehicles. Reducing parking stall size and incorporating alternative internal geometry or traffic patterns through the use of one-way aisles and angled parking stalls can reduce parking lot size and impervious cover.

    - Reduce parking stall dimensions to 9 feet wide and 18 feet long.
    - Encourage one-way aisles used in conjunction with angled parking to reduce the amount of aisle space needed to access each stall, depending on the geometry of the parking lot.
    - Allow for a portion of parking lots to be comprised of compact car spaces (e.g., 8-foot by 16-foot stalls or smaller) including signage clearly designating compact car spaces.

- **Alternative Paving Materials.** Impervious cover can also be reduced through the use of alternative paving materials (e.g., permeable pavement) for parking stalls, parking aisles, and overflow parking. Local land use regulations should allow for the use of permeable pavement and promote the use of such materials in low traffic areas such as overflow parking areas. Chapter 13 - Permeable Pavement contains design guidance for permeable pavement systems including porous asphalt, pervious concrete, permeable interlocking concrete pavers, and other open course paver systems (plastic turf reinforcing grids, concrete grass pavers, etc.).

- **Parking Lot Landscaping.** Landscaped areas within and around parking lots can reduce the amount of impervious cover, allow for retention and treatment of parking lot runoff, provide tree canopy and shading, and enhance the appearance of a parking lot and associated development. Small-scale infiltration and treatment stormwater BMPs (e.g., bioretention, tree filters, vegetated filter strips, water quality swales, etc.) can be incorporated into parking islands and around the perimeter of parking lots.

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[59] Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). 2011. Rhode Island Low Impact Development Site Planning and Design Guidance Manual.

[60] Center for Watershed Protection (CWP). 2017. Better Site Design Code and Ordinance Worksheet. December 2017.

- Require a minimum percentage of a parking lot to be landscaped.
- Allow the use of structural stormwater BMPs and open section drainage (via sheet flow and flush curbs or curb cuts) within landscaped areas, setbacks, or parking areas.
- Require landscaping within parking areas that "breaks up" pavement at fixed intervals and allow vegetated stormwater management areas to count toward required landscape minimums.
- Consider requiring a minimum amount of tree canopy coverage over on-site parking lots. A minimum landscape area width of 6 feet is recommended to support large, mature trees.

Preserving Pre-development Time of Concentration

The peak discharge rate and volume of stormwater runoff from a site are influenced by the runoff travel time and hydrologic characteristics of the site. Runoff travel time can be expressed in terms of "time of concentration" which is the time it takes for runoff to travel from the most distant point of the site or watershed to the downstream outlet or design point. Runoff flow paths, ground surface slope and roughness, and channel characteristics affect the time of concentration. Increasing the post-development time of concentration to match the time of concentration for pre-development conditions can substantially reduce development impacts in terms of peak rates of runoff and runoff volumes. Site design techniques that can modify or increase the runoff travel time and time of concentration include:

- Maximizing overland sheet flow.
- Maintaining pre-development flow paths on vegetated surfaces.
- Increasing the number of and lengthening flow paths on vegetated surfaces.
- Minimizing the number and length of flow paths on impervious surfaces.
- Maintaining overland flow across vegetated surfaces and areas with permeable soils.
- Maintaining pre-development infiltration rates by preserving those areas of the site. with high-permeability soils.
- Maximizing use of vegetated swales for the conveyance of stormwater instead of traditional curb/gutter and piped drainage systems.
- Maintaining or augmenting existing vegetation on the site.

Use of Low Maintenance Landscaping

As described in Chapter 6 - Source Control Practices and Pollution Prevention, lawns and other landscaped areas can contribute stormwater runoff pollution, resulting in adverse impacts to surface waters and groundwater, due to overfertilization, overwatering, overapplication of pesticides, and direct disposal of lawn clippings, leaves, and trimmings.

To reduce these potential impacts, low-maintenance, native vegetation should be used along with other LID landscaping techniques to minimize lawn area, irrigation needs, fertilizers, and pesticides. This approach can also help conserve water by reducing irrigation water demand and increase resilience of surface and groundwater resources during periods of drought. Chapter 6 -

Source Control Practices and Pollution Prevention contains links to additional sources of information on low maintenance and LID landscaping practices.

Communities should also develop or update their local land use regulations to reflect low maintenance or LID landscaping approaches that specifically address the link between a functional landscape and protection of water quality, water conservation, and resilience. LID landscape regulations should also be tailored to different land uses, densities, and locations.[61]

Manage Impacts at the Source

After all reasonable efforts to avoid and reduce impacts are exhausted, the final objective of the LID site planning and design process is to manage any remaining stormwater impacts including increases in runoff volume, pollutant loads, and peak flows. Techniques for managing stormwater impacts include disconnecting impervious surfaces by directing runoff to adjacent vegetated pervious areas (simple disconnection) or to structural stormwater BMPs located close to the source of runoff, conversion of impervious to pervious areas, and the use of source controls and pollution prevention.

Disconnecting Impervious Surfaces

As described in Chapter 2 - Stormwater Impacts, impervious surfaces with a direct hydraulic connection to a storm drainage system or a waterbody are considered "Directly Connected Impervious Area (DCIA)." Impervious surfaces that are separated from drainage systems or a waterbody by pervious surfaces or structural stormwater BMPs designed to retain the appropriate portion of the site's Water Quality Volume (WQV) are considered "disconnected" and contribute less runoff and reduced pollutant loading. Disconnecting impervious surfaces promotes infiltration and filtration of stormwater runoff and the reduction of DCIA. The two primary strategies for disconnecting impervious surfaces are described below.

Simple Disconnection. Impervious area disconnection, also called "simple disconnection," is a non-structural technique that involves directing stormwater runoff from impervious surfaces as sheet flow onto adjacent vegetated pervious surfaces where it has the opportunity for infiltration and treatment. Simple disconnection can be used to direct runoff from roofs, driveways, roads, parking lots, and solar arrays to vegetated pervious areas that meet specific characteristics (also called "Qualifying Pervious Areas") such that the appropriate portion of the site's WQV is dispersed and retained/infiltrated on-site without causing erosion or basement seepage. Key characteristics of the receiving pervious area include slope, soil infiltration capacity, dimensions and flow path length, size relative to the contributing area, and density of vegetation. Sites with flatter slopes, pervious soils, and a dense stand of vegetation are better

[61] Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). 2011. Rhode Island Low Impact Development Site Planning and Design Guidance Manual.

suited for maintaining dispersed flow. Flows for larger storm events should bypass or exit the pervious area in a controlled manner.

Credits for the use of simple disconnection to meet the runoff volume and pollutant reduction requirements of Standard 1 (refer to Chapter 4 - Stormwater Management Standards and Performance Criteria) are described in LID Site Planning and Design Credits, including minimum criteria for receiving credit and restrictions on the use of simple disconnection.

Disconnection Using Structural Stormwater BMPs. Impervious areas that discharge runoff to structural stormwater BMPs designed to retain the appropriate portion of the Water Quality Volume (i.e., Infiltration BMPs or Stormwater Reuse BMPs) are also considered disconnected. Small-scale structural stormwater BMPs located close to the impervious areas where runoff is generated are generally preferred over large end-of-pipe controls. Chapters 8-13 of this Manual provide guidance on the selection, design, construction, and maintenance of structural stormwater BMPs to meet the stormwater management standards and performance criteria outlined in Chapter 4.

Conversion of Impervious to Pervious Areas

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. This technique is applicable to redevelopment and retrofit situations. Credits for the use of impervious area conversion on redevelopment sites are described in LID Site Planning and Design Credits. Chapter 9 - Stormwater Retrofits provides additional guidance on impervious area conversion.

Source Controls and Pollution Prevention

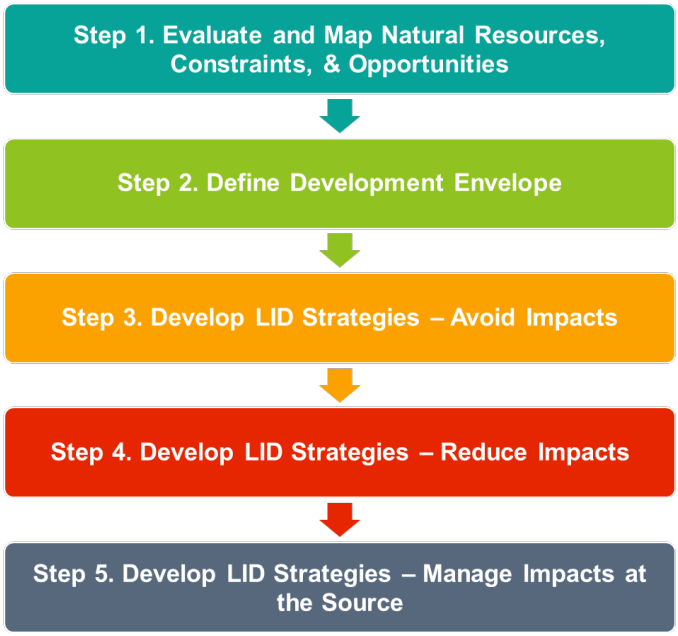
Utilizing the source controls and pollution prevention measures described in Chapter 6 - Source Control Practices and Pollution Prevention can help minimize or prevent the discharge of pollutants in stormwater runoff. Source control practices and pollution prevention are operational practices (e.g., street and parking lot sweeping, catch basin cleaning and drainage system maintenance, and lawn and landscape management) that limit the generation of stormwater pollutants at their source and should be incorporated, to the maximum extent practicable, into the site design and operational aspects of all land development projects.

LID Site Planning and Design Process

Using LID successfully requires consideration of LID site planning and design strategies from the project's inception through final design. The LID site planning and design process focuses on the basic LID principles of preserving natural site characteristics and pre-development hydrology.

The recommended LID site planning and design process is shown schematically in Figure 5-2. LID Site Planning and Design Process. This process is most applicable to new development, although the same principles and strategies can be applied to redevelopment projects and retrofits.

Figure 5-2. LID Site Planning and Design



Once the local, state, and federal regulatory requirements and relevant stormwater management standards for a project are determined, the LID site planning and design process begins by evaluating and mapping existing natural resources as well as site constraints and opportunities for the use of LID techniques. The areas identified to be preserved in a natural state help define the remaining developable area or "development envelope" for the site. LID strategies are then applied within the development envelope to further avoid impacts, reduce impacts, and manage impacts at the source, in that order of priority, as described in the previous sections.

Appendix E contains a checklist for use by project proponents, designers, and reviewers to help document the consideration and use of LID site planning and design techniques to the "Maximum Extent Practicable," as described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

Step 1. Evaluate and Map Natural Resources, Constraints, & Opportunities

The following natural resources, potential site development constraints, and opportunities for the use of LID techniques should be evaluated and shown on an existing conditions base map of the project site (also referred to as a "LID Site Planning and Design Opportunities and Constraints Plan").

Soils. Determine and map the major soil type(s) on the site and associated infiltration rates, erodibility, and other characteristics. General soils information can be obtained from the online USDA NRCS Web Soil Survey.

Wetlands, Rivers, and Streams. Show the boundaries of inland wetlands and watercourses (intermittent and perennial) on the site as delineated in the field by a Certified Soil Scientist or Professional Wetland Scientist. Assess the quality of each wetland system (functions and values) on the site using methodologies established by the U.S. Army Corp of Engineers. Field-verify upland soil types on the site during the field delineation. Show regulatory buffers such as upland review areas and applicable stream or riparian buffer requirements. Since regulatory buffers vary by municipality, it is important to consult with the municipal wetland staff early in the development of the site plan. Also, field-delineate and show unique or significant wetland types such as vernal pools and associated upland protection buffer areas.

Natural Drainage Patterns and Hydrologic Features. Map prominent hydrologic features such as seeps, springs, drainage swales, and isolated depression storage areas. Show existing drainage patterns on the base map, as verified in the field.

Vegetation. Identify and show the existing vegetation types (deciduous forest, coniferous forest, meadow, etc.) and patterns on the site including tree lines. Features such as tree clusters, grassy areas, tidal and/or inland wetlands vegetation, and unique vegetation should be shown. Include all significant tree species with a Diameter at Breast Height (DBH) of 24 inches and greater measured at 4.5' above ground surface.

Flood Hazard Zones. Delineate the limits of the 1 percent annual chance (100-year) flood on the site based on surveyed site topography and the base flood elevation shown on available flood insurance mapping and flood studies by the Federal Emergency Management Agency (FEMA).

Bedrock. Identify areas of shallow bedrock or ledge based on soils mapping, test pits or soil borings, and visible rock outcrops.

Topography and Steep Slopes. Show site topography at 2-foot contour intervals obtained from traditional field survey or aerial survey methods by a licensed land surveyor. For sites with slopes less than 2%, include spot elevations and 1-foot contours. Determine and show areas of steep slopes, which are defined as slopes of 25% (4H:1V slope) or greater as measured over a minimum distance of 50 feet.

Coastal Resources. Identify and show coastal resources on or adjacent to the site including tidal wetlands, beach soils, dunes, bluffs, escarpments, coastal flood hazard areas, coastal waters, estuarine embayments, intertidal flats, submerged aquatic vegetation, and shellfish concentration areas. If applicable, identify and show the location of the Connecticut Coastal Jurisdiction Line (CJL), which is the jurisdictional limit for tidal, coastal, and navigable waters.

Other Sensitive Areas. Identify and map other sensitive areas on or near the project site including but not limited to watercourses supporting cold water fisheries, waters with identified water quality impairments or approved Total Maximum Daily Loads (TMDLs), state and federal listed species and significant natural communities identified by the CT DEEP Natural Diversity

Database, terrace escarpments located in the Connecticut River valley, agricultural land (prime farmland, unique farmland, and farmland of statewide or local importance), and stone walls.

Step 2. Define Development Envelope

Determine the development envelope in which buildings, roads and other constructed features may be sited with minimal impacts to natural resources and site hydrology. Setting the development envelope should also consider construction techniques, and make efforts to retain and protect mature trees, minimize clearing and grading for buildings, access and fire prevention, and other construction activities, including stockpiles and storage areas. The envelope should also be confined to areas to be permanently altered. Limiting the development envelope also reduces the amount of site disturbance and impervious cover, thereby generating less runoff and requiring smaller stormwater management systems.

In general, the following steps should be followed to define the development envelope:

1. Determine those environmentally sensitive areas to be protected from development such as wetlands, watercourses, vernal pools, and their associated buffer areas (see Step 1).
2. Delineate the different vegetative cover types on the site. Highlight those areas of special characteristics or environmental sensitivities. Areas with concentrations of trees with a diameter at breast height (DBH) of 24 inches or greater should be noted on the plan.
3. Determine and delineate steep slopes (slopes greater than 25% or 4H:1V slope as measured over a minimum distance of 50 feet).
4. Determine and delineate those soil areas which have moderate to high infiltration rates (A and B soils). These areas should be reserved for impervious area disconnection or infiltration systems.
5. Once the above areas have been clearly delineated on the base plan, the remaining areas generally define the development envelope. Determine and define the pre-development runoff patterns on the site in order to provide a preliminary understanding of the sites' drainage patterns and the ultimate discharge points.

Step 3. Develop LID Strategies – Avoid Impacts

Once the development envelope is defined, utilize other LID strategies to further avoid impacts including minimizing soil compaction, minimizing site disturbance, and conservation or other compact development approaches, as described in the section titled Avoid Impacts.

Step 4. Develop LID Strategies – Reduce Impacts

Implement LID strategies to further reduce development impacts, such as minimizing the creation of new impervious surfaces, preserving the timing of site runoff to approximate pre-development conditions, and using low maintenance LID landscaping, as described in the section titled Reduce Impacts.

Step 5. Develop LID Strategies – Manage Impacts at the Source

Finally, after all reasonable efforts to avoid and reduce impacts are exhausted, manage any remaining stormwater impacts by disconnecting impervious surfaces (direct runoff to adjacent vegetated pervious areas or to structural stormwater BMPs), converting impervious areas to pervious surfaces, and implementing source controls and pollution prevention measures, as described in the section titled Manage Impacts at the Source.

LID Site Planning and Design Applications

LID site planning and design strategies can be applied in a variety of land use settings for new development and redevelopment projects. The following sections provide common applications of LID site planning and design techniques for residential development and commercial/industrial/institutional development. The use of LID site planning and design strategies for retrofits, including parcel-based and roadway or right-of-way retrofit applications, are addressed in Chapter 9 - Stormwater Retrofits.

Residential Development

Compact Development

For new development, implement conservation or open space design strategies as much as possible to avoid impacts as described in the Section titled Avoid Impacts (e.g., minimize soil compaction and site disturbance; protect sensitive natural areas, vegetated buffers, and flow paths; and permanently set aside open space for multiple objectives including stormwater management).

House Lots

- Orient lots and buildings to maximize opportunities for simple disconnection, use of infiltration-based structural stormwater BMPs, and conveyance of stormwater through the use of vegetated open channels including linear bioretention and water quality swales.
- Convey stormwater from lots not adjacent to pervious vegetated areas using swales or dispersed as low velocity sheet flow to areas more conducive to infiltration.
- Locate lots adjacent to preserved open space to improve aesthetics and privacy.
- Orient lots to use shared driveways to access houses along common lot lines.

Roads

- Lay out roads and lots to minimize grading. Road alignments should follow existing grades to the extent possible.
- Consider reduced driveway widths and reduced front yard setbacks to limit driveway lengths.

- Use roadside vegetated open channels or swales as an alternative to traditional curb and gutter drainage (i.e., curbing, catch basins, and pipes) in low or medium density developments and where roadside erosion is not a concern (typically slopes of less than 8 percent).
- Use swales on one side of the road where roads with a cross slope are allowed. Otherwise, use a crowned road cross section and swales on both sides of the road.
- Completely eliminate curbing to promote sheet flow to roadside swales or use curb openings to convey gutter flow to roadside swales.
- For roads with grades generally greater than 8%, use catch basins and curb/gutter drainage, with catch basin outlets connected to roadside swales or other structural stormwater BMPs within the road right-of-way.

Driveways

- Grade driveways to adjacent open space and lawn areas (simple disconnection), rain gardens, or water quality swales to retain and infiltrate runoff on the lot and prevent driveway runoff from reaching the road.
- Consider use of driveway infiltration trenches, which are stone-filled trenches along the edge of a driveway to collect water from the driveway, allowing it to soak into the ground and reducing erosion along the edge of the driveway.
- Consider use of permeable surfaces such as porous asphalt, porous concrete, permeable concrete pavers, grass pavers, plastic turf reinforcing grids, and geocells (cellular confinement systems).

Roofs

- Direct roof downspouts to pervious vegetated areas (simple disconnection), dry wells or other small-scale infiltration systems (i.e., rain gardens), or to rain barrels for non-potable reuse such as lawn, landscape, or garden watering.

Lawns

- Use low-maintenance LID landscaping techniques to minimize lawn area and maintenance needs (e.g., irrigation, fertilizers, and pesticides).
- Use diverse selection of native vegetation species.
- Create shade by maintaining existing tree canopy and preserving natural/wild areas.
- Maintain pre-development flow path lengths in natural drainage patterns.

Commercial, Industrial, and Institutional Development

This section addresses LID site planning and design strategies for new development and redevelopment sites in commercial (office buildings, small commercial buildings, and big box retail), industrial, and institutional settings. These sites typically have larger building footprints and parking facilities, which can result in greater impervious cover and stormwater impacts. Such sites also present opportunities to reduce and manage stormwater impacts by minimizing and disconnecting impervious surfaces.

Compact Development

- For new development, implement conservation or open space design strategies as much as possible to avoid impacts as described in the Section titled Avoid Impacts (e.g., minimize soil compaction and site disturbance; protect sensitive natural areas, vegetated buffers, and flow paths; and permanently set aside open space for multiple objectives including stormwater management).

Parking Lots

- Lay out and grade parking lots to direct runoff to structural stormwater BMPs (e.g., bioretention, tree filters, and water quality swales) in parking islands and around the perimeter of parking facilities to retain and infiltrate stormwater and convey it to other structural stormwater BMPs if necessary. Eliminate curbing or use curb cuts to direct sheet flow runoff into these features.

- Consider use of impervious area disconnection (simple disconnection) to direct runoff to adjacent vegetated areas if there is sufficient land area on the site.

- Where surface area is limited, use underground infiltration systems and underground detention below parking lots.

- Use permeable pavement for parking stalls, parking aisles, and overflow parking.

- Provide compact car spaces, minimize parking stall dimensions, and incorporating efficient parking aisles such as diagonal parking spaces with one-way aisles.

- Consider shared parking agreements with adjacent or nearby properties.

- Consider use of structured parking.

- Pretreatment is required for runoff from parking lots prior to entering a structural stormwater BMP (see Chapter 13 - Structural Stormwater BMP Design Guidance) or prior to discharge to adjacent vegetated areas through the use of impervious area disconnection (simple disconnection).

- Infiltration of stormwater from industrial and commercial facilities is restricted for certain Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10 - General

Design Guidance for Stormwater Infiltration Systems), in locations where contaminated soils exist, where the required vertical separation to SHGT cannot be met, or in locations with unacceptable horizontal setbacks for infiltration.

Roofs

- Direct roof downspouts to pervious vegetated areas (simple disconnection), dry wells or other infiltration systems, or to cisterns for non-potable reuse such as lawn or landscape irrigation.
- Consider use of green roofs to manage runoff from building roof areas.

Lawn and Landscaped Areas

- Use low-maintenance LID landscaping techniques to minimize lawn area and maintenance needs (e.g., irrigation, fertilizers, and pesticides).
- Use diverse selection of native vegetation species.
- Incorporate trees in bioretention systems within parking lot islands and around the perimeter of parking lots to provide shade and cooling of impervious surfaces and stormwater runoff during the summer.
- Maintain pre-development flow path lengths in natural drainage patterns.

LID Site Planning and Design Credits

Credits are a way of quantifying the benefits of LID site planning and design techniques, providing additional incentive to use non-structural approaches for meeting the runoff volume and pollutant reduction requirements of Standard 1, as described in Chapter 4 - Stormwater Management Standards and Performance Criteria. LID site planning and design credits may be used to reduce the required Water Quality Volume and Required Retention Volume, provided that the proposed measures meet specific minimum criteria. Implementing such LID site planning and design measures (i.e., those that meet the criteria to receive credits) can reduce or eliminate the need for structural stormwater BMPs.

This section presents credits for the following non-structural LID site planning and design techniques for managing impacts at the source:

- Impervious area conversion
- Impervious area (simple) disconnection
    - Roof runoff
    - Driveways, roads, and parking lot runoff
    - Stormwater runoff from solar arrays.

These techniques provide quantifiable runoff volume and pollutant reduction benefits. For each LID site planning and design technique, a description of the credit is provided along with the minimum criteria for receiving credit.

Credits are not provided for the LID site planning and design techniques described in this chapter that are designed to avoid or reduce impacts. Such techniques involve minimizing land disturbance and impervious area and conserving natural site features, all of which contribute to a reduction in runoff volume and pollutant loads. Standard 1 requires project proponents to consider the use of LID site planning and design strategies, to the MEA, prior to consideration of structural stormwater BMPs. Therefore, all of the LID strategies presented in this chapter should be considered for use, regardless of whether LID credits are available.

Impervious Area Conversion

Converting impervious surfaces (pavement, buildings, etc.) to pervious vegetated surfaces (lawn, meadow, woods) and restoring the pre-development infiltration rate and storage capacity (i.e., porosity) of the underlying soils can be an effective strategy for reducing existing impervious cover on redevelopment sites. Conversion of the impervious surface to a pervious vegetated surface results in a reduction in runoff volume and pollutant loads and an increase in infiltration and groundwater recharge.

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 underlying soils to restore the pre-development infiltration rate and soil porosity and improve soil quality to support vegetation.

Credit Description

An impervious area conversion credit is available when an existing impervious surface is converted to a pervious vegetated surface and the pre-development infiltration rate and storage capacity of the underlying soils is restored.

If the impervious area conversion meets the minimum criteria presented below, the converted area can be deducted from the total impervious area, reducing the required Water Quality Volume and Required Retention Volume and the size of the structural stormwater BMPs needed to meet the static storage volume and pollutant reduction requirements of Standard 1.

Minimum Criteria for Credit

The impervious area conversion credit is subject to the following minimum criteria and restrictions:

- The existing impervious surface must be replaced with a pervious vegetated surface (lawn, meadow, woods) to provide natural or enhanced hydrologic functioning.
- The soils beneath the previously paved surface, which are typically highly compacted, must be modified 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 must 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.
- Soil testing is required (by the University of Connecticut Soil Testing Laboratory, another university soil testing laboratory, or a commercial soil testing laboratory) to determine the suitability of the 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.
- Impervious area conversion 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 stormwater infiltration, unless the contaminated soil is removed and the site is remediated, or if approved by CT DEEP on a case-by-case basis.

Impervious Area (Simple) Disconnection

Impervious area (simple) disconnection can be used to direct runoff from roofs, driveways, roads, parking lots, and solar arrays to natural or landscaped vegetated areas that are of sufficient size and with adequately permeable soils (also called "Qualifying Pervious Areas" or QPAs) to disperse and retained runoff without causing erosion, basement seepage, or negative impacts to adjacent downgradient properties. QPA's may also be referred to as Qualifying Natural Dispersion areas in other stormwater management guidance / manuals locally or nationally. QPAs with flatter slopes, pervious soils, and a dense stand of vegetation are better suited for maintaining dispersed flow. Level spreaders may also be used to disperse the discharge, enhance infiltration, and avoid flow concentration and short-circuiting through the pervious area.

Credit Description

An impervious area disconnection credit is available when runoff from rooftops, driveways, roads, parking lots, and solar arrays are directed to a QPA such that the appropriate portion of the site's WQV is dispersed and retained/infiltrated on-site without causing erosion, basement seepage, or negative impacts to adjacent downgradient properties. This technique involves grading the site to direct runoff as sheet flow to specially designed vegetated areas that can treat and infiltrate the runoff.

If stormwater runoff from an impervious area is directed to a QPA that meets the minimum criteria described below, the area can be deducted from the total impervious area, reducing the

required Water Quality Volume and Required Retention Volume of the site and the size of the structural stormwater BMPs needed to meet the retention and treatment requirements of Standard 1.

Minimum Criteria for Credit

The impervious area disconnection credit is subject to the following general criteria and restrictions,[62] which apply to disconnection of runoff from all types of impervious surfaces.

General Criteria

- QPAs must be clearly shown and labeled as such on site plans.
- QPAs must be located outside of regulated wetland areas but may be used within the outer portion of wetland buffer areas (i.e., upland review areas) if allowed by the approving authority.
- Excessively fertilized lawn areas cannot be used as a QPA. For lawn areas to be considered as QPAs, they must consist of low-maintenance grasses adapted to the New England region (refer to Section 5.4.2 on the use of low-maintenance landscaping).
- QPAs can only receive runoff from land uses with higher potential pollutant loads (LUHPPLs), as defined in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems, provided that no runoff from the areas or activities that may generate runoff with a higher potential pollutant load is directed to a QPA.
- The QPA must be designed to not cause basement seepage. To prevent basement seepage, at a minimum, the QPA must be at least 10 feet away from any building foundation and must be directed away from any building foundation. This credit shall not be utilized in locations where there is a history of groundwater seepage and/or basement flooding.
- Construction vehicles must not be allowed to drive over the QPA to prevent compaction of the soil. If it becomes compacted, the soil must be amended, tilled, and re-vegetated once construction is complete to restore infiltration capacity.
- The QPA must have a minimum of 4 inches of topsoil or organic material. The QPA must sustain healthy vegetative cover (dense herbaceous vegetative ground cover) over the long term. Existing vegetation, grasses, and/or plantings are acceptable. Vegetation must

[62] These criteria have been adapted from the Rhode Island Stormwater Design and Installation Standards Manual (2015), MA MS4 General Permit Appendix F (2021), CTDOT Guidance for Natural Dispersion/Vegetative Filter Areas (2021), Trinkaus Engineering, LLC Morris, CT Low Impact Sustainable Development and Stormwater Management Design Manual (2018), CT DEEP Construction Stormwater General Permit Appendix I (Stormwater Management at Solar Array Construction Projects), and New Jersey Stormwater BMP Manual (2004).

cover 90% or more of the QPA. Forested areas used as QPAs must have dense herbaceous vegetative ground cover to effectively disperse flows and prevent soil erosion.

- The slope of the QPA shall be less than or equal to 8% for lawn and less than or equal to 15% for undisturbed meadow or forested areas. Full or partial credit for QPA's outside of this slope criteria may be given based on-site specific conditions and the design retention requirement as approved by the review authority.
- Flow from the impervious surface must enter the QPA as sheet flow. All discharges onto the QPA must be stable and non-erosive.
- Upon entering the QPA, all runoff must remain as sheet flow. The shape, slope, and vegetated cover in the QPA must be sufficient to maintain sheet flow throughout its length.
- A vegetated channel, swale, or structural stormwater BMP may be necessary downgradient of the QPA to manage stormwater from larger storm events that is not fully retained within the QPA for stormwater quantity control purposes.
- The flow path through the QPA should comply with the setbacks established for structural infiltration BMPs (refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems).
- QPAs should have a depth to the seasonal high groundwater table shall be 18 inches or greater. HSG classification will influence infiltration rates see Chapter 10 for guidance regarding the classifications and expected rates. HSG classification and depth to seasonal high groundwater table must be field verified by a Qualified Professional through field evaluation (i.e., test pits or soil borings) (refer to soil evaluation guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems).
- The QPA must be included in the Operation and Maintenance (O&M) Plan required by Standard 4. The O&M Plan shall include measures to inspect the QPA at least annually to remove any deposited sediment (e.g., sand from winter sanding operations) and trash, address any ponding and erosion, and re-plant any vegetation that has died to maintain vegetative cover of 90% or greater.
- The QPA must be owned or controlled (e.g., drainage easement) by the property owner and must remain as a landscaped or natural vegetated area over the long term.

The following additional criteria and restrictions apply to disconnection of runoff from the specific types of impervious surfaces listed below.

Roof Runoff

- The rooftop area contributing runoff to any one downspout cannot exceed 1,000 ft^2.

- If designing for retention of the full WQV the length of the QPA (in feet) is recommended to be equal to or greater than the contributing rooftop area (in square feet) divided by 13.3 (e.g., for 1,000 ft^2 roof/13.3 = 75 ft). Treatment can be achieved at varying lengths and widths.

- If designing for retention of the full WQV the width of the QPA is recommended to be equal to or greater than the roof length. For example, if a roof section is 20 feet wide by 50 feet long (1,000 ft^2 roof), the width of the QPA shall be at least 50 feet. Treatment can be achieved at varying lengths and widths.

- Although they may abut, there shall be no overlap between QPAs. For example, the runoff from two 1,000 ft^2 sections of roof must be directed to separate QPAs. They shall not be directed to the same area.

- Where provided, downspouts must be at least 10 feet away from the nearest impervious surface (e.g., driveways) to prevent reconnection to the stormwater drainage system.

- Where provided, downspouts must have a splash pad, level spreader, or dispersion trench to reduce flow velocity and induce sheet flow in the QPA.

- Where a gutter/downspout system is not used, the rooftop runoff must be designed to sheet flow at low velocity away from the structure housing the roof using an infiltration trench or similar level spreader.

- To take credit for rooftop disconnection associated with a LUHPPL (for non-metal rooftops), the rooftop runoff must not commingle with runoff from any paved surfaces or activities or areas on the site that may generate higher pollutant loads.

Driveway, Road, and Parking Lot Runoff

- The maximum contributing flow path from driveway, road, and parking lot impervious areas shall be 75 feet.

- QPA Sizing (0-8% slope): The length of the QPA (i.e., the dimension parallel to the direction of flow) must be equal to or greater than the length of the contributing impervious area. The width of the QPA (i.e., the dimension perpendicular to the direction of flow) shall be no less than the width of the contributing impervious surface. For roads, the minimum QPA width is 25 feet.

- QPA Sizing (8-15% slope): The length of the QPA must be equal to or greater than the length of the contributing impervious area. The width of the QPA shall be no less than the twice the width of the contributing impervious surface. For roads, the minimum QPA width is 50 feet. Full or partial credit for QPA's outside of this slope criteria may be given based on site specific conditions and the design retention requirement as approved by the review authority.

- Although they may abut, there shall be no overlap between QPAs. For example, the runoff from two consecutive segments of road must be directed to separate QPAs. They shall not be directed to the same area.
- Runoff from driveways, roadways, and parking lots may be directed over soft shoulders, through curb cuts, or level spreaders to QPAs. Measures must be employed at the discharge point to the QPA to prevent erosion and promote sheet flow.
- The drainage design must account for snow shelf blocking runoff during winter months.
- Salt tolerant vegetation shall be chosen for all roadside applications.

Solar Array Runoff

Roadways, gravel surfaces, and transformer pads within the solar array are considered Directly Connected Impervious Area (DCIA) for the purposes of calculating WQV. Solar panels are considered unconnected and therefore eligible for the impervious area disconnection credit if all of the following criteria are met:

- Post-construction slopes below the solar panels are less than 15%.
    - For slopes less than or equal to 5%, appropriate vegetation shall be established that will ensure sheet flow conditions and that will provide sufficient ground cover throughout the site.
    - For slopes greater than 5% but less than 10%, practices including, but not limited to, level spreaders, terraces, or berms shall be used to ensure long term sheet flow conditions.
    - For slopes greater than or equal to 8%, use erosion control measures in accordance with solar array requirements contained in the CT DEEP Construction Stormwater General Permit and the Connecticut Soil Erosion and Sediment Control Guidelines, as amended.
    - For slopes equal to or greater than 10% and less than 15%, use engineered stormwater control measures[63] designed to provide permanent stabilization and non-erosive conveyance of runoff to the property line of the site or downgradient from the site.
- The vegetated area receiving runoff between rows of solar panels is equal to or greater than the average width of the row of solar panels draining to the vegetated area.

[63] Engineered stormwater control measures does not refer to exclusively implemented by engineers, but rather the consideration that natural solutions may not solely provide the benefit needed.

- Overall site conditions and solar panel configuration within the array are designed and constructed such that stormwater runoff remains as sheet flow across the entire site and flows towards the intended stormwater management controls.
- The solar panels shall be designed and constructed in such a manner as to allow the growth of native vegetation beneath and between the panels. Pollinator-friendly vegetation is strongly encouraged. Chemical fertilization, herbicides, or pesticides cannot be used except as necessary to initially establish the vegetation.
- The lowest vertical clearance of the solar panels above the ground shall not be greater than 10 feet. The panels shall, however, be at an adequate height to support vegetative growth and maintenance beneath and between the panels. If the lowest vertical clearance of the solar panels above the ground is greater than 10 feet, non-vegetative control measures are required to prevent/control erosion and scour along the drip line or otherwise provide energy dissipation from water running off the panels.
- Appropriate vegetated buffers and setback distances between solar panels and downgradient wetlands or waters and property boundaries are maintained consistent with the requirements of the CT DEEP Construction Stormwater General Permit.

Additional Information Sources

- Sustainable Land Use Regulation Project and Model Regulations (Capitol Region Council of Governments)
- Livable Communities Toolkit: A Best Practices Manual for Metropolitan Regions (Capitol Region Council of Governments)
- Smart Growth Guidelines for Sustainable Design & Development (EPA and Capitol Region Council of Governments, November 2009)
- Transit Oriented Development Toolkit for CT (Connecticut Fund for the Environment, Partnership for Strong Communities, Regional Plan Association, Tri-State Transportation Campaign)
- Transit-Oriented Development and Responsible Growth Website (Connecticut Department of Economic and Community Development)
- Rhode Island Low Impact Development Site Planning and Design Guidance Manual (Rhode Island Department of Environmental Management and Rhode Island Coastal Resources Management Council, March 2011)
- The Rhode Island Conservation Development Manual: A Ten Step Process for the Planning and Design of Creative Development Projects (Rhode Island Department of Environmental Management, June 2003)
- City Green: Innovative Green Infrastructure Solutions for Downtowns and Infill Locations (EPA, May 2016)
- Smart Growth/Smart Energy Toolkit Modules – Open Space Design (OSD)/Natural Resource Protection Zoning (NRPZ) (Massachusetts Executive Office of Energy and Environmental Affairs)
- Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales (EPA 2009)
- Better Site Design Code and Ordinance Worksheet – 2017 Update (Center for Watershed Protection (December 2017)
- EPA Smart Growth Publications
- Smart Growth Network
- Sustainable Sites Initiative

Chapter 6 – Source Control Practices and Pollution Prevention

Introduction

Controlling the sources of pollution and preventing pollutant exposure to stormwater is an important aspect of an effective stormwater management strategy. Source control practices and pollution prevention are operational practices that limit the generation of stormwater pollutants at their source. Most are typically non-structural, require minimal or no land area, and can be implemented with moderate cost and effort as compared to structural measures.

What's New in this Chapter?

- Clarified project types and land use activities for which source control practices and pollution prevention should be implemented
- Minimum requirements for source control practices and pollution prevention
- Updated information on source control and pollution prevention practices with website links to sources of additional information

Source control practices and pollution prevention should be incorporated, to the maximum extent practicable, into the site design and operational aspects of all land development projects, including but not limited to new development and redevelopment activities associated with:

- Commercial and industrial sites
- Institutional facilities
- Residential development
- Municipal facilities and operations

Over the past several decades, a large amount of information on stormwater source control and pollution prevention practices has been developed and refined as part of the CT DEEP stormwater general permit programs, including the MS4 General Permit (Good Housekeeping and Pollution Prevention for Municipal Operations), Industrial Stormwater General Permit, and Commercial Stormwater General Permit. Many other Connecticut-specific and regional information sources are available on these topics through organizations such as the CT Nonpoint Education for Municipal Officials (NEMO) Program, UConn Center for Land Use Education and Research (CLEAR), and watershed groups throughout the state.

This chapter has been revised and abbreviated to provide basic guidance on the use of source control practices and pollution prevention for common land development activities and land use settings in the State of Connecticut. Website links are provided to other available sources of more detailed information on each topic, rather than duplicating the information in this

document, which may become outdated over time. CT DEEP may periodically update the website links and add or remove information sources.

Recommended Practices

This section provides guidance on the use of the following source control and pollution prevention practices for development-related activities in commercial, industrial, institutional, residential, and municipal settings. This list of practices is not exhaustive; the use of other source control and pollution prevention practices is also encouraged.

Street and Parking Lot Sweeping. Street and parking lot sweeping helps remove sediment and debris from paved surfaces, reducing exposure of these materials to stormwater runoff and transport to waterbodies.

Winter Road Materials Management. Salts, sand, and other materials are applied to roadways for improved safety during adverse winter weather conditions. Ant-icing and deicing materials can have adverse effects on surface waters, groundwater, drinking water supplies and public health, vegetation, soils, and aquatic life. Proper application and storage of anti-icing/deicing materials is important to avoid or minimize environmental and public health impacts.

Snow Storage and Disposal. Snow accumulated from plowing activities can be a source of contaminants and sediment to surface waters if not properly located and maintained.

Catch Basin Cleaning and Storm Drainage System Maintenance. Regular inspection and cleaning of catch basins and other storm drain system components preserves the stormwater management functions of the drainage system and helps reduce the discharge of pollutants from the drainage system. Inspection and maintenance of structural stormwater BMPs is addressed in other sections of this Manual.

Subsurface Sewage Disposal System Management. Approximately 40 percent of Connecticut's population relies on subsurface sewage disposal systems (also called septic systems). Failing or older, sub-standard systems can be major sources of pollution to surface waters and groundwater.

Illicit Discharge Detection and Elimination. Illicit discharges are unpermitted discharges to waters of the state that do not consist entirely of stormwater or uncontaminated groundwater, except certain allowable non-stormwater discharges. Wastewater connections to the storm drain system and illegal dumping are among the types of illicit discharges that can occur. Depending on the source, an illicit discharge may contain a variety of pollutants that can impact both human health and the aquatic environment. Identifying and eliminating these discharges is an important means of pollution source control in a stormwater drainage system.

Commercial and Industrial Pollution Prevention. Commercial and industrial facilities, including institutional facilities, can potentially contribute point or nonpoint pollution to stormwater through activities associated with operations, maintenance, and storage. CT DEEP provides general pollution prevention information and fact sheets applicable to a wide variety of industries.

Pet and Waste and Waterfowl Management. The fecal matter of domestic pets and waterfowl can be carried by stormwater runoff into nearby waterbodies or storm drainage systems. In addition to contributing solids to stormwater, animal fecal matter is a source of nutrients and pathogens, such as bacteria and viruses, in stormwater runoff. In Connecticut's coastal watersheds, domesticated animals (dogs and cats) and waterfowl, especially Canada geese, can be significant contributors in parks (including dog parks), landscaped shorelines, golf courses, and commercial areas.

Lawn and Landscape Management. Lawns and other managed landscape can contribute stormwater runoff pollution, resulting in adverse impacts to surface waters and groundwater, due to overfertilization, overwatering, overapplication of pesticides, and direct disposal of lawn clippings, leaves, and trimmings. The use of alternative landscaping techniques and judicious use of fertilizers and pesticides can reduce stormwater and nonpoint source pollution from lawns and managed landscapes in virtually all land use settings and project types.

Table 6- 1 summarizes the applicability of each type of practice for various land use settings, minimum requirements for use of each practice, and website links to suggested sources of additional information.

Source control and pollution prevention practices selected for a given project or site should be included in the post-construction Operation and Maintenance (O&M) Plan, which is a required element of a Stormwater Management Plan, as described in Chapter 12 – Stormwater Management Plan.

Table 6- 1 Guidance on the Use of Source Control and Pollution Prevention Practices

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercia	Industrial	Institutiona	Municipal	Residential		
Street and Parking Lot Sweeping	♦	♦	♦	♦	♦	➢ Required by MS4 regulated municipalities and institutional facilities, and CTDOT, under MS4 General Permits. ➢ Reuse and/or dispose of street sweepings in accordance with CT DEEP guidelines and requirements (see reference). ➢ Minimum frequency of once per year, in spring as soon as possible after snow melt and following winter activities such as sanding to capture sand and debris before it is washed into the storm drainage system. ➢ More frequent sweeping in targeted areas based on consideration of pollutant sources, land use, water quality, and other factors. ➢ Conduct sweeping in dry weather; dry cleaning methods preferable (avoid wet cleaning or flushing of the pavement). ➢ Select sweeping equipment depending on level of debris.	CT DEEP Guideline for Municipal Management Practices for Street sweepings & Catch Basin Cleanings, as amended https://www.unh.edu/unhsc/news/clean-sweep-tech-memo-outreach-toolkit-developed

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Winter Road Materials Management		♦	♦	♦		Application ➢ Minimize the use and optimize the application of chloride-based or other salts and anti-icing/deicing product (while maintaining public safety) and consider opportunities for use of alternative materials ➢ Application rate should be tailored to road conditions (i.e., high versus low volume roads, air & pavement temperature, weather forecast). ➢ Use anti-icing (pre-storm) application ➢ Trucks should be equipped with sensors that automatically control the deicer spread rate. ➢ Drivers and handlers of salt and other deicers should receive training to improve efficiency, reduce losses, and raise awareness of environmental impacts. Storage ➢ Salt storage piles should be completely covered, ideally by a roof and, at a minimum, by a weighted tarp, and stored on impervious surfaces. ➢ Runoff should be contained in appropriate areas. ➢ Spills should be cleaned up after loading operations. The material may be directed to a sand pile or returned to salt piles. ➢ Avoid storage in drinking water supply areas, water supply aquifer recharge areas, and public wellhead protection areas. Other ➢ Identify ecosystems such as wetlands that may be sensitive to salt. ➢ Use calcium chloride and CMA in sensitive ecosystem areas. ➢ To avoid over-application and excessive expense, choose deicing agents that perform most efficiently according to pavement temperature. ➢ Monitor the deicer market for new products and technology.	UConn Green SnowPro Program Winter Highway Maintenance Operations: Connecticut, A Report by the Connecticut Academy of Science and Engineering for the Connecticut Department of Transportation (July 2015) Road Salt Use in Connecticut Reference Guide Cary Institute of Ecosystem Studies, Road Salt

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Snow Storage and Disposal	●	●	●	●		➢ Snow disposal and storage activities, including selection of appropriate snow disposal sites, should adhere to CT DEEP guidelines and requirements (see reference). ➢ Snow accumulations removed from roadways, bridges, and parking lots should be placed in upland areas only, where sand and other debris will remain after snowmelt for later removal. ➢ Snow should not be pushed or dumped into waterbodies or wetlands, structural stormwater BMPs, stormwater drainage swales or ditches, or on top of catch basins. ➢ Snow should not be stored near drinking water areas, waterbodies, or wetlands. A minimum of 100 ft is recommended (the review authority may require more if site conditions are not adequate). ➢ Snow should not be stored in areas immediately adjacent to (within at least 100 feet) private or public drinking water well supplies (due to the possible presence of road salt). ➢ Avoid storing snow in areas that are unstable, areas of potential erosion, or high points where snow may melt and collect debris as runoff before it enters the stormwater system. ➢ Consider sun exposure when storing snow. Snow in areas with higher sun exposure will melt faster but may require deicers if the snowmelt refreezes.	CT DEEP Best Management Practices for Disposal of Snow Accumulations from Roadways and Parking Lots, as amended

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Catch Basin Cleaning and Storm Drainage System Maintenance	♦	♦	♦	♦		➢ Required by MS4 regulated municipalities and institutional facilities, and CTDOT, under MS4 General Permits. ➢ Establish a catch basin cleaning frequency such that no catch basin at any time will be more than fifty (50) percent full ➢ Clean more frequently catch basins with known heavier sediment and debris loads, near sensitive waterbodies, drainage problems, flat grades, etc. ➢ Cleaning should include removal of sediment from sump and removal of trash and debris from grate. ➢ Additional maintenance recommended in the fall to remove trash, leaves, and other debris. In rural areas and areas that experience significant accumulation of leaves, the recommended fall maintenance should be performed after leaf fall and before the first snowfall. ➢ Catch basin cleanings (solid material, such as sand, silt, leaves, and debris removed from storm drainage systems during cleaning operations) should be properly disposed of either via reuse, or via disposal at an approved site. (Note: Before reuse of the sand and organic matter it is recommended the material should be tested as they can carry various contaminants such as heavy metals.) ➢ Handle and dispose of catch basin and storm drainage system cleanings in accordance with CT DEEP guidelines and requirements (see reference)	CT DEEP Guideline for Municipal Management Practices for Street sweepings & Catch Basin Cleanings, as amended

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Subsurface Sewage Disposal System Management	●	●	●	●	●	➢ Stormwater management plans should describe appropriate operation and management for all subsurface disposal systems on the project site. ➢ Regularly inspect system and pump septic tank every three years by a septic service professional. Refer to CT DPH septic system inspection reporting form for inspection requirements. ➢ Do not park on, plant trees near, or discharge rainwater/stormwater near drain field. ➢ Maintain, upgrade, and repair system. ➢ Use water efficiently and properly dispose of waste (do not flush anything besides human waste and toilet paper).	CT DEEP Subsurface Sewage Treatment and Disposal System website CT DPH Subsurface Sewage website CT DPH Connecticut Recommended Minimum Existing Septic System Inspection Report CT DPH Septic Systems 101: Operation and Maintenance of a Subsurface Sewage Disposal System US EPA Septic Smart Homeowners

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Illicit Discharge Detection and Elimination	●	●	●	●	●	➢ Required by MS4 regulated municipalities and institutional facilities, and CTDOT, under MS4 General Permits. ➢ Employees, contractors, and property owners should be alert for evidence of illicit discharges or the threat of an illicit discharge into the storm drainage system at any point or any time. ➢ No illicit discharges are allowed as part of new development, redevelopment, or retrofit projects. ➢ Any illicit discharges discovered during site development or ongoing site operations shall be investigated and eliminated consistent with the CT DEEP MS4 General Permits and any local illicit discharge ordinances or regulations. ➢ Include storm drain marking (e.g., stenciling, glue-on or self-adhesive markers, or permanent pre-cast markings) at existing and new catch basin inlets to discourage dumping.	UConn CLEAR and NEMO, Connecticut MS4 Guide, Illicit Discharge Detection and Elimination Guide to Storm Drain Marking, Town of Wellesley DPW, Engineering Division

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Commercial and Industrial Pollution Prevention	●	●		●		➢ Projects involving commercial businesses/facilities regulated under the CT DEEP Commercial Stormwater General Permit should reference the required Stormwater Management Plan and associated source controls and pollution prevention practices. ➢ Projects involving industrial facilities and activities regulated under the CT DEEP Industrial Stormwater General Permit should reference the required Stormwater Pollution Prevention Plan (SWPPP) and associated source controls and pollution prevention practices. ➢ Commercial businesses and industrial facilities not subject to the CT DEEP Commercial or Industrial Stormwater General Permits should implement source controls and pollution prevention practices to the maximum extent practicable to minimize stormwater pollution.	CT DEEP Industrial Stormwater General Permit Program UConn CLEAR and NEMO, Industrial Stormwater General Permit CT DEEP Commercial Stormwater General Permit Program UConn CLEAR and NEMO, Construction Stormwater General Permit CT DEEP Pollution Prevention (P2) for Business, Industry, and Healthcare
Pet and Waterfowl Waste Management	●		●	●	●	➢ Required by MS4 regulated municipalities and institutional facilities, and CTDOT, under MS4 General Permits. ➢ Pet waste stations with pet waste bags and waste containers are recommended at municipal parks and open space areas where dog walking occurs, and at residential developments, particularly multi-unit dwellings such as apartments, town houses, and condominiums. ➢ On municipal or privately-owned land where geese or other waterfowl populations could contribute bacteria to the storm drainage system or directly to waterbodies (i.e., land with open water), prohibit the feeding of geese or waterfowl and implement a program to manage geese and waterfowl populations.	CT DEEP Pet Waste (Feces) Management Pet Waste Management, Think Blue Connecticut River CT DEEP Problems with Canada Geese

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Lawn and Landscape Management	♦	♦	♦	♦	♦	➢ Required by MS4 regulated municipalities and institutional facilities, and CTDOT, under MS4 General Permits. ➢ Use alternatives to managed turf. Use native plants that are adapted to Connecticut's climate and that require minimal watering, fertilizer, and pesticide application. Choose vegetation that is best suited to the local conditions and desired level of maintenance. ➢ Improve soils by adding soil amendments or using mulches to reduce the need for watering by increasing the moisture retained in the soil. ➢ Test soils every 1 to 3 years to determine suitability for supporting a lawn, and to determine how to optimize growing conditions. ➢ Use efficient irrigation techniques, watering only when needed and allowing the water to penetrate deeper into the soil will encourage deeper root growth. Consider use of rain barrels or rain gardens for stormwater reuse. ➢ Mow high and keep mower blades sharp. Lawns should not be cut shorter than 3 inches. Keep clippings on the lawn to release stored nutrients back into the soil. ➢ Mulch mow grass clippings into the lawn in order to help soil retain moisture and to recycle nutrients, which can help reduce need for future fertilizer applications. ➢ Most lawns require little or no fertilizer to remain healthy. Avoid the use of conventional fertilizers and pesticides. Use organic lawn care methods to the maximum extent practicable (see references on organic lawn care practices). If fertilizer is to be used, follow best management practices to minimize and optimize fertilizer usage (see sources to right): o Fertilize no more than twice a year - once in May-June (not before spring green up), and once in September	CT DEEP, Organic Lawn Care website CT DEEP, Transitioning to Organic Land Care (OLC) In Your Town CT DEEP, Sustainable Practices and Resources for the Landscaping and Lawn Care Industry Connecticut Chapter of the Northeast Organic Farming Association: Final Report to the New England and New York State Environmental Agency Commissioners: Regional Clean Water Guidelines for Fertilization of Urban Turf (NEIWPCC) University of Connecticut, New England Regional Nitrogen and Phosphorus Fertilizer and Associated Management Practice Recommendations University of Massachusetts Cooperative Extension, Best Management Practices for Lawn and Landscape Turf

Practice Type	Land Use					Minimum Requirements	Sources of Additional Information
	Commercial	Industrial	Institutional	Municipal	Residential		
Lawn and Landscape Management (continued)						○ Use slow-release formulations (50 percent or more water-insoluble nitrogen) to encourage more complete uptake. ○ Fertilize at a rate of no more than ½ pound of nitrogen per 1000 square feet. Typically apply one-half to one-third (or less) of that recommended on the fertilizer bag label and then monitor lawn response and adjust as needed. ○ Use a phosphorus-free fertilizer on lawns near or bordering waterbodies, unless soil tests indicate that the soils are low in phosphorus. ○ Do not apply fertilizer prior to when rain is forecast, which can reduce fertilizer effectiveness and increase the risk of surface and groundwater contamination. ○ Do not apply fertilizer to saturated or frozen ground. Avoid spreading fertilizer on impervious surfaces (sidewalks, patios, driveways, etc.). ○ Leave a buffer strip of unfertilized grass or other vegetation around waterbodies.	University of Connecticut Cooperative Extension, Sustainable Landscapes CT DEEP, BMPs for Grass Clipping Management University of Connecticut - Soil Nutrient Analysis Laboratory: UConn Cooperative Extension System's Home & Garden Education Center:
General Pollution Prevention and Good Housekeeping Practices	♦	♦	♦	♦	♦	➢ Refer to requirements listed above	UConn CLEAR and NEMO, Connecticut MS4 Guide, Pollution Prevention & Good Housekeeping

Chapter 7 – Overview of Structural Stormwater Best Management Practices

Introduction

Structural stormwater Best Management Practices (BMPs) – also commonly called Stormwater Treatment Practices, Stormwater Treatment Systems, Stormwater Control Measures, etc. – are constructed stormwater management systems used to reduce the discharge of pollutants and the volume of runoff from developed sites to maintain pre-development hydrology, pollutant loads, and groundwater recharge. Structural stormwater BMPs can be designed to collect, store, treat, infiltrate, and evapotranspire stormwater runoff. BMPs that primarily rely on vegetation and soils to mimic natural processes and manage rainwater close to where it falls are also commonly referred to as "Green Infrastructure (GI)."

What's New in this Chapter?

- Recategorized structural stormwater BMPs based on function, replacing previous "Primary and Secondary Treatment Practices" terminology and framework
- Increased flexibility for selection and design of structural stormwater BMPs to meet stormwater management standards and performance criteria
- General guidance on BMP design considerations to reduce or facilitate maintenance

As described in Chapter 3 - Preventing and Mitigating Stormwater Impacts of this Manual, structural stormwater BMPs are one element of a comprehensive stormwater management approach and should be selected and designed only after consideration of Low Impact Development (LID) site planning and design strategies (see Chapter 5 - Low Impact Development Site Planning and Design Strategies) and in combination with operational source control practices and pollution prevention (see Chapter 6 - Source Control Practices and Pollution Prevention). Such an approach can reduce the need for or the size and cost of structural stormwater BMPs and related structural drainage system components, as well as reduce maintenance needs. This Manual does not provide the details regarding every BMP type but rather the functional classes, general design guidance for each class and a few examples. It is anticipated that using these guiding principles will open the door for a multitude of BMP options and provide maximum flexibility for the best site design.

Functional Categories of Structural Stormwater BMPs

This section introduces the following major categories and types of structural stormwater BMPs that are recommended for use in Connecticut, based on their primary function:

- Pretreatment BMPs
- Infiltration BMPs
- Filtering BMPs
- Stormwater Pond BMPs
- Stormwater Wetland BMPs
- Water Quality Conveyance BMPs
- Stormwater Reuse BMPs
- Proprietary BMPs
- Other BMPs and BMP Accessories

Selection, design, construction, and maintenance considerations for structural stormwater BMPs are addressed in later sections of this Manual.

Pretreatment BMPs

Pretreatment BMPs remove coarse sediment and debris (e.g., trash, leaves, floatables) upstream of another structural stormwater BMP, while consolidating maintenance to a specific location. Properly designed Pretreatment BMPs help preserve pollutant removal efficiency, extend service life and reduce maintenance costs of the main stormwater BMP. All pretreatment practices require regular maintenance to function properly.

Pretreatment BMPs can be designed as an integral component of another BMP, such as a sediment forebay within another practice, or as a separate structure preceding the main stormwater BMP, such as an upstream structure or proprietary device. Pretreatment BMPs can also be configured as on-line or off-line. On-line systems are designed to treat the applicable Water Quality Volume or Water Quality Flow and safely convey larger flows through the system. Off-line systems are designed to treat a specified discharge rate or volume, such as the Water Quality Volume or Water Quality Flow, and bypass larger flows. Pretreatment BMPs addressed in this Manual include:

- Sediment Forebay
- Pretreatment Vegetated Filter Strip
- Pretreatment Swale
- Flow-through Devices
    - Deep Sump Hooded Catch Basin
    - Oil Grit Separator
    - Proprietary Pretreatment Device

Pretreatment BMPs are only suitable as pretreatment for other stormwater BMPs and cannot be used alone to meet the retention or treatment performance criteria, except for proprietary pretreatment devices. When designed to achieve the minimum required pollutant load reductions described in Chapter 4 - Stormwater Management Standards and Performance Criteria, proprietary devices can be used for stormwater treatment.

Infiltration BMPs

Infiltration BMPs reduce stormwater runoff volumes and pollutant loads, and help to recharge groundwater, by capturing, temporarily storing, and infiltrating stormwater in permeable soils below the bottom of the BMP. Pollutant removal occurs through physical filtering, adsorption of pollutants onto soil particles, and subsequent biological and chemical conversion in the soil. Infiltration practices must be carefully designed and maintained to prevent clogging and system failure. Infiltration BMPs addressed in this Manual include:

- Infiltration Trench
- Underground Infiltration System
- Infiltration Basin
- Dry Well
- Infiltrating Catch Basin
- Permeable Pavement

Unlike the Filtering BMPs described in the next category, the Infiltration BMPs in this category are not designed with underdrains (unless located in Hydrologic Soil Group C or D soils) and therefore are not considered "filtering" practices. Infiltration BMPs can be used to meet the retention and treatment performance criteria and can also be designed for stormwater quantity control.

Filtering BMPs

Filtering BMPs treat stormwater runoff by capturing, temporarily storing, and filtering stormwater through sand, soil, organic material, or other porous media. As the water flows through the filter media, sediment particles and attached pollutants, as well as some soluble pollutants, are removed through physical straining and adsorption. The filtered water is then collected via an underdrain and discharged back to the drainage system or to a receiving waterbody. Pretreatment is generally required to remove debris and floatables and to prolong the service life of the filter media.

Filtering BMPs are generally less cost-effective than Infiltration BMPs and therefore are typically used where site characteristics limit the use of Infiltration BMPs, such as in areas with low permeability soils, where minimum setback distances cannot be met, or where infiltration of stormwater may contaminate groundwater. Each of these filtering practices can be designed as infiltration systems (i.e., exfiltration into the underlying soils) using a raised underdrain and when used in areas with sufficiently permeable soils. Filtering BMPs addressed in this Manual include:

- Bioretention
- Sand Filter
- Tree Filter

Unless specifically designed for infiltration, Filtering BMPs do not provide significant retention or runoff volume reduction and therefore may not fully meet the retention performance criterion.

Filtering BMPs are suitable for providing treatment in combination with other BMPs or in situations where the retention performance criterion cannot be fully achieved.

Stormwater Pond BMPs

Stormwater ponds maintain either a permanent pool of water or a combination of a permanent pool and extended detention. The permanent pool of water in these systems enhances pollutant removal through mechanisms such as sedimentation, biological uptake, microbial breakdown, gas exchange, volatilization, and decomposition. This category of stormwater ponds does not include traditional dry detention basins or dry flood control basins, which do not provide significant water quality treatment functions. Stormwater Pond BMPs addressed in this Manual include:

- Wet Pond
- Micropool Extended Detention Pond
- Wet Extended Detention Pond
- Multiple Pond System

Stormwater ponds do not provide sufficient retention or runoff volume reduction through infiltration or other processes and therefore cannot be used to meet the Standard 1 retention performance criterion of this Manual. Stormwater ponds are suitable for treatment and stormwater quantity control.

Stormwater Wetland BMPs

Stormwater wetlands are constructed wetland systems designed to treat polluted stormwater runoff by several mechanisms, including sedimentation, adsorption, biological uptake, photodegradation, and microbial breakdown. Stormwater wetlands typically include sediment forebays, shallow and deep pool areas, meandering flow paths, and vegetative measures to enhance pollutant removal. Stormwater wetlands are engineered specifically for pollutant removal and flood control purposes. They typically do not have the full range of ecological functions of natural wetlands or wetlands constructed for compensatory storage or wetland mitigation. Stormwater Wetland BMPs addressed in this Manual include:

- Subsurface Gravel Wetland
- Shallow Wetland
- Extended Detention Shallow Wetland
- Pond/Wetland System

Stormwater wetlands do not provide sufficient retention or runoff volume reduction through infiltration or other processes and therefore cannot be used to meet the Standard 1 retention performance criterion of this Manual. Stormwater wetlands are suitable for treatment and stormwater quantity control.

Water Quality Conveyance BMPs

Water Quality Conveyance BMPs include several types of water quality swales. Water quality swales reduce the velocity of, and temporarily store, stormwater runoff and promote infiltration. Pollutant removal mechanisms in water quality swales are similar to constructed wetlands and include sedimentation, adsorption, biological uptake, and microbial breakdown. These practices differ from conventional grass channels and ditches that are designed for conveyance only, as they provide higher levels of pollutant removal. Water Quality Conveyance BMPs addressed in this Manual include:

- Dry Water Quality Swale
- Wet Water Quality Swale

Given their reliance on infiltration, dry water quality swales can be used for stormwater retention, while wet water quality swales are generally more suitable for treatment.

Stormwater Reuse BMPs

Stormwater Reuse BMPs, also commonly called "stormwater or rainwater harvesting and use" are designed to collect, store, potentially treat, and later use the water to meet various demands such as landscape irrigation. Less common uses include drinking, washing, cooling, and flushing. Stormwater Reuse BMPs addressed in this Manual include:

- Rain Barrel
- Cistern

Stormwater Reuse BMPs reduce the volume of runoff from a site and therefore can be used for meeting the retention performance criterion. Small-scale Stormwater Reuse BMPs (i.e., rain barrels) alone may be insufficient to retain the runoff volume required to fully meet the retention performance criterion.

Proprietary BMPs

Proprietary stormwater BMPs are manufactured systems that use proprietary settling, filtration, absorption/adsorption, vortex principles, vegetation, and other processes to remove pollutants from stormwater runoff. The most common types of proprietary

BMPs include hydrodynamic separators, filtration systems, wet vaults, and catch basin inserts. 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. Proprietary BMPs may be used for pretreatment (in conjunction with other BMPs) or as stand-alone treatment; however, proprietary BMPs alone cannot be used to meet the stormwater retention performance criterion since they generally do not reduce runoff volumes. Chapter 11 - Proprietary Stormwater BMPs of this Manual addresses criteria for evaluating the use of proprietary BMPs when proposed as stand-alone treatment, including existing systems and emerging/innovative systems and new technologies.

Other BMPs and BMP Accessories

This Manual includes other common structural practices that are used as part of an overall stormwater management system:

- Green Roof
- Dry Extended Detention Basin
- Underground Detention (no infiltration)
- Inlet and Outlet Controls

Green roofs can be used for on-site retention, thereby reducing runoff volumes and peak runoff rates, but are generally not used for stormwater treatment because they capture rainwater that falls directly on the roof surface before it encounters pollutant sources or nearby sources of pollution may perpetually deposit pollutants on all surfaces. Dry extended detention basins and underground detention systems are designed to provide peak runoff attenuation through surface and subsurface storage, respectively, but do not provide sufficient levels of pollutant removal or infiltration to meet stormwater treatment or retention goals. Inlet and outlet controls measures manage runoff into and out of structural stormwater BMPs.

Pollutant Removal Mechanisms

Structural stormwater BMPs remove pollutants from stormwater through various physical, chemical, and biological mechanisms. Table 7- 1 lists the major stormwater pollutant removal mechanisms and the affected stormwater pollutants.

Table 7- 1 Stormwater Pollutant Removal Mechanisms

Mechanism	Pollutants Affected
Gravity settling of particulate pollutants	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Filtration and physical straining of pollutants through a filter media or vegetation	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Infiltration of particulate and dissolved pollutants	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Adsorption on particulates and sediments	Dissolved phosphorus, metals, synthetic organics, petroleum hydrocarbons
Photodegradation	COD, petroleum hydrocarbons, synthetic organics, pathogens
Gas exchange and volatilization	Volatile organics, synthetic organics
Biological uptake and biodegradation	BOD, COD, petroleum hydrocarbons, synthetic organics, phosphorus, nitrogen, metals
Chemical precipitation	Dissolved phosphorus, metals
Ion exchange	Dissolved metals
Oxidation	COD, petroleum hydrocarbons, synthetic organics
Nitrification and denitrification	Ammonia, nitrate, nitrite
Density separation and removal of floatables	Petroleum hydrocarbons, trash

BOD – Biochemical Oxygen Demand, COD – Chemical Oxygen Demand

Since many pollutants in stormwater runoff are attached to solid particles, BMPs designed to remove suspended solids from runoff will remove other pollutants as well. Exceptions to this rule include nutrients (particularly nitrogen), which are often in a dissolved form, soluble metals and organics, some deicing constituents such as chloride, and extremely fine particulates (i.e., diameter smaller than 10 microns), which can only be removed by treatment processes other than traditional separation methods.

BMP Effectiveness

Structural stormwater BMPs differ in their ability and effectiveness to provide specific management functions. Once LID site planning and design principles have been considered and

applied, structural stormwater BMPs should be selected and designed based on site characteristics to meet the stormwater management standards and performance criteria described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

Pollutant-specific treatment efficiency and the ability of BMPs to retain runoff on-site are important factors for preserving pre-development hydrologic characteristics and pollutant loads. Stormwater BMPs that can retain the required runoff volume on-site, such as infiltration systems and stormwater reuse BMPs, are suitable for meeting the stormwater retention performance criterion, while other "treatment-only" stormwater BMPs such as filtering BMPs and stormwater ponds/wetlands, can be used to treat runoff in situations where the retention performance criterion cannot be fully achieved. Pretreatment BMPs are restricted in their use as pretreatment for other stormwater BMPs only. Other types of BMPs that provide substantial storage volumes, such as stormwater ponds and wetlands and underground chambers, can be used either alone or in combination with other BMPs to meet the stormwater quantity control standards for larger storms.

- Chapter 5 - Low Impact Development Site Planning and Design Strategies, identifies acceptable LID site planning and design strategies and structural stormwater BMPs for meeting specific stormwater management standards and performance criteria.
- Chapter 8 - Selection Considerations for Stormwater BMPs provides additional guidance on the selection of structural stormwater BMPs to meet specific stormwater management objectives for a particular site.

Use of Multiple BMPs in Series

Stormwater BMPs can be combined in series to meet water quality and stormwater quantity control objectives. The use of multiple structural stormwater BMPs in series is referred to as a "treatment train" approach. The use of a treatment train approach can:

- Accomplish multiple stormwater management objectives to meet the stormwater management standards and performance criteria
- Increase the level and reliability of system performance
- Increase the lifespan of stormwater BMPs by distributing pollutant removal over multiple practices
- Allow multiple BMPs to target different pollutants to improve overall treatment effectiveness.

A treatment train typically consists of a pretreatment BMP, followed by a retention and/or treatment BMP to meet the runoff volume and pollutant reduction (retention/treatment) standard, and potentially another stormwater BMP to fully meet the stormwater runoff quantity control standard.

Maintenance Considerations

Structural stormwater BMPs require regular maintenance to perform successfully. Failure to perform adequate maintenance can lead to reductions in pollutant removal efficiency or increase pollutant loadings and aggravate downstream impacts. Stormwater BMPs should be routinely inspected and maintained following construction to ensure that the controls are in proper working condition and operating as designed.

BMP Design Considerations to Reduce and Facilitate Maintenance

Effective design of stormwater BMPs can reduce maintenance requirements and help facilitate routine maintenance activities, which can improve the long-term operation and function of the BMP. General design recommendations to reduce and facilitate BMP maintenance include:

- Identify the parties responsible for conducting long-term inspections and maintenance and develop BMP designs that align with their operation and maintenance capabilities.
- Place inlet/outlet structures along the perimeter of the stormwater BMP for easier access.
- Place a 4-foot high (minimum) flexible delineator post adjacent to infrastructure that may become hidden and can potentially become a safety hazard (e.g., trip and fall), may be damaged during maintenance, or may damage maintenance equipment. Examples include inlet structures, clean-outs, observation wells, and raised outlet structures.
- Identify adequate space to stage maintenance activities and equipment. Consider parking lot use and on-street parking limitations when identifying this area. Access paths can also serve as a staging area for equipment during maintenance.
- Consider the weight of the maintenance equipment and portable weight displacement tracks/plywood. Equipment should not adversely impact the functionality of the stormwater BMP (i.e., compacting the subsurface soil media). For instance, not relying on sediment removal equipment (e.g., excavator) accessing surfaces where water infiltrates as well as ensuring that surfaces to be mowed by larger mowing equipment can withstand typical tire pressures from such equipment.[64]
- Designate safe entry and exit points to the stormwater BMP; design to allow for safe approach and exit speeds for BMPs near roads.
- Consider existing and proposed barriers (e.g., guardrail, fence, etc.) that may hinder access to the BMP. Provide a gap, gate, etc. in the barrier accordingly.
- Provide the appropriate level of access to the varying components of the stormwater BMP. For instance, it is necessary to provide vehicular access to the BMP, but it may only be

[64] Strategies for mitigating these impacts can be found in the Soil Erosion and Sediment Control Guidelines

necessary to provide access for mowing equipment to the vegetated portions within the BMP.

- At a minimum, the access path should abut pretreatment facilities and provide safe access to all points that require routine maintenance or sediment removal. Consider the equipment type and any limitations including excavator reach and vacuum truck hose length. Also consider vegetation that may limit access, such as shrubs that would hinder the use of a hose.
- Depict the access path on the figure that will be incorporated with the long-term operation and maintenance plan.
- Evaluate the potential for snow storage on the stormwater BMP. Sediment/debris that accumulates within the plowed snow may impact the effectiveness of the BMP after the snow melts and the sediment/debris remains.
- BMPs will need to withstand anticipated snow loads if plowed/shoveled snow is permitted to accumulate over the BMP.
- Use transition curbs or steel plates where curb cuts are proposed to limit the potential for damage from snowplows.
- Depict any snow storage areas on the figure that will be incorporated with the long-term operation and maintenance plan. In areas where snow storage is not permitted, identify these areas as well.
- Place the least expensive and most easily maintained components of a stormwater BMP treatment train at the most upstream point in the treatment train to reduce the maintenance requirements of the downstream components.

General Inspection and Maintenance Requirements

General maintenance guidelines for stormwater BMPs are summarized below. Chapter 13 - Structural Stormwater BMP Design Guidance provides recommended maintenance for specific stormwater BMPs. Appendix B contains BMP-specific maintenance inspection checklists.

- **Inspections.** Inspections should be performed at regular intervals to ensure proper operation of structural stormwater BMPs. Inspections should be conducted at least annually, with additional inspections following large storms. Inspections should include a comprehensive visual check for evidence of the following (not all items apply to every BMP type):
    - Accumulation of sediment or debris at inlet and outlet structures
    - Erosion, settlement, or slope failure
    - Clogging or buildup of fines on infiltration surfaces
    - Vegetative stress and appropriate water levels for emergent vegetation

- Algae growth, stagnant pools, or noxious odors
- Deterioration of pipes or conduits
- Seepage at the toe of ponds or wetlands
- Deterioration or sedimentation in downstream channels and energy dissipators
- Evidence of vandalism
- Evidence of structural damage by beavers, muskrats, and other wildlife

- **Routine Maintenance.** Routine maintenance should be performed on a regular basis to maintain proper operation and aesthetics. Routine maintenance should include:

  - Debris and litter removal
  - Silt and sediment removal
  - Terrestrial vegetation maintenance
  - Aquatic vegetation maintenance
  - Maintenance of mechanical components (valves, gates, access hatches, locks)

- **Non-routine Maintenance.** Non-routine maintenance refers to corrective measures taken to repair or rehabilitate stormwater BMPs to proper working condition. Non-routine maintenance is performed as needed, typically in response to problems detected during routine maintenance and inspections, and can include:

  - Erosion and structural repair
  - Sediment removal and disposal
  - Nuisance control (odors, mosquitoes, weeds, excessive litter)

Stormwater BMP maintenance requirements are an integral part of a site stormwater management plan (see Chapter 12 – Stormwater Management Plan). These requirements should include, at a minimum, detailed inspection and maintenance tasks, schedules, responsible parties, and financing provisions. The owner typically maintains stormwater treatment practices at commercial, industrial, and rental residential developments. These facilities generally have staff dedicated to maintenance activities or contract for such services. Maintenance of non-rental residential installations is typically performed by private landowners or property/homeowner associations, which in many cases do not have the technical expertise, resources, or funds to inspect and maintain their stormwater systems. In some cases, municipalities may accept responsibility for inspecting and maintaining stormwater BMPs. Municipalities should require legally binding maintenance agreements for stormwater treatment practices to clearly delineate maintenance responsibilities.

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:

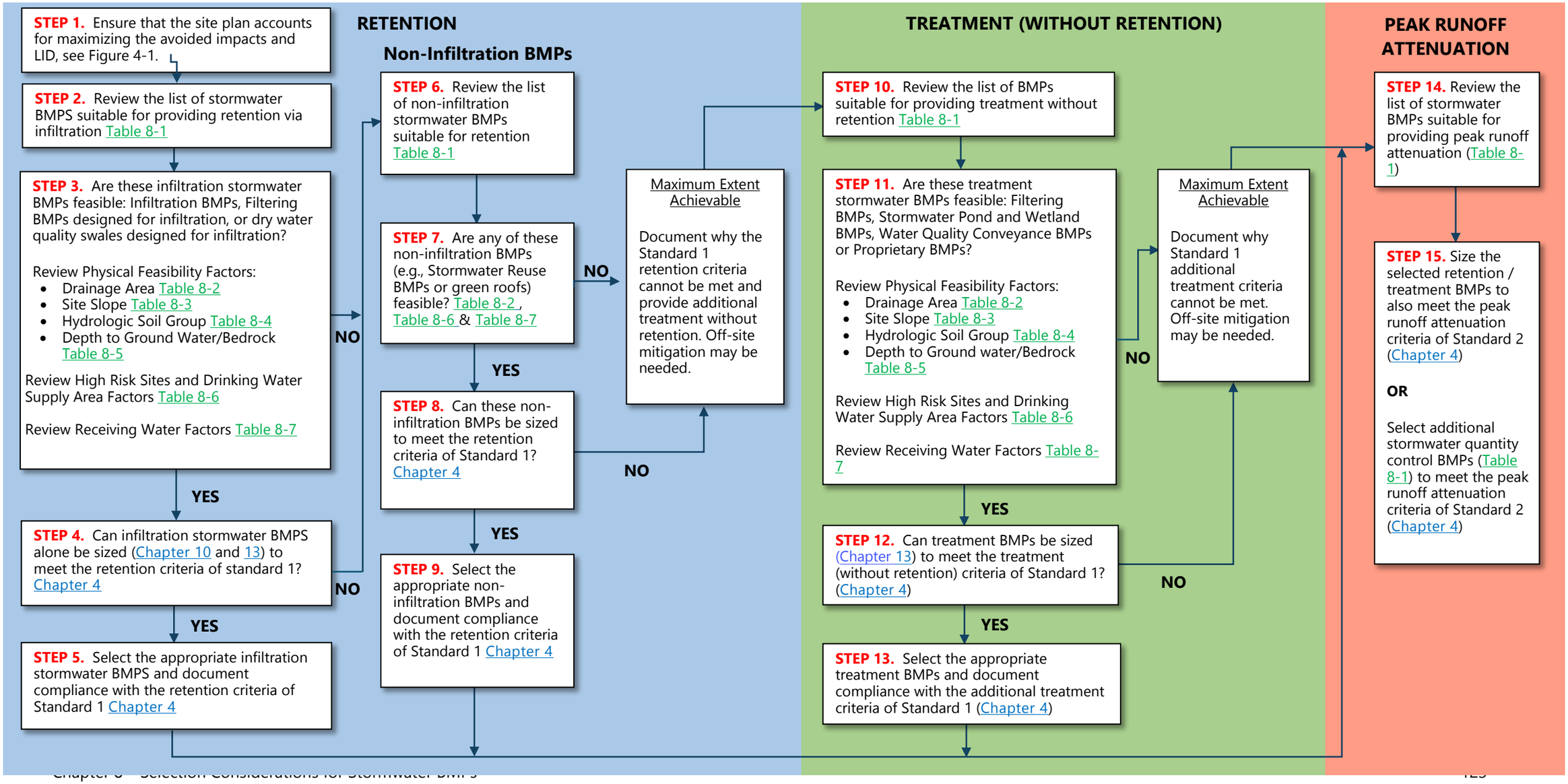
- Initial data has been collected to define existing site conditions
- Stormwater retention, treatment, and peak runoff attenuation requirements have been determined based on the stormwater management standards and performance criteria (Chapter 4 - Stormwater Management Standards and Performance Criteria)

- 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.

[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:

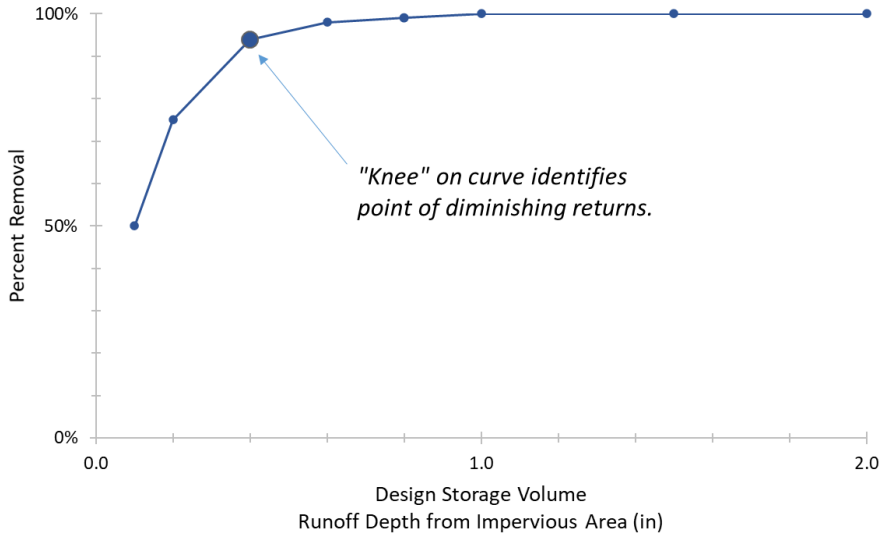
- Optimize retrofit sizing based on anticipated pollutant reduction performance, and

- 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):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.

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).

Chapter 12 – Stormwater Management Plan

Introduction

A Stormwater Management Plan documents how the proposed stormwater management measures meet the stormwater management standards, performance criteria, and design guidelines contained in this Manual, as well as other local, state, and federal stormwater management requirements.

What's New in this Chapter?

- Updated Stormwater Management Plan content consistent with revised stormwater management standards and performance criteria
- Updated Stormwater Management Plan Checklist (Appendix E)

A Stormwater Management Plan is required as described in Chapter 4 - Stormwater Management Standards and Performance Criteria, a Stormwater Management Plan is required (Standard 5 – Stormwater Management Plan) for all new development, redevelopment, retrofits, and other land disturbance activities that require a local, state, or federal permit or approval. A Stormwater Management Plan is not required for retrofit projects that do not require review and approval, although designers are encouraged to document the design basis for all stormwater retrofits following good engineering/design practice. A Stormwater Management Plan should be prepared by the project proponent and designing qualified professional, as defined in the General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities and submitted for review by the local or state reviewing authority.

The chapter presents the recommended minimum content for a Stormwater Management Plan. Many municipalities and state agencies have stormwater management submission requirements as specified by municipal land use regulations and state permit programs. The recommended Stormwater Management Plan presented in this chapter is provided as guidance only and does not replace other local and state submission requirements. Municipalities or state agencies may adopt this or similar Stormwater Management Plan requirements into future updates of municipal land use regulations and state permit programs.

Plan Content

A Stormwater Management Plan should include the following major elements:

- Stormwater Management Report (narrative)
- Design Calculations
- Design Drawings (plans)
- Soil Erosion and Sediment Control Plan
- Operation and Maintenance Plan
- Other Supporting Documents

Appendix E contains a checklist that can be used in preparing or reviewing a Stormwater Management Plan.

Stormwater Management Report

The stormwater management report provides a written narrative of the project, including existing and proposed conditions, proposed stormwater management measures, and how the project meets the stormwater management standards and performance criteria contained in this Manual. The stormwater management report should include, but is not limited to, the following sections and information.

General Information

- Applicant's name, address, contact information (email & phone)
- Licensed professional engineer's name, address, contact information (email & phone)
- Street address of project site
- Site locus map
- Current use and zoning of property
- Proposed use of property

Project Summary

- Project description and purpose
- Project schedule and project phasing (if any)
- Applicable local, state, and federal regulatory permits, approvals, and associated regulatory requirements related to post-construction stormwater management
- Applicable regulatory authority(ies)

Existing (Pre-Development) Conditions Description (As Applicable)

- Site area, ground cover, vegetation, existing development features (roads, buildings, utilities, septic systems, etc.)
- Site topography (2-foot contours based on aerial or field survey), slopes, drainage patterns, drainage systems, drainage areas, and stormwater discharge locations
- Existing impervious area and existing Directly Connected Impervious Area (DCIA)
- On-site and adjacent waterbody information[74]
    - Water quality classifications
    - Water quality impairments and Total Maximum Daily Loads (TMDLs)
- Site soils as identified by USDA NRCS mapping or soil scientist
    - Soil types
    - Hydrologic Soil Groups
- Soil evaluation results
    - Initial screening information

[74] The applicable waterbody information can be found at: MS4 Map | CT NEMO Program (uconn.edu)

  - Test pits and soil borings results
  - USDA soil textural class
  - Depth to bedrock
  - Depth to seasonal high groundwater
  - Significant subsurface or geologic features
  - Field infiltration testing results (if required)
- Other site constraints
  - Site contamination
- On-site and off-site critical resources
  - Inland wetlands and watercourses, tidal wetlands, and associated regulatory setbacks
  - Streams
  - Lakes/ponds
  - Vernal pools
  - Coastal waters including Connecticut Coastal Jurisdiction Line
  - Coldwater streams
  - Drinking water supply areas (wells, Aquifer Protection Areas, public drinking water supplies)
  - Tree canopy
  - Steep slopes (25% and greater)
  - Conservation easement areas
- Locations of 100-year floodplain, floodway, and flood elevations from current FEMA mapping
- Land uses and development adjacent to the site

Proposed (Post-Development) Conditions Description (As Applicable)

- Type of project or activity (new development, redevelopment, linear project, retrofit)
- Proposed ground cover, vegetation, development features (roads, buildings, utilities, septic systems, etc.)
- Proposed drainage area boundaries and design points
- Proposed activities classified as Land Uses with Higher Potential Pollutant Loads (LUHPPLs)
- Proposed impervious area and DCIA
- Proposed area of land disturbance
- Coastal Jurisdiction Line (CJL) for properties fronting coastal, tidal, or navigable waters

Applicable Stormwater Management Standards and Performance Criteria

- Standard 1 – Runoff Volume and Pollutant Reduction
  - LID Site Planning and Design
  - Stormwater Retention and Treatment
- Standard 2 – Stormwater Runoff Quantity Control
  - Design Storm Rainfall Depth and Distribution
  - Peak Runoff Attenuation
  - Conveyance Protection

- Emergency Outlet Sizing

Proposed LID Site Planning and Design Strategies Description

- Avoid Impacts
  - Minimizing Soil Compaction
  - Minimizing Site Disturbance
  - Protecting Sensitive Natural Areas
  - Preserving Vegetated Buffers
  - Avoiding Disturbance of Steep Slopes
  - Siting on Permeable and Erodible Soils
  - Protecting Natural Flow Pathways
  - Conservation and Compact Development
- Reduce Impacts
  - Reducing Impervious Surfaces (Roads, Cul-de-sacs, Sidewalks, Driveways, Buildings, Parking Lots)
  - Preserving Pre-development Time of Concentration
  - Use of Low Maintenance Landscaping
- Manage Impacts at the Source
  - Disconnecting Impervious Surfaces - Impervious Area (Simple) Disconnection
  - Conversion of Impervious Areas to Pervious Areas
  - Source Controls

Proposed Structural Stormwater BMPs

- Description of proposed structural stormwater BMPs and why they were selected
  - Location, size, types by drainage area/design point
  - Design criteria

Summary of Compliance with Stormwater Management Standards and Criteria

Standard 1 – Runoff Volume and Pollutant Reduction (for each design point for Site Development and Redevelopment Projects)[75]

- LID Site Planning and Design
  - LID Site Planning and Design Opportunities and Constraints Plan
  - Completed LID Site Planning and Design Checklist
  - Total LID Site Planning and Design credits and DCIA reduction

[75] Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

- Stormwater Retention and Treatment
    - Impervious area and Directly Connected Impervious Area (DCIA)
    - Retention and Treatment Required
        - Water Quality Volume and Water Quality Flow
        - Required Retention Volume
    - Retention and Treatment Provided including Maximum Extent Achievable Documentation, as applicable
        - Explanation of site limitations
        - Description of the stormwater retention practices implemented
        - Explanation of why this constitutes the Maximum Extent Achievable
        - Alternate retention volume
        - Description of measures used to provide additional stormwater treatment without retention
        - Use of EPA stormwater BMP performance curves to demonstrate compliance with required average annual pollutant load reductions

Standard 2 – Stormwater Runoff Quantity Control for Site Development and Redevelopment Projects (for each design point)[76]

- Design Storm Rainfall Depth and Distribution
- Comparison of pre- and post-development
    - Runoff volume and peak flow rate
        - 2-year, 10-year, and potentially the 25-year and 100-year, 24-hour storms
- Downstream analysis
    - Comparison of pre- and post-development peak flows, velocities, and hydraulic effects at critical downstream locations (stream confluences, culverts, other channel constrictions, and flood-prone areas) to the confluence point where the 10 percent rule applies
- Conveyance Protection
- Emergency Outlet Sizing

Design Calculations

The Stormwater Management Plan should include the following design calculations to demonstrate that the proposed stormwater management measures meet the standards and performance criteria described in Chapter 4 - Stormwater Management Standards and

[76] Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

Performance Criteria and are designed in accordance with the guidance contained in this Manual.

- Standard 1 – Runoff Volume and Pollutant Reduction (for each design point)
  - LID Site Planning and Design Credit Calculations
  - Impervious area and Directly Connected Impervious Area (DCIA)
  - Water Quality Volume, Water Quality Flow, and Required Retention Volume
  - Structural Stormwater BMP Sizing Calculations
    - Static and dynamic sizing methods (infiltration systems)
    - Drain time and groundwater mounding analysis (infiltration systems)
    - Required versus provided design volumes
    - Pollutant specific load reductions (BMP performance curves) where Standard 1 cannot be met by retention alone

- Standard 2 – Stormwater Runoff Quantity Control (for each design point)
  - Stormwater Runoff Calculations for Pre-Development and Post-Development (with and without stormwater BMPs) Conditions
    - Design storm depth and duration, recurrence interval, and rainfall distribution
    - Runoff volume and peak flow rate (2-year, 10-year, and potentially the 25-year, 100-year, 24-hour storms)
    - Runoff Curve Number
    - Time of Concentration (and associated flow paths)
  - Routing analysis for proposed stormwater BMPs including drainage routing diagram
  - Conveyance protection (including flow velocity calculations and outlet protection sizing) and emergency outlet sizing calculations
  - Downstream analysis hydrograph routing calculations
  - Storm drain system conveyance calculations

Design Drawings

Design drawings should be prepared by designing qualified professional, as defined in the General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities. Design drawings should be signed and sealed by the appropriate design professionals (landscape architects and/or professional engineers) responsible for the project design and consistent with their areas of expertise, including LID site planning and design elements and structural stormwater BMPs. The following design drawings should be included with a Stormwater Management Plan.

- Existing (Pre-Development) Conditions Plan
  - Location of existing man-made features on or adjacent to the site, such as roads, buildings, driveways, parking areas, other impervious surfaces, drainage systems, utilities, easements, septic systems, etc.
  - Surveyed locations of property boundaries and easements

- Drainage systems and sanitary sewers should include rim and invert elevations of all structures and sizes and connectivity of all pipes
- Vegetative communities on the site, including locations of tree canopy
- Site topography (2-foot contours based on aerial or field survey), slopes, drainage patterns, conveyances systems (swales, storm drains, etc.), drainage area boundaries, flow paths, times of concentration
- Locations of existing stormwater discharges
- Areas of steep (25% or greater) slopes
- Perennial and intermittent streams
- Inland wetlands and watercourses (and associated regulatory setbacks) as defined by a soil scientist in the field and flags located by a licensed land surveyor
- Locations of vernal pools
- Locations of 100-year floodplain, floodway, and flood elevations from current FEMA mapping
- Locations of soil types as identified by USDA NRCS mapping or soil scientist, test pit and soil boring locations, and field infiltration testing locations
- Areas of site contamination
- Location, size, type of existing structural stormwater BMPs and conveyance systems
- Limits of developable area based on site development constraints
- Coastal Jurisdiction Line (CJL) for properties fronting coastal, tidal, or navigable waters

- Proposed (Post-Development) Conditions Plan
  - Location of proposed man-made features on or adjacent to the site such as roads, buildings, driveways, parking areas, other impervious surfaces, drainage systems, utilities, easements, septic systems, etc.
  - Surveyed locations of property boundaries and easements
  - Drainage systems and sanitary sewers should include rim and invert elevations of all structures and sizes and connectivity of all pipes
  - Vegetative communities on the site, including proposed limits of clearing and disturbance
  - Site topography (2-foot contours based on aerial or field survey), slopes, drainage patterns, conveyances systems (swales, storm drains, etc.), drainage area boundaries, flow paths, times of concentration
  - Locations of proposed stormwater discharges/design points
  - Perennial and intermittent streams
  - Inland wetlands and watercourses (and associated regulatory setbacks) as defined by a soil scientist in the field and flags located by a licensed land surveyor
  - Locations of vernal pools
  - Locations of 100-year floodplain, floodway, and flood elevations from current FEMA mapping

- Locations and results of on-site soil evaluation (test pits/soil borings and field infiltration testing)
- Areas of site contamination
- Development envelope and areas of site preserved in natural condition
- Location, size, type of proposed structural stormwater BMPs and conveyance systems. Structural BMPs should have rim, invert, and contour elevations and pipe sizes and construction material.
- Locations of soil erosion and sedimentation controls
- Locations of non-structural source controls

- LID Site Planning and Design Opportunities and Constraints Plan
- Structural Stormwater BMP Design Details and Notes
- Coastal Jurisdiction Line (CJL) for properties fronting coastal, tidal, or navigable waters

Soil Erosion and Sediment Control Plan

Consistent with Standard 3 of this Manual, project proponents must develop and implement a Soil Erosion and Sediment Control (SESC) Plan in accordance with local and/or state regulatory requirements, the Connecticut Guidelines for Soil Erosion and Sediment Control Guidelines, as amended (Guidelines), and the requirements of the CTDEEP General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities. The SESC Plan should, at a minimum, demonstrate the methods and designs to be utilized during construction and stabilization of the site following completion of construction activity. Erosion and sediment control measures should be included on the plans with sufficient detail to facilitate review of the design by the reviewing authority and proper construction of the measures.

Operation and Maintenance Plan

As required by Standard 4, project proponents must develop and implement a long-term Operation and Maintenance (O&M) Plan, which identifies required inspection and maintenance activities for structural stormwater BMPs. Chapter 13 - Structural Stormwater BMP Design Guidance of this Manual contains operation and maintenance guidelines and recommendations for each type of stormwater BMP. Appendix B contains maintenance inspection checklists.

Recommended elements of an O&M Plan include but are not limited to:

- Detailed inspection and maintenance requirements/tasks
- Inspection and maintenance schedules
- Parties legally responsible for maintenance (name, address, and telephone number)
- Provisions for financing of operation and maintenance activities
- As-built plans of completed structures
- Letter of compliance from the designer
- Post-construction documentation to demonstrate compliance with maintenance activities

Operational source control and pollution prevention measures for the site (see Chapter 6 - Source Control Practices and Pollution Prevention) should also be described in the O&M Plan.

Other Supporting Documents

Other information relevant to the design of the stormwater management measures for a project should be included (or referenced, if appropriate) in the Stormwater Management Plan. Pertinent information may include but is not limited to:

- Completed Stormwater Management Plan Checklist
- LID Site Planning and Design Checklist (Chapter 5 – Low Impact Development Site Planning and Design Strategies)
- NRCS Soils Mapping
- Soil Evaluation Documentation (Test Pits/Soil Borings and Field Infiltration Testing Results)
- DCIA Tracking Worksheet required by the reviewing authority to satisfy MS4 Permit requirements
- Groundwater impacts for proposed infiltration structures
- Reports on wetlands and other surface waters (including available information such as Maximum Contaminant Levels [MCLs], Total Maximum Daily Loads [TMDLs], 303(d) or 305(b) impaired waters listings, etc.)
- Water quality impacts to receiving waters
- Impacts on biological populations/ecological communities including fish, wildlife (vertebrates and invertebrates), and vegetation, including the Natural Diversity Database evaluation.
- Flood study/calculations
- Other permits and approvals issued for the project.

Chapter 13 – Structural Stormwater BMP Design Guidance

Introduction

This chapter provides detailed guidance on the design, construction, and maintenance of the structural stormwater Best Management Practices (BMPs) contained in this Manual. Table 13- 1 lists each of the stormwater BMPs for which detailed guidance is provided. It is important to note this is not intended to be an exhaustive list, but rather a method to provide the soundest science available and develop guiding principles to BMP design. Hyperlinks are provided corresponding to sections of this chapter where information on specific BMPs can be found. Guidance for multiple types of BMPs is provided in a single combined section for several categories of BMPs (Pretreatment BMPs, Stormwater Pond and Wetland BMPs).

Table 13- 1 Structural Stormwater BMPs Addressed in Chapter 13

BMP Category	BMP Type
Pretreatment BMPs	Pretreatment BMPs Sediment Forebay Pretreatment Vegetated Filter Strip Pretreatment Swale Deep Sump Hooded Catch Basin Oil Grit Separator Proprietary Pretreatment Device
Infiltration BMPs	Infiltration Trench Underground Infiltration System Infiltration Basin Dry Well & Infiltrating Catch Basin Permeable Pavement
Filtering BMPs	Bioretention Tree Filter Sand Filter
Stormwater Pond and Wetland BMPs	Stormwater Pond Wet Pond Micropool Extended Detention Pond Wet Extended Detention Pond Multiple Pond System Stormwater Wetland Subsurface Gravel Wetland Shallow Wetland Extended Detention Shallow Wetland Pond/Wetland System
Water Quality Conveyance BMPs	Dry Water Quality Swale Wet Water Quality Swale
Stormwater Reuse BMPs	Rain Barrel and Cistern Rain Barrel Cistern
Other BMPs and BMP Accessories	Green Roof Dry Extended Detention Basin Underground Detention (no infiltration) Inlet and Outlet Controls

The following BMP-specific design guidance is provided in each section:

- **Description.** A brief description of the stormwater BMP and common design variations. The stormwater management benefits of the BMP (runoff volume and pollutant reduction, stormwater runoff quantity control, etc.) and effectiveness for removal of specific categories of pollutants are summarized at the beginning of each section for quick reference and screening.
- **Advantages.** The major beneficial factors or considerations (e.g., environmental, economic, safety) for selecting a specific stormwater BMP.
- **Limitations.** The major limitations or drawbacks of a stormwater BMP that may preclude its use for a given site.
- **Siting Considerations.** The site conditions required for implementation of a stormwater BMP such as subsurface conditions and minimum setbacks.
- **Soil Evaluation.** Where necessary, evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate (for infiltration systems).
- **Design Requirements.** Specific technical requirements for designing the major elements of a stormwater BMP such as pretreatment, system sizing and dimensions for retention and treatment, drain time, conveyance, materials, vegetation, etc.[77]
- **Construction Requirements.** Recommended construction procedures and methods, as well as recommended stages of construction to be inspected by a qualified inspector as defined in the General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities, to ensure that stormwater BMPs are constructed as designed.
- **Maintenance Requirements.** Routine and non-routine operation and maintenance, including inspection frequencies, required for the stormwater treatment practice to function properly over time.

[77] Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

Pretreatment BMPs

General

Pretreatment BMPs remove coarse sediment and debris (e.g., trash, leaves, floatables) upstream of other structural stormwater BMPs, while consolidating maintenance to a specific location. Properly designed Pretreatment BMPs help preserve the pollutant removal efficiency, extend the service life, and reduce maintenance costs of the main stormwater BMP.

Pretreatment BMPs Included in this Section

- Sediment Forebay
- Pretreatment Vegetated Filter Strip
- Pretreatment Swale
- Flow-through Devices
  - Deep Sump Hooded Catch Basin
  - Oil Grit Separator
  - Proprietary Pretreatment Device

Pretreatment BMPs can be designed as an integral component of another BMP, such as a sediment forebay within another practice, or as a separate structure preceding the main stormwater BMP, such as an upstream proprietary device. Pretreatment BMPs can also be configured as on-line or off-line. On-line systems are designed to provide pretreatment for the entire design volume or flow rate and safely convey larger flows. Off-line systems are typically designed to receive a specified volume or flow rate, such as the design Water Quality Volume (WQV) or Water Quality Flow (WQF), and bypass larger flows. A flow diversion structure (flow splitter) is used to divert the design volume or flow rate to the off-line stormwater BMP. The Inlet and Outlet Controls section addresses the design of flow diversion structures.

Pretreatment BMPs are only suitable as pretreatment for other stormwater BMPs and cannot be used alone to meet the retention or treatment performance criteria, with the exception of proprietary devices. When designed to achieve the minimum pollutant load reductions described in Chapter 4 - Stormwater Management Standards and Performance Criteria, proprietary devices can be used for stormwater treatment.

Access Considerations

The performance of pretreatment practices is dependent on regular maintenance. Pretreatment practices should be designed for easy maintenance. Maintenance access must be carefully considered and incorporated into the design. Refer to the general maintenance considerations provided in Chapter 7 - Overview of Structural Stormwater Best Management Practices, which also apply to Pretreatment BMPs.

Selection

Pretreatment BMPs should be selected based on the following factors:

- The downstream stormwater BMP
- Site-specific constraints (e.g., available space, topography, accessibility)
- Flow type (e.g., sheet flow or concentrated flow)

- Required pretreatment capacity.

Table 13- 2 and Table 13- 3 provide a general summary of the applicability of different types of Pretreatments BMPs and can assist in selecting an appropriate pretreatment practice. Multiple pretreatment BMPs may be used, as necessary, to enhance pretreatment effectiveness.

Table 13- 2 Pretreatment BMP Selection Factors

Pretreatment BMP	Pollutant Removal Processes	Inlet Flow Type	Sizing Criteria (Capacity)	Maintenance Frequency	Maintenance Effort	Required Space	Capital Cost
Sediment Forebay	Settling	Concentrated	10% to 25% of the WQV (Small to large)	Moderate	Moderate	Moderate to High	Low to Moderate
Pretreatment Vegetated Filter Strip	Filtration, Some Infiltration, Vegetative Uptake	Diffuse	Length / Drainage Area Dependent (small)	Low	Low to Moderate	High	Low
Pretreatment Swale	Filtration, Some Infiltration, Vegetative Uptake	Diffuse/ Concentrated	WQF & 10-minute Residence Time (Small to medium)	Low	Low to Moderate	Moderate	Low
Deep Sump Hooded Catch Basin	Settling & Floatables Removal	Concentrated	WQF (small)	Moderate to High	Moderate	Low	Low
Oil Grit Separator	Settling & Floatables	Concentrated	WQF (small)	High	Moderate	Low to Moderate	Moderate
Proprietary Pretreatment Device	Settling & Floatables Removal	Concentrated	WQF (small/medium)	High	Moderate	Low	Moderate to High

WQV = Water Quality Volume WQF = Water Quality Flow

- Inlet flow type is either diffuse flow such as sheet flow or concentrated flow such as pipe flow or channelized flow.
- Pretreatment BMPs are sized on a volume or flow rate basis. Sediment forebays are sized as a percentage of the WQV, typically 10% to 25% of the WQV. The storage volume of the sediment forebay can be included in the overall design storage volume of the main stormwater BMP provided that the sediment forebay drains to the BMP. Most other Pretreatment BMPs are sized to treat the WQF, which is the peak flow rate associated with the WQV.
- Maintenance frequency reflects how often maintenance will typically be required for these practices, while maintenance effort reflects the anticipated time, skill of labor, and equipment necessary to complete maintenance. These vary depending on pretreatment device placement (ease of access), size, and the pollutants/soil types in the drainage area. These ratings are relative to the other pretreatment practices.
- Required space is the anticipated footprint used by the specific pretreatment practice after installation. This provides a relative comparison of the footprint required for the various pretreatment practices. If the practice is large but located below ground, it is considered to have a small footprint and is classified as low.
- Capital cost is the anticipated cost required for purchasing the practice and/or the installation costs that are required to implement the pretreatment practice.

Table 13- 3 Suitability of Pretreatment BMPs Based on Type of Primary Stormwater BMP

BMP Category	BMP Type	Sediment Forebay	Pretreatment Vegetated Filter Strip	Pretreatment Swale	Deep Sump Hooded Catch Basin (1)	Oil Grit Separator (2)	Proprietary Pretreatment Device (3)
Infiltration BMPs	Infiltration Trench	♦	♦	♦	♦	♦	♦
	Underground Infiltration System				♦	♦	♦
	Infiltration Basin	♦	♦	♦	♦	♦	♦
	Dry Well	Pretreatment Not Required					
	Infiltrating Catch Basin (4)				♦	♦	♦
	Permeable Pavement	Pretreatment Not Required					
Filtering BMPs	Bioretention	♦	♦	♦	♦	♦	♦
	Surface Sand Filter	♦	♦	♦	♦	♦	♦
	Tree Filter				♦	♦	♦
Stormwater Pond BMPs	Wet Pond	♦	♦	♦		♦	♦
	Micro pool Extended Detention Pond	♦	♦	♦		♦	♦
	Wet Extended Detention Pond	♦	♦	♦		♦	♦
	Multiple Pond System	♦	♦	♦		♦	♦
Stormwater Wetland BMPs	Subsurface Gravel Wetland	♦	♦	♦		♦	♦
	Shallow Wetland	♦	♦	♦		♦	♦
	Extended Detention Shallow Wetland	♦	♦	♦		♦	♦
	Pond/Wetland System	♦	♦	♦		♦	♦

BMP Category	BMP Type	Sediment Forebay	Pretreatment Vegetated Filter Strip	Pretreatment Swale	Deep Sump Hooded Catch Basin (1)	Oil Grit Separator (2)	Proprietary Pretreatment Device (3)
Water Quality Conveyance BMPs	Dry Water Quality Swale	●	●	●	●	●	●
	Wet Water Quality Swale	●	●	●	●	●	●
Stormwater Reuse BMPs	Rain Barrel	Pretreatment Not Required					
	Cistern				●	●	●
Proprietary BMPs	Manufactured Treatment Systems (5)	Pretreatment Not Required					
Other BMPs and BMP Accessories	Green Roof	Pretreatment Not Required					
	Dry Extended Detention Basin	●	●	●		●	●
	Underground Detention (no infiltration)				●	●	●

Notes:

(1) Recommended for use with other Pretreatment BMPs or for space constrained sites where no other Pretreatment BMPs are feasible. Deep sump hooded catch basins can be impractical for use with surface stormwater BMPs (unless adequate grade difference exists between the drainage system and BMP) due to the depth of the catch basin outlet pipe.

(2) Oil grit separators are useful pretreatment practices for runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) that are expected to have high pollutant loads of oil and grease (refer to Chapter 4 - Stormwater Management Standards and Performance Criteria for list of LUHPPLS).

(3) Proprietary pretreatment devices are useful pretreatment practices for runoff from LUHPPLs that are expected to have high pollutant loads of oil and grease, metals, and other targeted pollutants.

(4) Requires pretreatment BMP separate from the infiltrating catch basin itself.

(5) See Chapter 11 - Proprietary Stormwater BMPs for use of proprietary stormwater BMPs as stand-alone treatment.

Legend		
	●	Suitable for use with primary stormwater BMP
		Generally not suitable

Sediment Forebay

Source: MassDEP, https://megamanual.geosyntec.com/npsmanual/sedimentforebays.aspx

Stormwater BMP Type

Pretreatment BMP	■
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	■
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants

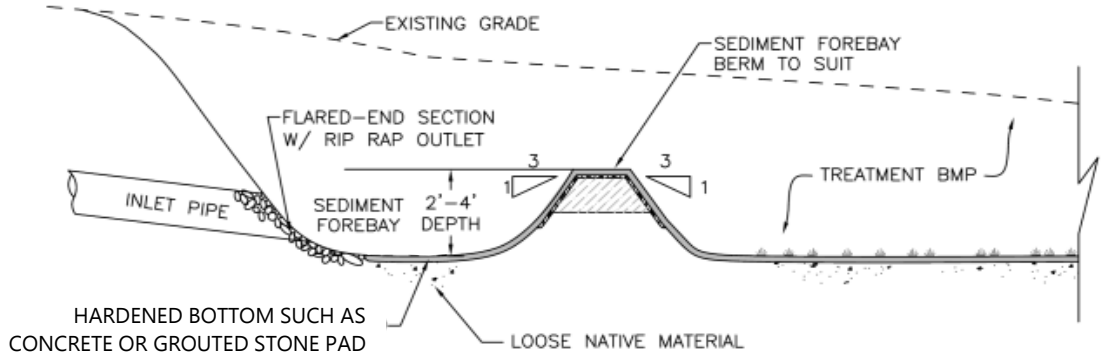
Implementation

Capital Cost	**Low to Moderate**
Maintenance Burden	**Moderate**
Land Requirement	**Moderate to High**

Description

A sediment forebay is a separate cell within or immediately upstream of a structural stormwater BMP designed to capture, temporarily store, and settle coarse sediment and debris from runoff in an accessible area. A sediment forebay is formed by a barrier such as an earthen berm, concrete weir, granite curbing, or stone gabion baskets. Sediment forebays are highly flexible and can be adapted to meet site-specific constraints. The forebay has a non-erosive outlet into the primary stormwater BMP and can be configured as a riser and pipe, overflow weir, or culvert. The elevation of the outlet should be set such that the forebay is sized to temporarily store 10% to 25% of the Water Quality Volume (WQV). Figure 13-1 shows a schematic elevation view of a sediment forebay designed within a stormwater BMP.

Figure 13-1. Sediment Forebay Schematic



Source: Adapted from Rhode Island Stormwater Design and Installation Standards Manual (2015)

Siting Considerations

Sediment forebays should be located at each inflow point into the primary stormwater BMP. There may be multiple inflow points into a single forebay.

Design Recommendations

Sizing and Dimensions

- Inflow Velocity
  - In accordance with Inlet and Outlet Controls section of Chapter 13
- Length/Width
  - Minimum: 1:1 ratio (2:1 or greater preferred)
- Freeboard
  - Minimum: 0.5-foot for off-line BMPs; 1-foot for on-line BMPs
- Bottom Surface Area
  - Use the following equation (Camp-Hazen equation) for sizing the surface area of the bottom of the forebay:

$$A = -\frac{Q}{W}\ln(1 - E) = 0.066 * \%WQV$$

where:

A = minimum required surface area of sediment forebay (square feet)
Q = discharge from drainage area (cubic feet per second)
= $\%WQV$ / 86,400 seconds
$\%WQV$ = percent of the water quality volume required for sediment forebay design (cubic feet)
W = 0.0004 feet per second particle settling velocity for silt
E = sediment removal efficiency (assume 0.9 or 90%)

- Volume
  - Size the sediment forebay to store 10% to 25% of the WQV below the outlet invert unless specified otherwise in the respective BMP design sections of this Manual. The storage volume of the sediment forebay can be included in the overall design storage volume of the main stormwater BMP provided that the sediment forebay drains to the BMP.
  - Do not account for infiltration in the forebay sizing analysis.
  - Ensure adequate depth to prevent resuspension of collected sediments during the design storm with flowthrough velocities not exceeding 2 feet/second for all design storms.

- Side Slope
  - Maximum: 3(H):1(V)

Features

- Forebay Berm
  - Use gabion baskets, concrete or granite curbing, precast or cast-in-place concrete weirs, or earthen berm. Earthen berms should be armored to prevent erosion of the embankment.

- Bottom of Forebay
  - Use a hardened bottom (line with a concrete or grouted stone pad) to make sediment removal easier. Ungrouted stone riprap should not be used within the forebay since it makes removal of accumulated sediment more difficult and costly.
  - If using concrete or a grouted stone pad, provide at least two weep holes (2.5 inches in diameter) for every 25 square feet of surface area in the bottom of the forebay to facilitate low level drainage.

- Stage Indicator/Gage
  - Install a stage indicator/gage to monitor sediment levels.
  - The gage should indicate the level at which the forebay is considered full.

Materials

- Curbing
  - If used, granite or concrete curbing should conform to State of Connecticut Department of Transportation Standard Specifications, Section M.12.06 (Stone Curbing) and Section 8.11 (Concrete Curbing).

- Gabion Basket
  - If used, should conform to ASTM A-974-97 and US Federal Specification QQ-W-461H and coated in accordance with ASTM A641, Finish 5, Class 3.

- Grouted Riprap
  - If used, stone riprap should conform to State of Connecticut Department of Transportation Standard Specifications, Section M.12.02 (Riprap).
  - Grout should be a non-shrink grout having a 4,000 psi 28-day compressive strength and a 2,400 psi 7-day compressive strength in accordance with State of Connecticut Department of Transportation Standard Specifications, Section M.03.05.

- Outlet or Riser Pipe
  - Refer to Inlet and Outlet Controls section of Chapter 13.

- Poured-in-Place Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section 6.01 (Concrete for Structures).

- Precast Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section M.08.02-4 (Precast Concrete).

Maintenance Needs

- Inspect the sediment forebay and measure the depth of accumulated sediment twice a year.

- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.

Pretreatment Vegetated Filter Strip

Stormwater BMP Type

Pretreatment BMP	■
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	■
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**Variable**
Nitrogen	**Variable**
Bacteria	**Low**

*Includes sediment-bound pollutants

Implementation

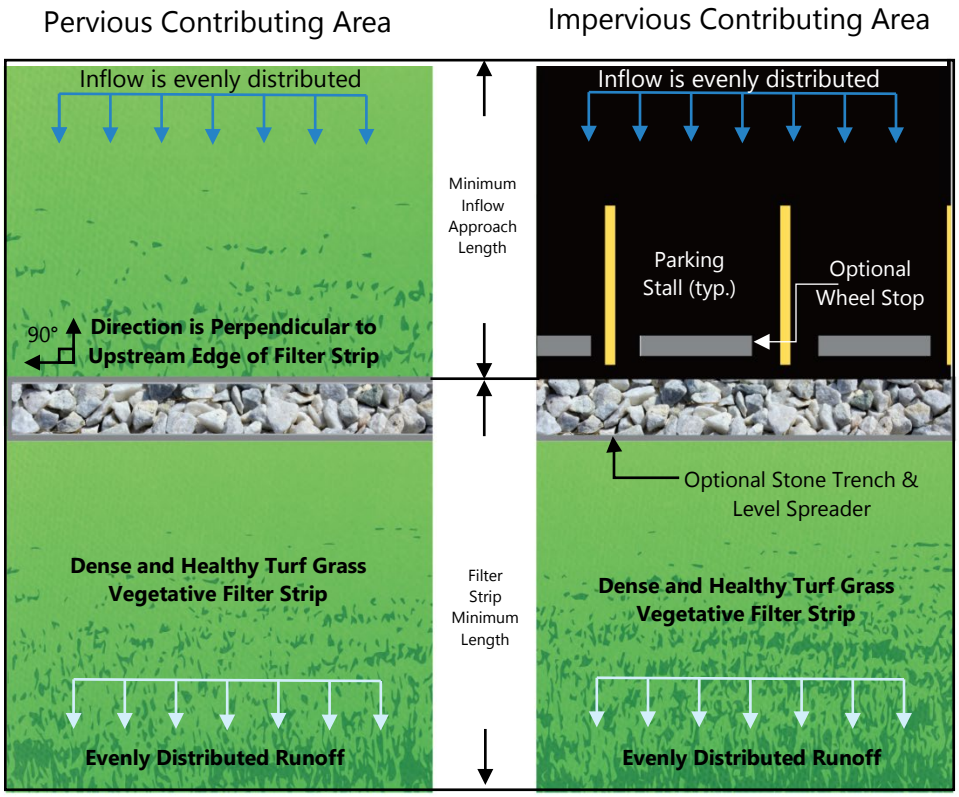
Capital Cost	**Low**
Maintenance Burden	**Low to Moderate**
Land Requirement	**High**

Description

A pretreatment vegetated filter strip is a uniformly graded, vegetated area (i.e., grass or close-growing native vegetation) that is used to treat sheet flow from adjacent pervious and impervious areas prior to entering a structural stormwater BMP. Pretreatment vegetated filter strips reduce runoff velocity and utilize vegetation to filter coarse sediment and debris. Pretreatment vegetated filter strips should span the entire width of the contributing area to ensure treatment of runoff from the entire area and are most effective if they receive uniformly distributed sheet flow. A level spreader is required if the filter strip receives concentrated flow or flow that could become concentrated because concentrated flows reduce the effectiveness of the practice. Figure 13-2 shows a schematic of a vegetated filter strip used for pretreatment of runoff from pervious and impervious areas prior to discharge to a structural stormwater BMP.

Unlike the vegetated pervious areas that are suitable for providing stormwater retention and treatment credit as described in Chapter 5 - Low Impact Development Site Planning and Design Strategies, pretreatment vegetated filter strips are not stand-alone treatment practices due to their relatively small size and should only be used immediately upgradient of another structural stormwater BMP. Pretreatment vegetated filter strips provide relatively limited runoff volume reduction, infiltration, and peak flow reduction.

Figure 13-2. Pretreatment Vegetated Filter Strip Schematic



Source: Adapted from New Jersey Stormwater Best Management Practices Manual (2021)

Siting Considerations

- Applicable to small drainage areas and when trying to manage sheet flow.
- Best located in wide, uniformly sloped areas with ample space and mild slopes between the pollutant source and the downstream stormwater BMP.
- Locate where:
  - Area is not subject to excessive fertilizer application or excessive irrigation.
  - Site conditions promote a dense vegetative growth.
  - Site use and aesthetic considerations allow for infrequent mowing (2-4 times a year).
  - Filter strip slopes between the pollutant source and downstream BMPs are between 2% and 4%.
  - Sheet flow should be maintained across the length and width of the filter strip.
  - There is at least 18 inches of separation to seasonal high groundwater.
  - Contributing watersheds have low sediment and floatable loads.

Design Recommendations

Inlet

- The pretreatment vegetated filter strip should receive evenly distributed sheet flow.
- If runoff directed to a pretreatment vegetated filter strip is concentrated or could become concentrated, design the filter strip to include a level spreader in accordance with the Inlet and Outlet Controls section of Chapter 13.
- The velocity of the sheet flow should be non-erosive (less than 3 feet per second).
- Contributing upstream area should not have a slope in the direction perpendicular to flow that exceeds 2%, and a slope in the direction parallel to flow that exceeds 5%.
- The top of the filter strip (or the level spreader if using a stone-filled trench) should be set 2 inches below the adjacent pavement so that sediment and debris accumulated at the edge of the strip does not prevent runoff from exiting the pavement surface.

Sizing and Dimensions

- Length (direction of flow). Refer to Table 13-4.

Table 13-1. Pretreatment Vegetated Filter Strip Sizing Guidelines

Parameter	Impervious Contributing Area				Pervious Contributing Area			
Maximum Inflow Approach Length (feet)	35		75		75		150	
Filter Strip Slope (%)	<2	2-4	<2	2-4	<2	2-4	<2	2-4
Filter Strip Minimum Length (feet)	10	15	20	25	10	12	15	18

- Width (perpendicular to direction of flow)
  - Set width equal to or greater than the width of the upgradient contributing area.
- Slope
  - Minimum Slope: 2%; slopes less than 2% may result in ponding and other nuisances
  - Maximum Slope: 4%; slopes greater than 4% may results in concentrated flow and erosion
  - Maximum velocity for water quality storm: 1 foot per second
  - Maximum velocity for 10-year, 24-hour design storm: 3 feet per second

- If velocities are greater than the maximum velocities listed above, provide turf reinforcement matting (TRM).
- Slopes may be between 4% and 6% if TRM is provided.

- Vegetation
  - Vegetation should consist of 100% ground cover and be selected with guidance of Appendix F of this Manual based on site-specific conditions.
  - Use non-erosive vegetation that can withstand relatively high velocity flows, and both wet and dry conditions.
  - Some woody vegetation is acceptable. However, to maximize pretreatment effectiveness, most of the area should be grassed. Woody vegetation is more susceptible to re-concentration of flow than turf and other herbaceous species.
  - Manage vegetation to be thick and vigorous. Clumping vegetation should be avoided.

Maintenance Needs

- Regular maintenance is critical for the effectiveness of vegetated filter strips, especially to ensure that concentrated flow does not short-circuit the system. Early detection and maintenance of erosion and/or head cuts is key to long-term performance.

- Inspect the vegetated filter strip and any level spreaders twice a year. Measure the depth of accumulated sediment and inspect the vegetation for erosion, bare spots, and overall health.

- Remove sediment and debris from the filter strip and level spreader, and re-seed bare spots as necessary.

- Regular, frequent mowing of the grass to a height of 3 to 4 inches is recommended.

Pretreatment Swale

Stormwater BMP Type

Pretreatment BMP	■
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	■
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**Variable**
Nitrogen	**Variable**
Bacteria	**Low**

*Includes sediment-bound pollutants

Implementation

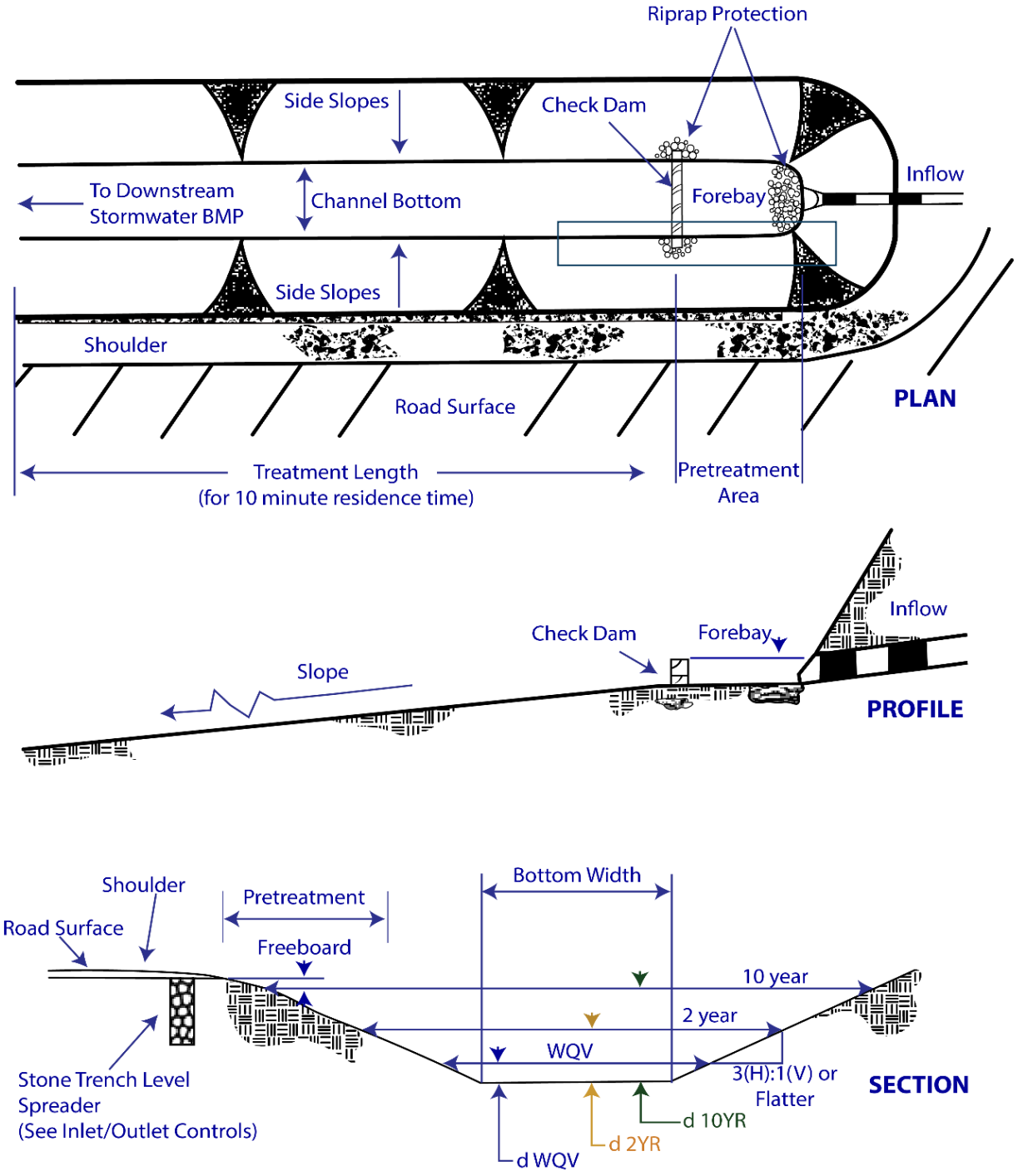
Capital Cost	**Low**
Maintenance Burden	**Low to Moderate**
Land Requirement	**Moderate**

Description

A pretreatment swale is a gradually sloped channel that increases travel time, reduces runoff velocity, and utilizes vegetation to filter coarse sediment and debris from runoff. Pretreatment swales provide both conveyance and pretreatment for downstream stormwater BMPs. Check dams may be utilized to increase pretreatment capacity by temporarily storing runoff, further reducing the runoff velocity in the swale. Pretreatment swales can be incorporated into highway and road drainage systems but can also be used in place of traditional curb and gutter drainage systems. Figure 13-3 shows a schematic of a pretreatment swale used for pretreatment of runoff from an adjacent road surface prior to discharge to a structural stormwater BMP.

Unlike the Water Quality Conveyance BMPs (Wet Water Quality Swale and Dry Water Quality Swale), which are suitable for providing stormwater retention and treatment credit, pretreatment swales are not stand-alone treatment practices due to their limited pollutant removal, runoff volume reduction, and groundwater recharge. Pretreatment swales should only be used upgradient of another structural stormwater BMP.

Figure 13-3. Pretreatment Swale Schematic



Note: Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit. the General Construction Permit and in the supporting materials that CTDOT has developed.

Siting Considerations

- Pretreatment swales can be used as an alternative conveyance mechanism to traditional curb and gutter systems.
- Adequate length to ensure sufficient filtering of runoff.
- Do not use in areas with:
  - Steep grades
  - In watersheds with high sediment loads
  - Unstable upgradient areas
- Should not be used for runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) unless the swales are lined to prevent infiltration.

Design Recommendations

Inlet

- A sediment forebay should be used at the upstream end of the channel to trap incoming coarse sediments and debris. A stone-filled trench level spreader and vegetated filter strip can also be used to pretreat sheet flow runoff that enters the sides of the channel.
- Design the inlet(s) in accordance with the Inlet and Outlet Controls section of Chapter 13.

Sizing and Dimensions

- Cross Section Channel Shape
  - Minimum Bottom Width: 2 feet
  - Shape: Trapezoidal or parabolic; maximize wetted perimeter to the extent possible to increase vegetation contact and reduce velocities
- Side Slope
  - Maximum: 3(H):1(V)
  - For enhanced pollutant removal, design the swale side slopes to serve as vegetated filter strips by accepting sheet flow runoff.
- Length
  - Provide minimum residence time of 10 minutes from inlet to outlet for the water quality storm. Where sheet flow enters the swale, residence time is measured from the mid-point between the upgradient-most part of the swale to the outlet.
- Longitudinal Slope
  - Optimal Range: 1% to 2%
  - Utilize check dams if necessary to ensure adequate residence time for steeper slopes.

- Velocity
  - Maximum velocity for water quality storm: 1 foot per second
  - Maximum velocity for 10-year, 24-hour design storm: 3 feet per second
  - If velocities are greater than the maximum velocities listed above, provide turf reinforcement matting (TRM).

Features

- Topsoil
  - Minimum Depth: 4 inches

- Check Dams
  - Can be installed to increase hydraulic residence time and promote additional infiltration.
  - Can be created using gabion baskets, concrete or granite curbing, or precast or cast-in-place concrete.
  - Maximum Height: 1/2 the height of swale bank
  - Spacing and height of check dams will depend on both the longitudinal slope of the swale and the runoff travel time.
  - Anchor check dams into swale side slopes to prevent washout. Each side of the dam must extend 2-3 feet into the swale side slopes and bottom.
  - Protect downstream side of check dam from scour with stabilized surface measure.
  - When check dams are used near the inlet to control the inlet flow velocity, protect the swale from scour with stabilized surface measure if inlet velocities are greater than 3 feet per second.

- Culverts can be used to maintain swale connectivity where a driveway, walkway, or roadway crosses the swale. The culvert should be sized to pass the 10-year, 24-hour design storm (at a minimum) without causing overtopping.

Materials

- Vegetation
  - Select vegetation with guidance provided in Appendix F of this Manual based on site-specific conditions.
  - Use non-erosive vegetation that can withstand relatively high velocity flows, and both wet and dry conditions.

- Turf Reinforcement Matting
  - If used, shall be a woven material included on the CTDOT Qualified Products List or equivalent that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

- Curbing
  - If used, granite or concrete curbing shall conform to State of Connecticut Department of Transportation Standard Specifications, Section M.12.06 (Stone Curbing) and Section 8.11 (Concrete Curbing).

- Gabion Basket
  - If used, should conform to ASTM A-974-97 and US Federal Specification QQ-W-461H and coated in accordance with ASTM A641, Finish 5, Class 3.

- Poured-in-Place Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section 6.01 (Concrete for Structures).

- Precast Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section M.08.02-4 (Precast Concrete).

- Check Dams
  - If used, construct of gabions, granite or concrete curbing, or poured-in-place or precast concrete.

Maintenance Needs

- Inspect the pretreatment swale and any sediment forebay, check dams, and level spreaders twice a year. Measure the depth of accumulated sediment in the forebay and swale and inspect the vegetation for erosion, bare spots, and overall health.

- Remove sediment from the sediment forebay when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay when drawdown time exceeds 36 hours after the end of a storm event.

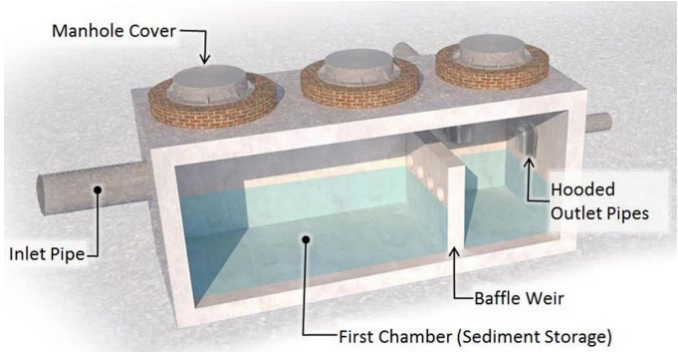
- Remove sediment from the swale and check dams when it accumulates to a depth of more than 50% of the design depth and reconfigure the channel to its original dimensions.

- Remove sediment from any level spreaders, as necessary.

- Mow the vegetation in the swale at least 2 times during the growing season to a height of 4 to 6 inches.

- If the surface of the grass channel becomes clogged to the point that standing water is observed on the surface 48 hours after the end of a storm event, the bottom of the swale should be roto-tilled or cultivated to break up any hard-packed sediment, and then re-seeded.

Oil Grit Separator



Source: University of Illinois at Urbana-Champaign and UNH Stormwater Center (2017), https://railtec.illinois.edu/wp/wp-content/uploads/pdf-archive/14.3.pdf

Stormwater BMP Type

Pretreatment BMP	■
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	■
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables

Implementation

Capital Cost	**Moderate**
Maintenance Burden	**Moderate to High**
Land Requirement	**Low to Moderate**

Description

Oil grit separators are underground, multi-chambered systems designed to remove coarse sediment, debris, and floatables including trash and oil. Oil grit separators are typically designed as off-line systems for pretreatment of runoff from small impervious areas and bypass of larger flows. Due to their limited storage capacity and volume, these systems have only limited water quality treatment and peak flow attenuation capabilities.

Oil grit separators typically consist of multiple baffled chambers (Figure 13-4) and rely on gravity and the physical characteristics of oil and sediments to achieve pollutant removal. In a typical three-chamber system, the first chamber is a sedimentation chamber where floatable debris is trapped and gravity settling of sediments occurs, the second chamber is designed primarily for oil separation, and the third chamber provides additional settling prior to discharging to the storm drain system or downstream treatment practice. Many design modifications exist to enhance system performance including the addition of orifices, inverted elbow pipes, and diffusion structures. A two chambered system, as shown in Figure 13-5, can be used to maximize sediment storage when the outlet pipes, in the second chamber, are fitted with hoods.

Single-chamber wastewater oil/water separators should not be used for stormwater applications because the single-chamber design does not provide sufficient protection against re-suspension of sediment during runoff events.

Proprietary separators and similar devices can be used as pretreatment. These are addressed in the Proprietary Pretreatment Device section of this Manual, as well as in Chapter 11 - Proprietary Stormwater BMPs.

Figure 13-4. Typical Three-Chamber Oil Grit Separator

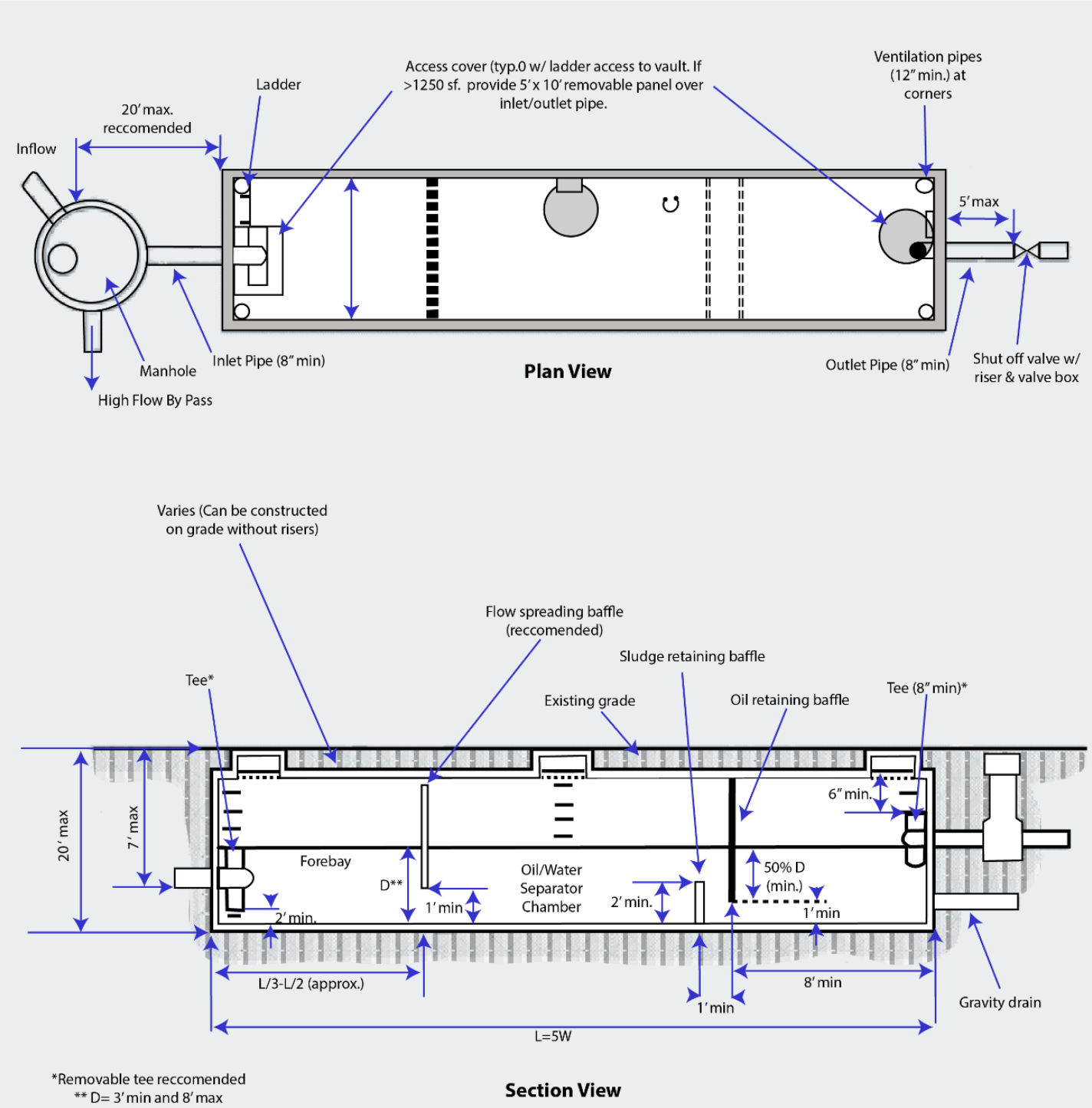
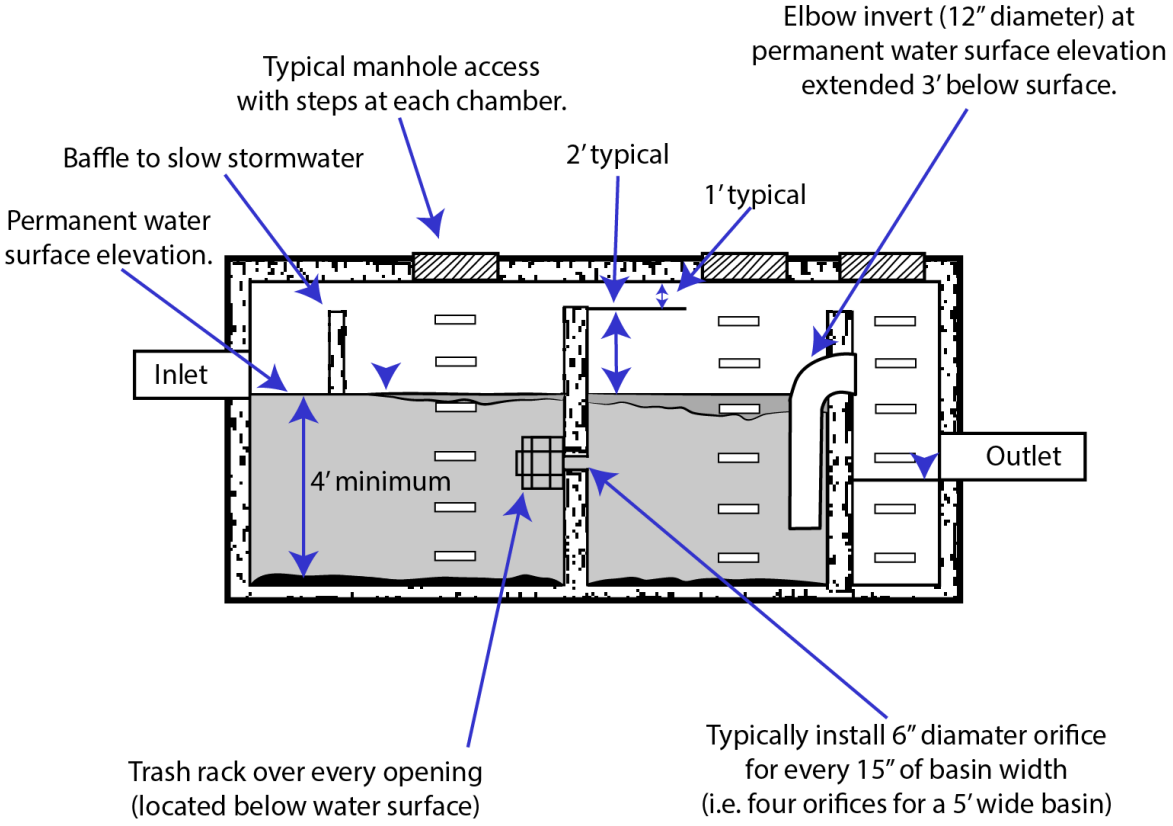


Figure 13-5. Typical Two-Chamber Oil Grit Separator



Siting Considerations

- Contributing drainage area to an oil grit separator generally should not exceed 1 acre of impervious cover.
- Locate where:
  - Land use requirements prohibit use of other pretreatment approaches.
  - Underground features are necessary due to site conditions.
  - Can accept runoff from watersheds with high trash, debris, oil and grease and other floatable loads.
- In areas with high groundwater, buoyancy and anchoring requirements must be considered.
- Siting limitations include:
  - Depth of bedrock
  - Presence of utilities
  - Unstable subsurface conditions that limit depth of excavation.

Design Recommendations

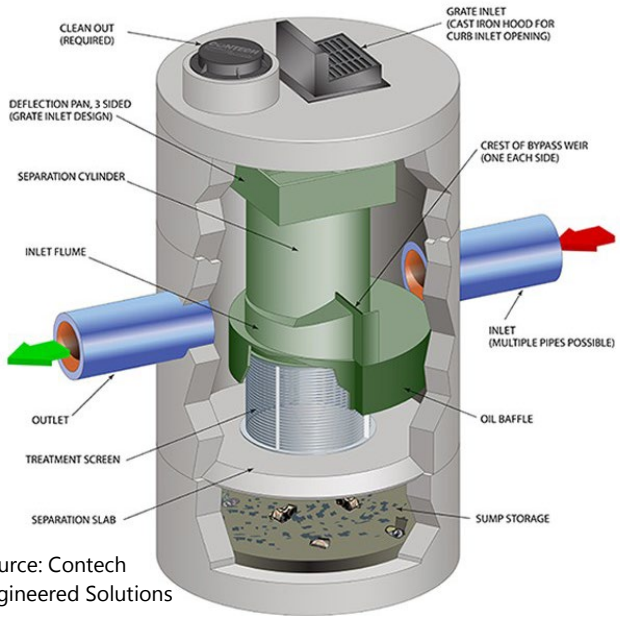
- Separators should only be used in an off-line configuration to treat the Water Quality Flow (peak flow associated with the Water Quality Volume). Design the device to bypass storms greater than the WQF.
- Upstream diversion structures can be used to divert higher flows around the separator. On-line units receive higher flows that cause increased turbulence and resuspension of settled material.
- Oil grit separator tanks can also be designed as flow diversion structures (see Inlet and Outlet Controls section of Chapter 13).
- Make the permanent pool at least 4 feet deep relative to the outlet invert.
- The separator should be fitted with frame and cover to facilitate maintenance access to each chamber.
- The separator should be designed with enough internal vault space to allow access for a vacuum truck suction nozzle without damaging hoods or access ladder steps.

Maintenance Needs

- Oil grit separators should be accessible for maintenance and/or emergency removal of oil or chemical spills.

- Inspect oil grit separators a minimum of 2 times per year – in late Spring after snowmelt and in late Fall after leaf fall and before the first snowfall. Establish a cleaning frequency such that the oil grit separator storage capacity is reduced by no more than 50%.
- 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.

Proprietary Pretreatment Device



Source: Contech Engineered Solutions

Stormwater BMP Type

Pretreatment BMP	■
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	■
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables

Implementation

Capital Cost	**Moderate to High**
Maintenance Burden	**Moderate to High**
Land Requirement	**Low**

Description

Proprietary stormwater 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, as described in this section (Proprietary Pretreatment Device), or as treatment systems in retrofit applications where physical site constraints limit the use of other retention and/or treatment BMPs (refer to Chapter 11 - Proprietary Stormwater BMPs for use of Proprietary BMPs for stand-alone treatment).

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.

Chapter 11 - Proprietary Stormwater BMPs of this Manual further describes the appropriate uses and limitations of proprietary stormwater BMPs, third-party BMP performance verification requirements for proprietary BMPs, and general design criteria and maintenance requirements.

Siting Considerations

- Proprietary pretreatment devices are generally designed to pretreat runoff from relatively small impervious drainage areas. The maximum contributing drainage area to a proprietary

pretreatment device varies depending on the type of device and manufacturer's recommendations.

- Locate where:
  - Land use requirements prohibit use of other pretreatment approaches.
  - Underground features are necessary due to site conditions.
  - Can accept runoff from watersheds with high trash, debris, oil and grease, floatables, and other pollutant loads.
  - In areas with high groundwater, buoyancy and anchoring requirements must be considered.

- Siting limitations include:
  - Depth of bedrock
  - Presence of utilities
  - Unstable subsurface conditions that limit depth of excavation.

Design Recommendations[78]

Proprietary devices should meet all the following criteria to qualify as acceptable for pretreatment applications:

- 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 Chapter 11 - Proprietary Stormwater BMPs 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 is based.

The following are general design criteria for proprietary pretreatment devices, 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.

[78] Per the CTDOT MS4 Permit, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit, the General Construction Permit and in the supporting materials that CTDOT has developed.

- The proprietary device should be designed and installed with the same configuration utilized during the performance verification testing.
- Locate proprietary devices 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 devices 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 devices 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 Needs

- Maintain proprietary devices in accordance with the manufacturer's guidelines.
- Perform inspections of proprietary devices a minimum of once per year. However, 2 times per year – in late Spring after snowmelt and in late Fall after leaf fall and before the first snowfall is recommended to prevent BMP failure.
- 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 devices 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.

Deep Sump Hooded Catch Basin

Source: University of Illinois at Urbana-Champaign and UNH Stormwater Center (2017), https://railtec.illinois.edu/wp/wp-content/uploads/pdf-archive/14.3.pdf

Stormwater BMP Type

Pretreatment BMP	■
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	■
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables

Implementation

Capital Cost	**Low**
Maintenance Burden	**Moderate to High**
Land Requirement	**Low**

Description

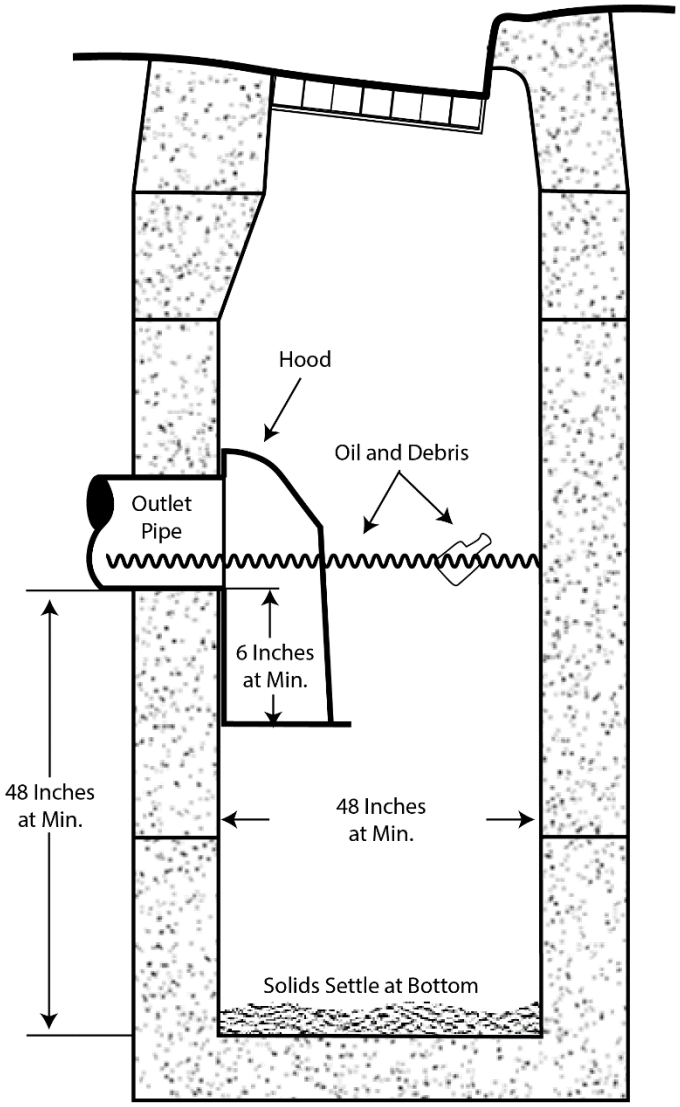
Deep sumps catch basins are storm drain inlets that have a sump below the outlet pipe to capture trash, debris, and coarse sediment. Deep sump catch basins are unique pretreatment BMPS, in that they function very differently and therefore have very different design and maintenance needs than other pretreatment BMPs.

Stormwater runoff enters the catch basin via a grated or curb inlet at the top of the catch basin. The catch basin outlet pipe is located below the inlet and is equipped with a hood (e.g., an inverted pipe). Floatables such as trash and oil and grease are trapped on the permanent pool of water, while coarse sediment settles to the bottom of the catch basin sump. Figure 13-6 shows a schematic of a typical deep sump hooded catch basin.

Deep sump hooded catch basins may be used in conjunction with other Pretreatment BMPs or for space constrained sites where no other Pretreatment BMPs are feasible. Deep sump hooded

catch basins and can be impractical for use with surface stormwater BMPs due to the depth of the catch basin outlet pipe.

Figure 13-6. Typical Deep Sump Hooded Catch Basin



Source: Adapted from https://upstreamtechnologies.us/docs/snout-design.pdf

Siting Considerations

- To be used as pretreatment for other stormwater BMPs or in conjunction with other Pretreatment BMPs. Recommended for space constrained sites where no other Pretreatment BMPs are feasible. Can be impractical for use with surface stormwater BMPs due to the depth of the catch basin outlet pipe.

- Only use deep sump hooded catch basins in an off-line configuration (i.e., catch basin-to-manhole, NOT catch basin-to-catch basin) to minimize re-suspension of sediment. On-line configurations (catch basin-to-catch basin) cannot be counted as pretreatment.
- Contributing drainage area to a single deep sump catch basin should not exceed 0.25 acres.
- Locate where:
  - Land use requirements prohibit use of other pretreatment approaches.
  - Underground features are necessary due to site conditions.
  - Can accept runoff from watersheds with high trash, debris, oil and grease and other floatable loads.
    - In areas with high groundwater, buoyancy and anchoring requirements must be considered.
- Siting limitations include:
  - Depth of bedrock
  - Presence of utilities
  - Unstable subsurface conditions that limit depth of excavation.

Design Recommendations

Sizing and Dimensions

- Inlet grate should be sized based on the contributing drainage area to ensure that the flow rate does not exceed the capacity of the grate. The grate should not allow flow rates greater than 3 cubic feet per second for the 10-year, 24-hour storm event.
- The sump depth (distance from the bottom of the lowest outlet pipe to the floor of the sump) should be a minimum of 48 inches.
- All outlet pipes in the catch basin that discharge to a stormwater BMP should be equipped with hoods (e.g., inverted elbow pipe, pre-manufactured PVC hood). The bottom of the hood opening should extend a minimum of 6 inches below the invert of the outlet pipe. Hooded outlets may be impractical for outlet pipes larger than 24 inches in diameter.
- Use catch basin hoods that reduce or eliminate siphoning.
- Catch basins should be watertight to maintain a permanent pool of water and provide higher floatable capture efficiency.

Maintenance Needs

- Inspect catch basins twice per year – in late Spring after snowmelt and in late Fall after leaf fall and before the first snowfall. Establish a catch basin cleaning frequency such that the catch basin is no more than 50% full.

- Clean more frequently catch basins with known heavier sediment and debris loads, sensitive waterbodies, drainage problems, flat grades, etc.

- Cleaning should include:
  - Removal of sediment from catch basin sump
  - Removal of floatables and hydrocarbons from the water surface inside the catch basin
  - Removal of trash and debris from catch basin grate.

- 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.

Infiltration Trench

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	■
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation*	■

*On-line systems only

Pollutant Removal

Sediment*	**High**
Phosphorus	**High**
Nitrogen	**Low**
Bacteria	**High**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Low**
Maintenance Burden	**Low**
Land Requirement	**Medium**

Description

Infiltration trenches are shallow, excavated, stone-filled trenches in which stormwater is collected and infiltrated into the ground. Infiltration trenches can be constructed at a ground surface depression to intercept overland flow. This BMP can also receive piped runoff discharged directly into the trench such that the trench is designed to distribute the flow from a point discharge in a manner that does not result in erosion. Runoff gradually percolates through the bottom and sides of the trench, removing pollutants through sorption, trapping, straining, and bacterial degradation, or transformation. Infiltration trenches may also be used to provide stormwater quantity control when designed as on-line facilities.

Infiltration trenches are a cost-effective approach to managing stormwater where there is adequate space for a narrow stormwater feature and where plantings are not needed, and the surface of the trench can be left open. They require less space than infiltration basins as they utilize the void spaces of the stone in the trench to temporarily store water.

Advantages

- Cost-effective approach to recharge stormwater.
- Requires less surface area than infiltration basins.
- Ideal for linear applications such as along sidewalks, medians, roadways, and bicycle paths.

- High solids, phosphorus, and bacteria removal efficiency. While not high removal efficiency Nitrogen reduction can be enhanced with careful design, typical removal efficiencies range between 10-55%.[79]
- Can provide stormwater retention, runoff volume reduction, groundwater recharge, and some peak runoff attenuation when designed as an on-line system.
- Surface of trench can be vegetated (with grass or plants) to provide landscaped features.

Limitations

- Pretreatment options are limited and should not be used in locations with the potential for high sediment loads.
- System clogging would require replacement of the trench.
- Low removal of dissolved pollutants especially in coarse soils.
- Should not be used with underdrain systems.

Siting Considerations

- **Potential Locations:** Best located parallel to linear features such as roads, sidewalks, and bicycle paths where runoff from a limited impervious surface can sheet flow onto the surface of the trench after being pretreated by a vegetative filter strip between the trench and impervious surface. Can be designed to receive point-source discharges to prevent erosion in the trench and distribute stormwater across the trench.

- **Drainage Area:** The maximum contributing drainage area for infiltration trenches is 5 acres.

- **General:** Meet the soils, water table, bedrock, and horizontal setback requirements specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems(General Design Guidance for Stormwater Infiltration Systems). Infiltration trenches can be designed as on-line or off-line practices.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation guidance.

[79] https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/vol2-appB.pdf

Design Recommendations

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the infiltration trench in accordance with the Pretreatment BMPs section of this Manual.
- Acceptable pretreatment measures include vegetative filter strips, sediment forebays, pretreatment swales, deep sump hooded catch basins,[80] oil grit separators, and proprietary pretreatment devices.
- Sediment forebays should have a minimum storage volume of 25% of the Water Quality Volume (WQV), while flow-through Pretreatment BMPs should treat at least the equivalent Water Quality Flow (WQF). A minimum sediment forebay storage volume of 10% of the WQV may be used in urban settings, space constrained sites, and as retrofits, with the approval of the review authority.

Sizing and Dimensions

- Trench should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Trench should completely drain in 48 hours or less after the end of the design storm as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Trench depth may be limited by the requirement to maintain adequate separation to groundwater and bedrock as specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Ponding Depth
    - Maximum for required water quality storm: 12 inches
    - Maximum for overflow events: 36 inches
- Bottom and Top Slope
    - Slope of the bottom of the trench should be level. Slope of the top of the trench should not exceed 0.5%.
- Side Slopes
    - Side slopes above the trench should be 3(H):1(V) or flatter especially on grassed slopes where mowing is required.
    - In ultra-urban locations or space constrained areas; side slopes of 2(H):1(V) may be utilized if properly designed to account for erosion and slope stability.

[80] Only recommended for space constrained sites where no other Pretreatment BMPs are feasible.

Stabilize the slope with turf reinforcement matting or equivalent if the slope could potentially erode.
    - If site topography does not allow for 3(H):1(V) slopes or adequately stabilized 2(H):1(V) slopes, vertical concrete walls with a maximum height of 30 inches can be used. Drop curbs or similar precast structures can also be used to create stable, vertical side walls.
    - The excavated side walls of the trench ideally should be vertical to maximize storage and infiltration capacity.

- Ensure adequate vehicle access to the entire length of the trench and pretreatment practices in order to allow trench media to be replaced if needed.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Runoff can be introduced through overland flow, curb cuts, inlet structures, swales/channels, and/or pipes.

- Design in an off-line configuration to the extent feasible if runoff is delivered by a storm drainpipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Outlets are typically a stabilized spillway, gabion berm, concrete weir, curb cut opening, precast concrete structure, or polyethylene/polyvinyl chloride riser structure.

- On-line systems should have a primary outlet sized to convey the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event (assuming the primary outlet is not designed to pass the 100-year storm event).

- Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm.

Materials

- Crushed Stone Storage Media
    - The trench should be filled with clean (washed and free from dirt and debris), crushed, angular aggregate with a diameter of 1.5" to 3" (porosity of 40 percent).
    - The sides and top of the trench should be lined with a non-woven geotextile (filter fabric).

- Observation Well
  - An observation well should be installed along the trench centerline to monitor the water drainage in the system. The well should consist of a well-anchored, vertical perforated 4- to 6-inch diameter PVC pipe with a lockable aboveground cap. Install one observation well per 50 feet of length.

- Surface Cover
  - Should consist of a minimum 3-inch-thick layer of pea gravel to suppress weed growth and improve sediment filtering in the top of the trench.
  - Pea gravel should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.
  - 4 to 6 inches of loam/topsoil and grass can also be used as an alternative surface cover for the surface of the trench. Select vegetation in accordance with Appendix F of this Manual.

- Filter Fabric
  - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

Winter Operations

- Infiltration trenches should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the infiltration trench and scarification of bottom and sidewalls of excavation
  - After installation of observation well
  - After placement and leveling of stone storage media
  - After installation of bypass, outlet/overflow, and inlet controls
  - After pea gravel or loam/topsoil and grass surface cover have been installed

- The designing qualified professional should provide an as-built plan of the completed infiltration trench along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- Infiltration trenches should not be used as temporary sediment traps for construction erosion and sediment control.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.
- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The infiltration trench should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. A hydraulic excavator or backhoe loader, operating outside the limits of the infiltration trench, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.
- The stone storage media and pea gravel layer should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the infiltration trench and then hand-raked to the desired elevation.
- Install vegetation (e.g., drought tolerant grass) on the side slopes and surface of the infiltration trench (if grass is used instead of pea gravel) in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.

Maintenance Needs

- Infiltration trenches should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.

- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the filter media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect the sediment forebay or other pretreatment area twice a year.
- Inspect the remainder of the infiltration trench annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.
- Remove sediment from the infiltration trench surface when the sediment accumulation exceeds 2 inches or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the system is clogged.
- Weed as necessary. Mow grass within infiltration trench to a height of 4 to 6 inches. Maintain a healthy, vigorous stand of grass cover; re-seed as necessary.
- Maintain vegetated filter strips or grassed side slopes of infiltration trench in accordance with maintenance recommendations in the Pretreatment BMPs section of this Manual.
- Periodically remove grass clippings to prevent clogging of the surface of the infiltration trench.
- Mowing should not be performed when the ground is soft to avoid the creation of ruts and compaction, which can reduce infiltration.

Figure 13-7. Infiltration Trench Schematic 1

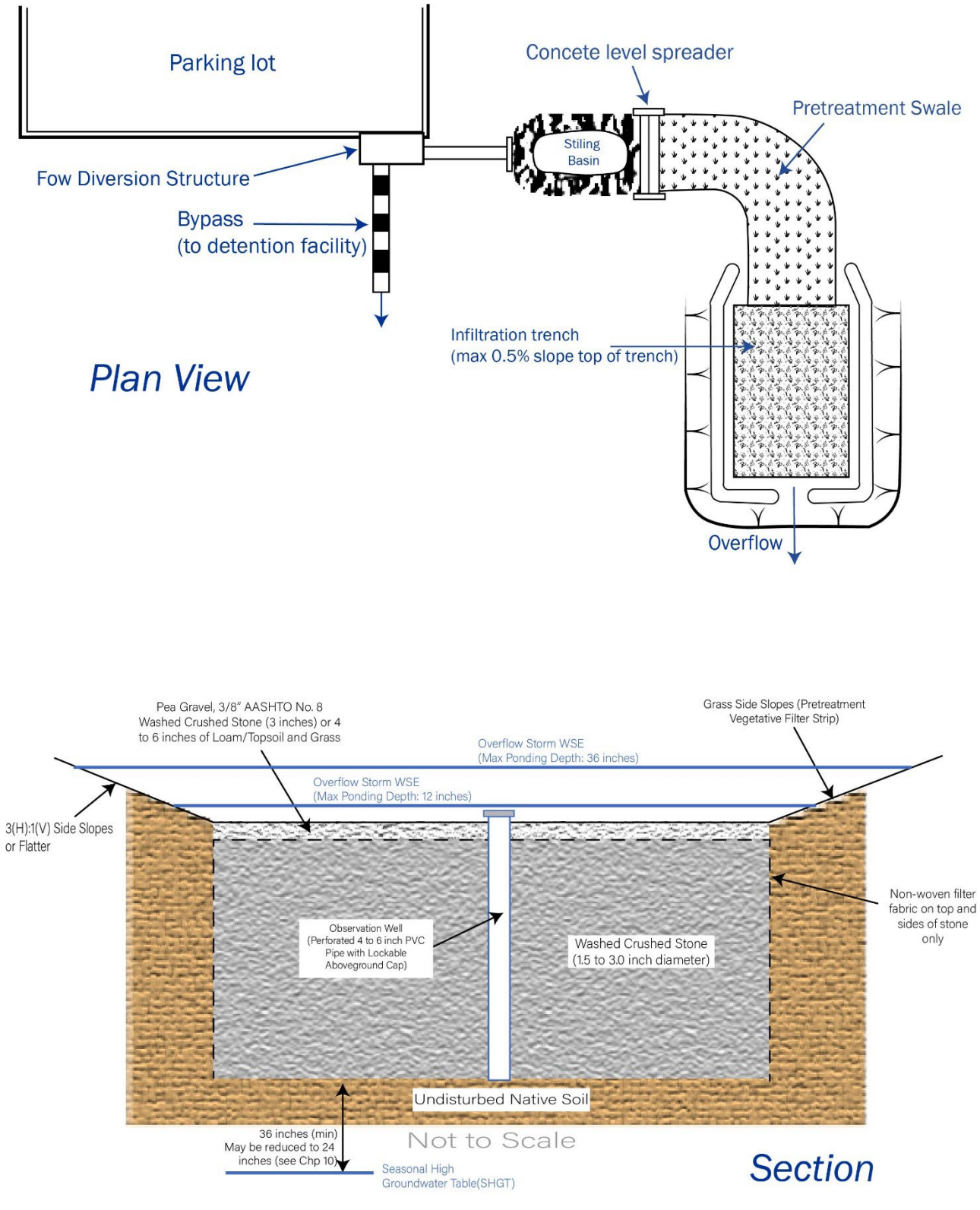


Figure 13-8. Infiltration Trench Schematic 2

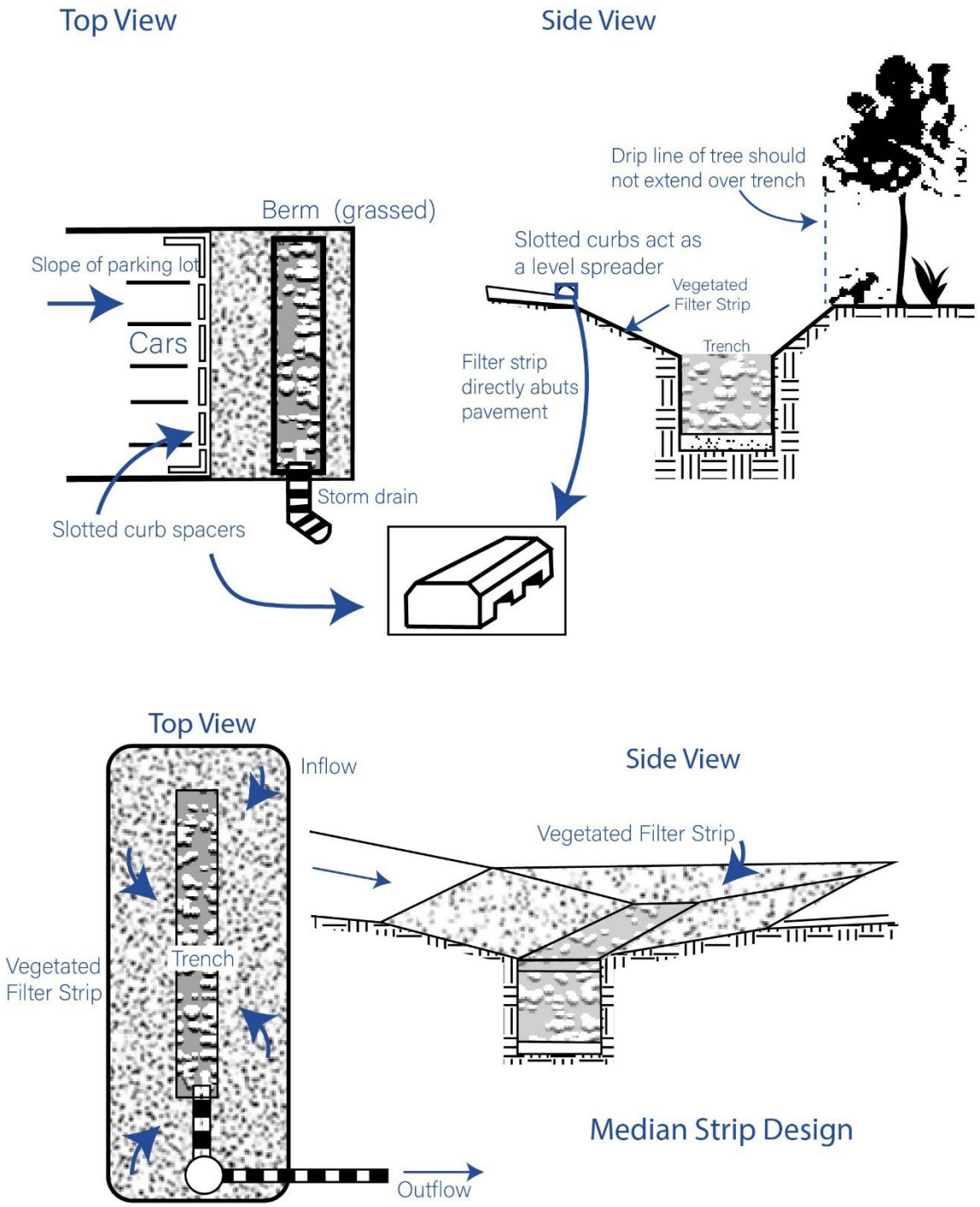
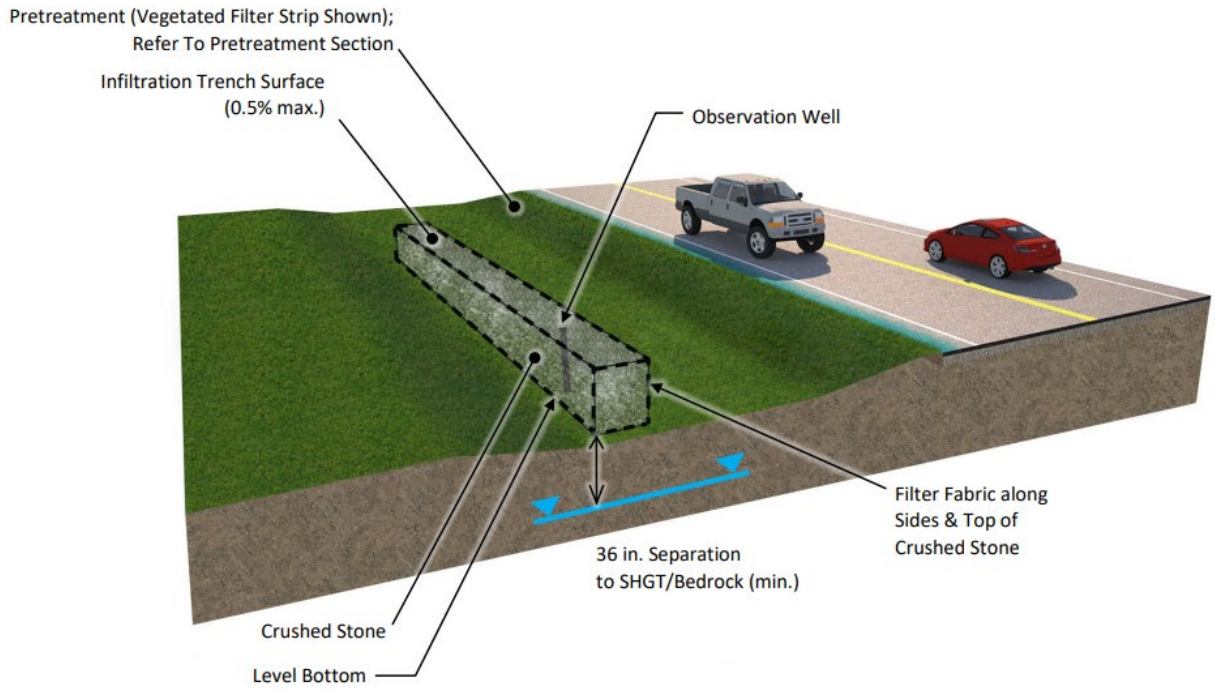


Figure 13-9. Infiltration Trench Schematic - Near Road



Source: Rhode Island Department of Transportation Linear Stormwater Manual, RIDOT (2019)

Underground Infiltration System

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	■
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation*	■

*Soils with high infiltration rates or when designed with additional storage

Pollutant Removal

Sediment*	**High**
Phosphorus	**High**
Nitrogen	**Low**
Bacteria	**High**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**High**
Maintenance Burden	**Medium**
Land Requirement	**Medium**

Description

An underground infiltration system consists of open-bottomed storage chambers in a crushed stone reservoir. The chamber and crushed stone reservoir provide temporary storage for stormwater before it infiltrates into the underlying soil. A number of underground infiltration chamber products, including pipes, vaults, and modular structures, have been developed as alternatives to infiltration trenches and basins for space-limited sites and stormwater retrofit applications. Similar to traditional infiltration trenches and basins, these systems are designed to capture, temporarily store, and infiltrate stormwater runoff. Underground infiltration systems are typically designed as off-line systems for retention/runoff reduction, treatment, and groundwater recharge. These systems can provide stormwater quantity control for larger storms when used in soils with high infiltration rates or when designed with additional below-ground storage. The design and layout of these systems varies by manufacturer and system design.

While underground infiltration systems are more costly than other Infiltration BMPs that are located at the surface, they can be an effective approach to manage stormwater where there is little or no space on the surface.

Advantages

- Allows stormwater to be recharged on sites where there is little space available at the ground surface. Can be located under pavement.

- Suitable in both urban and rural settings.
- Suitable for piped drainage systems.
- Can be used to enhance storage and recharge capability of other BMPs.
- High solids, phosphorus, and bacteria removal efficiency.
- Can provide stormwater retention, runoff volume reduction, and groundwater recharge.
- Can also provide stormwater quantity control for larger storms when used in soils with high infiltration rates or when designed with additional below-ground storage.

Limitations

- Infiltration surfaces are buried, often under paved surfaces. Failed systems require excavating and replacing the system as well as repairing at-grade improvements built over the system. As a result, pretreatment is more critical for underground systems.
- Routine maintenance can be overlooked because the practice is not readily visible.
- Buried utilities can also be a substantial conflict to constructing these systems. While these systems can be constructed in a road right-of-way, utility conflicts can be a challenge in those spaces.
- Typically requires a piped drainage system to divert runoff into the buried chambers.
- Lower removal of dissolved pollutants especially in coarse soils.
- Should not be used with underdrain systems.

Siting Considerations

- **Potential Locations:** Best located where there is inadequate surface area for more cost-effective approaches to infiltrate stormwater. Suitable under parking lots, roads, sidewalks, and other at-grade, built features. Can also be placed under landscaped areas. Surfaces above the system may need to be excavated in the future in the case of a failed system, and thereby need to be replaceable. Therefore, infiltration chambers should not be used under structures.[81]
- **Drainage Area:** The maximum contributing drainage area for underground infiltration systems is 5 acres.

[81] Note: Infiltration systems below CT DOT roads are not permitted. Infiltration systems adjacent to CTDOT roads shall be directed exfiltration away from pavements base, subbase and subgrade. An impermeable barrier may be required.

- **Maintenance Considerations:** Ensure adequate vehicle access to pretreatment elements for the system as well as to inspection ports and manholes. Any at-grade improvements constructed above the systems should be replaceable in case of the need to replace the system if it fails.

- **General:** Meet the soils, water table, bedrock, and horizontal setback requirements specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems. Infiltration chambers can be designed as on-line or off-line practices.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 for soil evaluation guidance.

Design Recommendations

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the infiltration system in accordance with the Pretreatment BMPs section of this Manual.

- Acceptable pretreatment measures are those that are suitable for piped drainage systems and include deep sump hooded catch basins,[82] oil grit separators, and proprietary pretreatment devices.

- Pretreatment measure(s) should treat at least the Water Quality Flow (WQF).

Sizing and Dimensions

- Infiltration systems should be designed by either the Static or Dynamic Methods as described in Chapter 10, including design guidance of the product manufacturer.

- Water Surface
    - Water surface elevations in the system should be designed to avoid flooding the subbase of the overlying paved surfaces.

- Bottom Slope
    - Bottom slope of the system should be level.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

[82] Only recommended for space constrained sites where no other Pretreatment BMPs are feasible.

- Runoff is typically introduced into the system through a piped drainage system.
- Design in an off-line configuration, to the extent feasible, to bypass flows in excess of the water quality storm or larger storms if designed to provide stormwater quantity control.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.
- Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm and typically do not require an outlet. Once the system has reached its capacity (i.e., once the system is full), additional flow will bypass the system via a flow diversion structure.
- Underground infiltration systems designed in an on-line configuration should have a primary outlet sized to convey the 10-year, 24-hour storm event, at a minimum, to the storm drainage system.
- Outlets are typically a closed conduit/pipe that discharges to a storm drainage system.

Materials

- Underground Infiltration Chambers
  - As available from the manufacturer. Appurtenant structures (e.g., end caps, cross connectors, observation wells, etc.) should be from or approved for use by the chamber manufacturer.
  - Designer should comply with manufacturer's written specifications, details, installation instructions, and other guidance documents.
- Crushed Stone
  - The chambers should be underlain and backfilled with clean (washed and free from dirt and debris), crushed, angular aggregate with a diameter of 1.5" to 3" (porosity of 40 percent), or as specified by the manufacturer.
  - The top and sides of the stone reservoir surrounding the chambers should be lined with a non-woven geotextile (filter fabric). The non-woven geotextile should be compatible with the soil textures and application.
- Inspection Ports or Manholes
  - Inspection ports or inspection manholes should be provided along the infiltration chambers to monitor the water drainage in the system and to allow for sediment removal. The number and locations of observation ports or manholes should be in accordance with the manufacturer's recommendations.
- Filter Fabric

- Wrap around the exterior sides and top of the crushed stone only. Do not provide filter fabric on the bottom of the crushed stone unless recommended by the manufacturer of the underground infiltration system.
- Install fabric (including overlap) as specified by the manufacturer.
- Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional r should inspect the installation during the following stages of construction, at a minimum:
  - After excavation and scarification of bottom and sidewalls of excavation
  - After placement and leveling of stone below the chambers, placement of the chambers and inspection ports/manholes, and placement of stone above the chambers
  - After installation of bypass, outlet/overflow, and inlet controls
  - After infiltration system has been backfilled

- The designing qualified professional should provide an as-built plan of the completed infiltration system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans and manufacturer's guidelines.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.

- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.

- The system should be fenced off during the construction period to prevent disturbance of the soils.

- The infiltration system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. A hydraulic excavator or backhoe loader, operating outside the limits of the

infiltration system, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.

- The stone storage media should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the infiltration system and then hand-raked to the desired elevation.

Maintenance Needs

- Underground infiltration systems should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintain infiltration chambers in accordance with the manufacturer's guidelines.
- Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment from the pretreatment structure using a vacuum truck and removal of accumulated sediment from the infiltration chambers using a high-pressure water nozzle (i.e., JetVac process) and vacuum truck.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect the pretreatment structure and isolator row (if one is used) twice a year.
- Inspect the remainder of the infiltration system annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove sediment from the pretreatment structure when it accumulates to more than 50% of the design depth.
- Remove sediment from the infiltration chambers when the sediment accumulation exceeds 2 inches throughout the length of the chamber or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the system is clogged.

Infiltration Basin

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	■
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation*	■

*On-line systems only

Pollutant Removal

Sediment*	**High**
Phosphorus	**High**
Nitrogen	**Low**
Bacteria	**High**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Low**
Maintenance Burden	**Low**
Land Requirement	**Medium**

Description

Infiltration basins are open stormwater impoundments designed to capture and infiltrate the stormwater over several days but do not retain a permanent pool of water. The bottom of an infiltration basin typically contains vegetation to increase the infiltration capacity of the basin, allow for vegetative uptake, and reduce soil erosion and scouring of the basin. This BMP can receive both sheet flow and piped runoff discharged directly into the basin. Runoff gradually infiltrates into the underlying soil through the bottom of the basin, removing pollutants through sorption, trapping, straining, and bacterial degradation, or transformation. Infiltration basins may also be used to provide stormwater quantity control when designed as on-line facilities.

Infiltration basins are a cost-effective approach to managing stormwater where there is adequate space. Water is stored above the bottom of the basin rather than in subsurface storage media, which is more cost-effective than other infiltration approaches.

Advantages

- Cost-effective approach to recharge stormwater as it does not require subsurface storage media and stormwater can be temporarily stored aboveground.
- Naturally can take advantage of topographic low areas.
- High solids, phosphorus, and bacteria removal efficiency.
- Can provide stormwater retention, runoff volume reduction, groundwater recharge, and some peak runoff attenuation when designed as an on-line system

Limitations

- Require adequate space to store stormwater aboveground. Difficult to site in urban and fully developed locations.
- System clogging would require replacement of basin surface.
- Lower removal of dissolved pollutants especially in coarse soils.
- Should not be used with underdrain systems.

Siting Considerations

- **Potential Locations:** Best located where there is adequate surface area to temporarily store stormwater. Infiltration basins are suitable in urban and rural settings, but require adequate space, which makes their use limited in urban areas. Locate where:
  - The topography allows the design of the infiltration basin bottom to be level
  - Snow storage will not occur atop the basin
  - There is a low likelihood that pedestrian traffic will cut across the basin.

- **Drainage Area:** The maximum contributing drainage area for infiltration basins is 10 acres.

- **General:** Meet the soils, water table, bedrock, and horizontal setback requirements specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems. Infiltration basins can be designed as on-line or off-line practices.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation guidance.

Design Recommendations

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the infiltration basin in accordance with the Pretreatment BMPs section of this Manual.

- Acceptable pretreatment measures include vegetative filter strips, sediment forebays, pretreatment swales, deep sump hooded catch basins,[83] oil grit separators, and proprietary pretreatment devices.

- Sediment forebays should have a minimum storage volume of 25% of the Water Quality Volume (WQV), while flow-through Pretreatment BMPs should treat at least the equivalent Water Quality Flow (WQF). A minimum sediment forebay storage volume of 10% of the

[83] Only recommended for space constrained sites where no other Pretreatment BMPs are feasible.

WQV may be used in urban settings, space constrained sites, and as retrofits, with the approval of the review authority.

Sizing and Dimensions

- Basin Surface Area
  - Basin should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
  - Basin should completely drain in 48 hours or less after the end of the design storm as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- Ponding Depth
  - Maximum depth of water above the basin bottom: 36 inches

- Bottom Slope
  - Bottom slope of the basin should be level.

- Side Slopes
  - Side slopes should be 3(H):1(V) or flatter especially on grassed slopes where mowing is required.
  - In ultra-urban locations or space constrained areas; side slopes of 2(H):1(V) may be utilized if properly designed to account for erosion and slope stability. Stabilize the slope with turf reinforcement matting or equivalent if the slope could potentially erode.
  - If site topography does not allow for 3(H):1(V) slopes or adequately stabilized 2(H):1(V) slopes, vertical concrete walls with a maximum height of 30 inches can be used. Drop curbs or similar precast structures can also be used to create stable, vertical side walls.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Runoff can be introduced through overland flow, curb cuts, inlet structures, swales/channels, and/or pipes.

- Design in an off-line configuration to the extent feasible if runoff is delivered by a storm drainpipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Outlets are typically a stabilized spillway, gabion berm, concrete weir, curb cut opening, precast concrete structure, or polyethylene/polyvinyl chloride riser structure.

- On-line systems should have a primary outlet sized to convey the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event (assuming the primary outlet is not designed to pass the 100-year storm event).

- Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm.

Materials

- Surface Cover
    - Should use 4 to 6 inches of loam/topsoil and seed to establish stabilized permanent vegetative cover as desired for the site and application. Select vegetation with the guidance provided in Appendix F of this Manual.
    - Alternatively, the bottom of the basin can be landscaped utilizing plant materials suitable for the site and application. Select plants with the guidance provided in Appendix F of this Manual.
    - Mulch can be 2 to 4 inches of shredded hardwood bark mulch, aged for 6 month or 3 inches of 3/8" to ¾" size pea gravel conforming to AASHTO No. 8 or No. 5 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape. Mulch may be used directly around the plants, but mulch should NOT be used to cover the entire bottom of the infiltration basin.
    - Do not plant any woody vegetation (e.g., shrubs and trees) on embankments that are used to retain water in the basin. Those embankments should be stabilized with a grass cover.

Winter Operations

- Infiltration basins should not be used for storage of plowed snow. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
    - After excavation of the infiltration basin and scarification of bottom and side slopes of excavation
    - After installation of bypass, outlet/overflow, and inlet controls
    - After pea gravel or loam/topsoil and grass surface cover have been installed

- The designing qualified professional should provide an as-built plan of the completed infiltration basin along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- Infiltration basins should not be used as temporary sediment traps for construction erosion and sediment control.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.
- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The infiltration basin should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. A hydraulic excavator or backhoe loader, operating outside the limits of the infiltration basin, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.
- The pea gravel layer (if used) should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the infiltration basin and then hand-raked to the desired elevation.
- Install vegetation (e.g., drought tolerant grass) on the side slopes and surface of the infiltration basin (if grass is used instead of pea gravel) in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.

Maintenance Needs

- Infiltration basins should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.

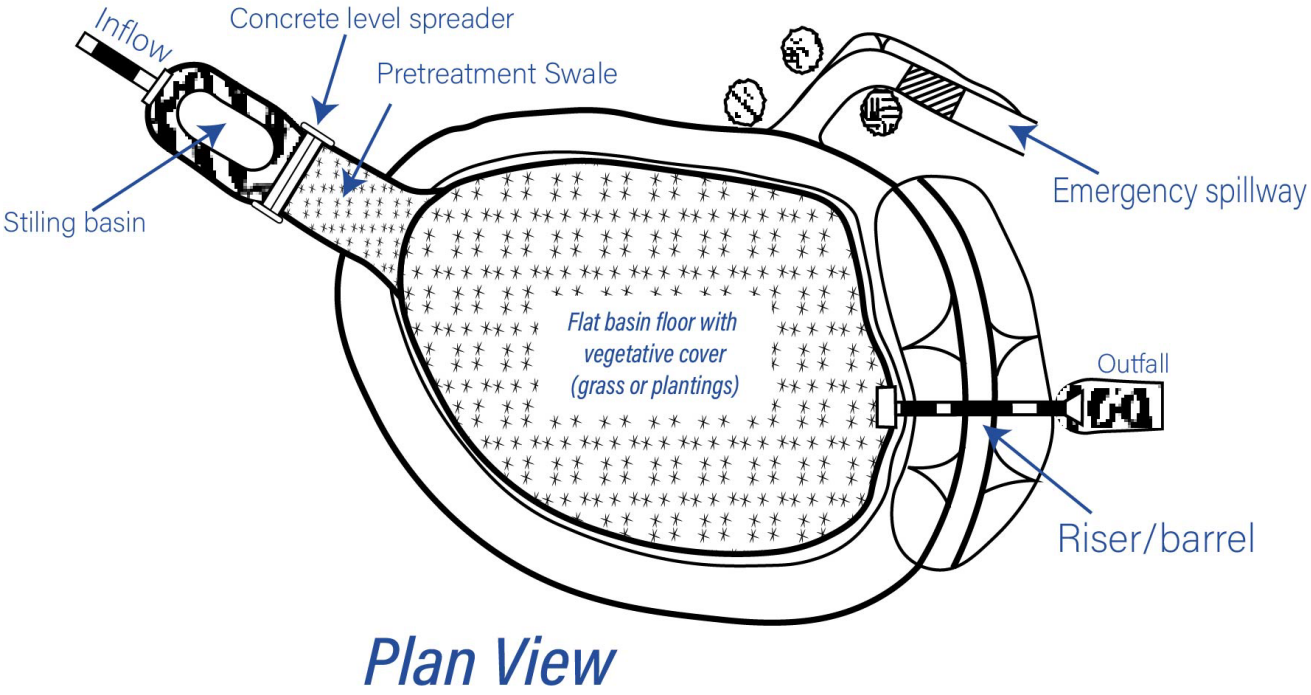
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Site Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the filter media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

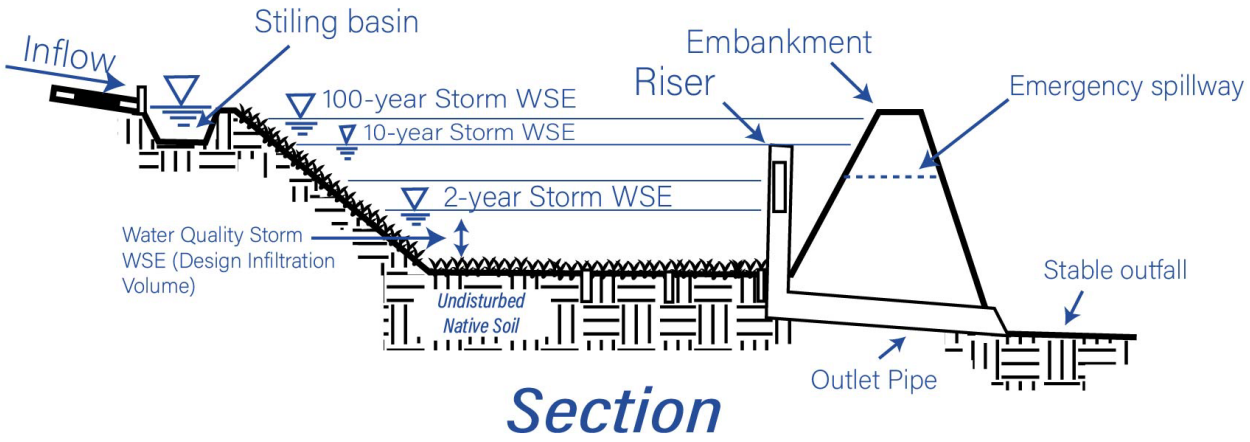
Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect the sediment forebay or other pretreatment area twice a year.
- Inspect the remainder of the infiltration basin annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.
- Remove sediment from the infiltration basin surface when the sediment accumulation exceeds 2 inches or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the system is clogged.
- Weed as necessary. Mow grass within infiltration basin to a height of 3 to 6 inches. Maintain a healthy, vigorous stand of grass cover; re-seed as necessary.
- Maintain vegetated filter strips or grassed side slopes of infiltration basin in accordance with maintenance recommendations in the Pretreatment BMPs section of this Manual.
- Periodically remove grass clippings to prevent clogging of the surface of the infiltration basin.

Mowing should not be performed when the ground is soft to avoid the creation of ruts and compaction, which can reduce infiltration.

Figure 13-10. Infiltration Basin Schematic





Dry Well & Infiltrating Catch Basin

Source: Eastern CT Conservation District, nianticriverwatershed.org

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	■
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	□

Pollutant Removal

Sediment*	**High**
Phosphorus	**High**
Nitrogen	**Low**
Bacteria	**High**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**Low**

Description

Dry wells and infiltrating catch basins are open-bottom subsurface storage structures and/or stone reservoirs designed to infiltrate stormwater in a small footprint. While the general design is consistent between the two applications, a dry well is used to manage clean, roof runoff and thereby does not require pretreatment. An infiltrating catch basin is used to manage stormwater from other sources such as roads and parking lots and thereby requires pretreatment.

Dry wells and infiltrating catch basins can both be designed as perforated precast concrete structures surrounded by crushed stone. The perforated structure that makes up the system temporarily stores stormwater before it infiltrates into the surrounding soils. Dry wells can also consist of an excavated stone-filled pit. Filter fabric is used along the sidewalls of both dry wells and infiltrating catch basins. Both types of systems should be designed as off-line practices for retention/runoff reduction, treatment, and groundwater recharge of stormwater runoff from the water quality storm.

These systems are typically more costly than other infiltration BMPs that are located at the surface. Infiltrating catch basins require a separate pretreatment structure such as a proprietary BMP or separate deep sump hooded catch basins. Their advantage is that they are buried, and their footprint is small compared to infiltration chambers. As a result, these practices are ideal when space is limited and only small, discrete controls can fit into a site.

and Figure 13-12 are schematics of two typical dry well designs, one using a stone-filled pit and the other a perforated precast concrete structure. Figure 13-13 and Figure 13-14 show schematics of two different infiltrating catch basin designs, including a perforated precast concrete structure and a vertical corrugated perforated pipe.

Advantages

- Allows stormwater to be recharged on sites where there is little space available at the ground surface and below grade because of utility conflicts. Can be located under pavement. As a result, useful in stormwater retrofit applications where space is limited and where additional runoff control is required.
- Suitable in both urban and rural settings.
- Suitable for piped drainage systems.
- Can be used to enhance storage and recharge capability of other BMPs.
- High solids, phosphorus, and bacteria removal efficiency.
- Can provide stormwater retention, runoff volume reduction, and groundwater recharge.

Limitations

- Infiltration surfaces are buried, often under paved surfaces. Failed systems require excavating and replacing the system as well as repairing at-grade improvements built over the system. As a result, pretreatment is more critical for underground systems.
- Routine maintenance can be overlooked because the practice is not readily visible.
- Buried utilities can be a substantial conflict to constructing these systems, but less potential conflict compared to infiltration chambers.
- Typically requires a piped drainage system to divert runoff into the structure.
- Lower removal of dissolved pollutants especially in coarse soils.
- Should not be used with underdrain systems.
- Cannot provide significant stormwater quantity control unless used in areas with very high infiltration rates, or if a dry well is used in conjunction with a cistern and rainwater harvesting system.

Siting Considerations

- **Potential Locations:** Best located where there is inadequate surface area for more cost-effective approaches to infiltrate stormwater. Suitable under parking lots, roads, sidewalks and other at-grade, built features. Dry wells can also be placed under lawn areas to

infiltrate roof runoff. Surfaces above the system may need to be excavated in the future in the case of a failed system, and thereby need to be replaceable. As a result, these systems should not be used under structures. Suitable in urban and rural settings.[84]

- **Siting In / Adjacent to Roadways:** The top elevation of the perforated chamber is recommended to be kept at least 2' below the bottom of the roadway base material.[84]
- **Drainage Area:** The maximum contributing drainage area should not exceed 1 acre; however, a series of connected dry wells or infiltrating catch basins can be used to manage a larger area to a maximum of 5 acres.
- **Maintenance Considerations:** Ensure adequate vehicle maintenance access to pretreatment elements for infiltrating catch basins. Any at-grade improvements constructed above the systems should be replaceable in case of the need to replace the system if it fails.
- **General:** Meet the soils, water table, bedrock, and horizontal setback requirements specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems (General Design Guidance for Stormwater Infiltration Systems). Should be designed as off-line practices.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 for soil evaluation guidance.

Design Recommendations

Pretreatment

- Pretreatment is not required for dry wells that only receive clean roof runoff.
- For infiltrating catch basins that manage runoff from other sources, incorporate pretreatment measures at locations where runoff enters the system in accordance with the Pretreatment BMPs section of this Manual.
- Acceptable pretreatment measures are those that are suitable for piped drainage systems and include deep sump hooded catch basins and proprietary pretreatment devices.

[84] Note: Infiltration systems below CT DOT roads are not permitted. Infiltration systems adjacent to CTDOT roads shall be directed exfiltration away from pavements base, subbase and subgrade. An impermeable barrier may be required.

- Pretreatment measure(s) should have a minimum storage volume of 25% of the Water Quality Volume (WQV) or treat at least the equivalent Water Quality Flow (WQF) if using a proprietary treatment device.

Sizing and Dimensions

- Size the precast concrete structure and crushed stone reservoir to hold and infiltrate the design volume below the elevation of any outlet and fully dewater within 48 hours after the end of a storm event.
- Multiple connected structures can be used to achieve the required design volume.
- These systems should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Water Surface
  - Water surfaces elevations in the system should be designed to avoid flooding the subbase of paved surfaces.
- Bottom Slope
  - Bottom slope should be level.
- Surface Cover
  - Dry wells and infiltrating catch basins should be covered by a minimum of 12 inches of soil or subbase material.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.
- Runoff is typically introduced through inlet structures and pipes.
- Design infiltrating catch basins in an off-line configuration to the extent feasible if runoff is delivered by a storm drainpipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.
- Outlets are typically a pipe that discharges to a storm drainage system. The outlet should be designed in a manner that allows the desired storage volume to be maintained in the system.
- Dry wells that receive runoff from a roof downspout are typically designed to bypass flows in excess of the water quality storm via a surface overflow to a splash pad and vegetated area.

Materials

- Precast Concrete Structures
  - Open-bottom perforated precast concrete vault as available from the manufacturer.

- Crushed Stone
  - Perforated precast concrete dry wells and infiltrating catch basin structures should be underlain and backfilled with clean (washed and free from dirt and debris), crushed, angular stone with a diameter of 1.5 to 3 inches (porosity of 40 percent).
  - A minimum of 6 inches of crushed stone should be placed below the bottom of the precast concrete structure and a minimum of 12 inches of crushed stone surrounding the structure. Additional stone may be used on the bottom and sides of the structure to increase the available storage volume.
  - Dry wells constructed as stone-filled excavated pits should be backfill with clean (washed and free from dirt and debris), crushed, angular stone with a diameter of 1.5 to 3 inches (porosity of 40 percent).

- Observation Well
  - For dry wells constructed as stone-filled excavated pits, an observation well should be installed within the dry well to monitor the water drainage in the system. The well should consist of a well-anchored, vertical perforated 4- to 6-inch diameter PVC pipe with a lockable aboveground cap (Figure 13-14).

- Observation wells are not required in precast concrete dry wells or infiltrating catch basins because water levels in these systems can be visually inspected via a manhole.

- Filter Fabric
  - Wrap around the exterior sides and top of the crushed stone only. Do not provide filter fabric on the bottom of the crushed stone.
  - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:

  - After excavation and scarification of bottom and sidewalls of excavation

  - After placement and leveling of stone

- After placement of precast concrete structure
- After installation of bypass, outlet/overflow, and inlet controls
- After infiltration system has been backfilled

- The designing qualified professional should provide an as-built plan of the completed infiltration system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans and manufacturer's guidelines.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.
- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The infiltration system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. Excavation equipment should not be allowed within the limits of the system.
- The stone storage media should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the infiltration system and then hand-raked to the desired elevation.

Maintenance Needs

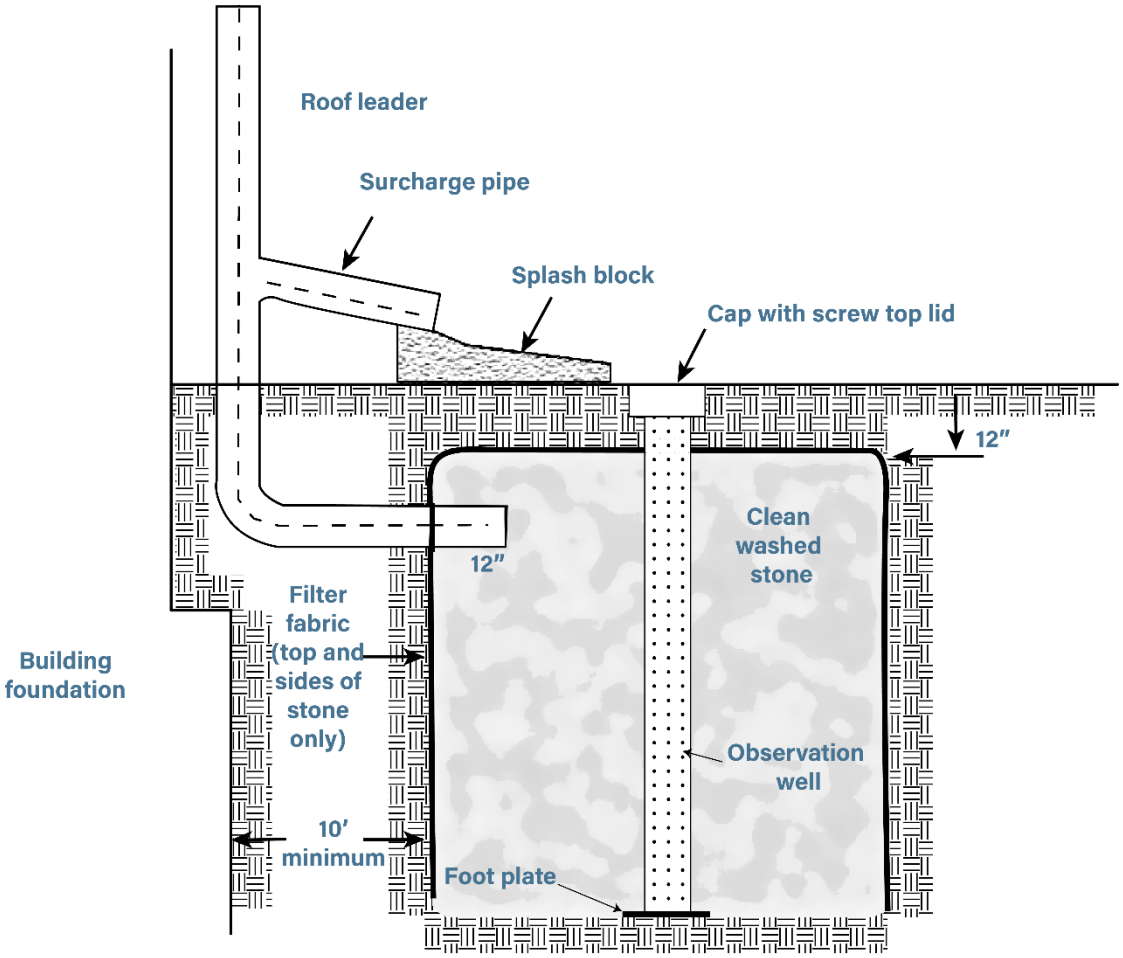
- Dry wells and infiltrating catch basins should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.

- Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment from the precast concrete structure and any pretreatment structures using a vacuum truck.

Recommended Maintenance Activities

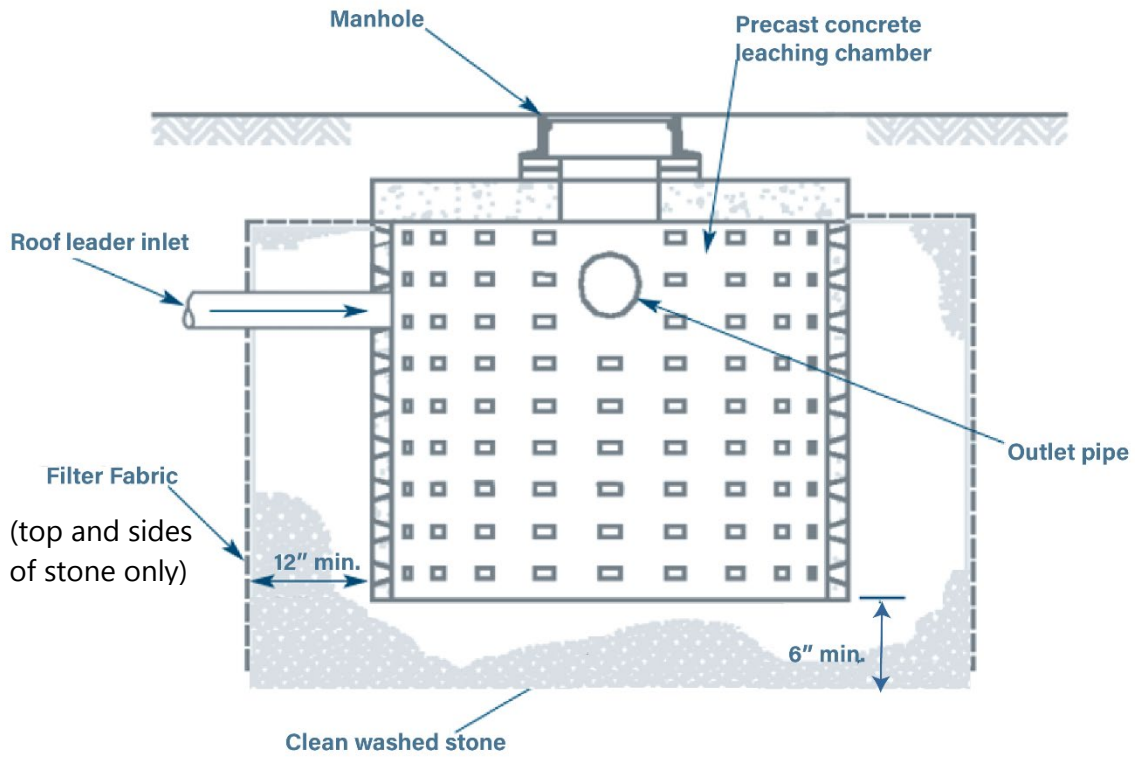
- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect precast concrete infiltration structure and any pretreatment structures twice a year.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove sediment from the pretreatment structure when it accumulates to more than 50% of the design depth.
- Remove sediment from the precast concrete infiltration structure when the sediment accumulation exceeds 2 inches throughout the bottom of the structure or when drawdown time exceeds 48 hours after the end of a storm event (for any style dry well or infiltrating catch basin), indicating that the system is clogged.

Figure 13-11. Schematic of Typical Drywell



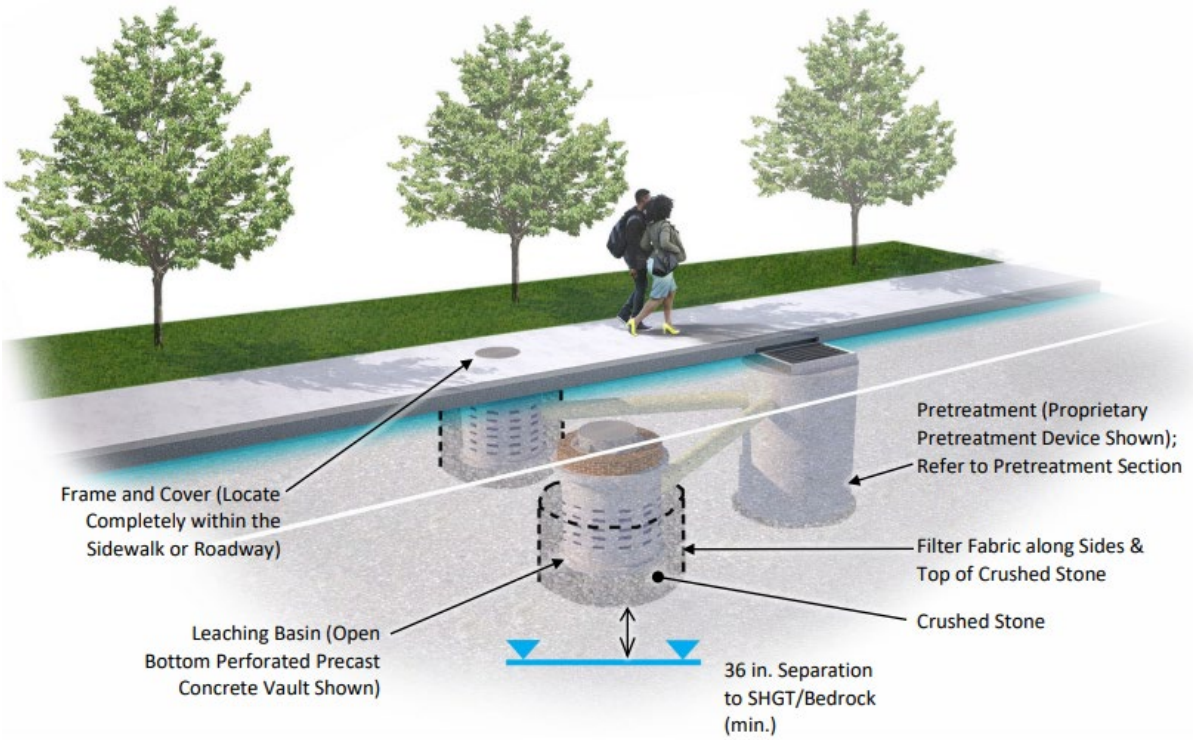
Source: Adapted from Center for Watershed Protection, 2000.

Figure 13-12. Schematic of Typical Perforated Precast Concrete Drywell



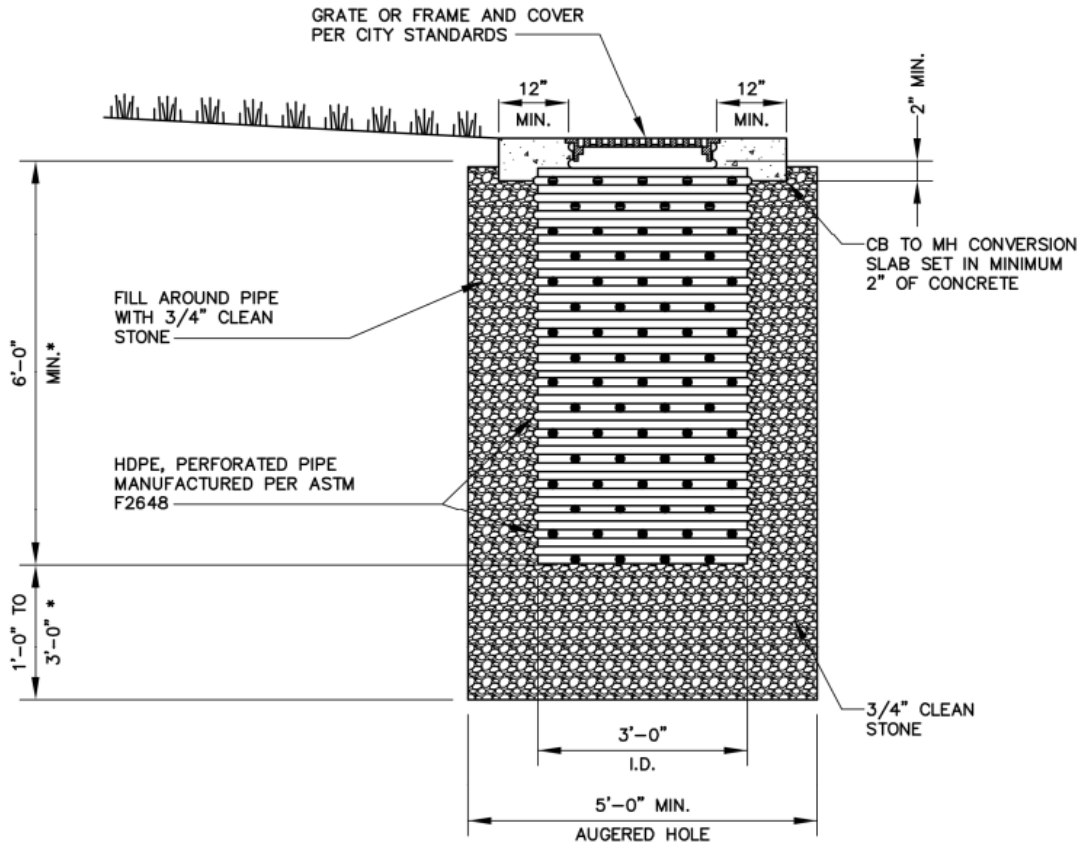
Source: Fuss & O'Neill, Inc.

Figure 13-13. Schematic of Typical Perforated Precast Concrete Infiltrating Catch Basin



Source: RIDOT, 2019.
Note: Infiltration systems below CT DOT roads are not permitted. Infiltration systems adjacent to CTDOT roads shall be directed exfiltration away from pavements base, subbase and subgrade. An impermeable barrier may be required.

Figure 13-14. Schematic of Typical Vertical Corrugated Perforated Pipe Infiltrating Catch Basin



Source: Adapted from City of New Haven Engineering Department.

Permeable Pavement

Source: UConn NEMO Program

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	■
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention*	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	■

*Exfiltration systems only

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**High**

*Includes sediment-bound pollutants

Implementation

Capital Cost	**High**
Maintenance Burden	**High**
Land Requirement	**Low**

Description

Permeable pavement is an alternative paved surface and stormwater management facility designed to capture stormwater runoff and snowmelt and allow it to move through void spaces in the surface course or through the joints in paver units. The captured stormwater is filtered as it moves vertically through the surface course, a transition and filter course, and a storage bed of open-graded aggregate where it is temporarily stored. The stormwater is discharged from the system through infiltration into the underlying soil or using an optional underdrain. Permeable pavement can be used to manage stormwater that falls on the pavement surface, but it may also accept some runoff from adjacent impervious areas.

When design for infiltration, permeable pavement can provide retention of stormwater, reducing runoff volumes and recharging groundwater. Filtration of stormwater is the primary pollutant removal mechanism in permeable pavement systems, although hydrocarbons and other pollutants can biodegrade in the system. Permeable pavement can be designed to store larger volumes of water and provide peak runoff attenuation for larger storms. Similar to other Infiltration BMPs, permeable pavement systems should be lined for certain applications.

There are many types of permeable pavement systems, but the most common are porous asphalt, pervious concrete, and permeable interlocking concrete pavers (PICP). The following photographs show common types of permeable pavement installations in Connecticut.

Porous Asphalt (Storrs Hall, UConn, Storrs, CT)

Grass and Grid Pavers (Hole in the Wall Parking Lot, East Lyme, CT)

Pervious Concrete (Residential Subdivision, East Haddam, CT)

Concrete Pavers (residential driveway, Middletown, CT)

Photos Source: UConn NEMO Program

Advantages

- Well-suited to locations where space for other stormwater BMPs is limited.
- Provide dual functions, and therefore co-benefits including retention (volume reduction), groundwater recharge, treatment, and some stormwater quantity control.

- Other benefits include improved traction while wet, reduced surface ponding, reduced freeze-thaw, and reduced need for de-icing due to well drained base.

Limitations

- Susceptible to clogging by sediment.
- Not recommended in areas with high traffic volumes. Should only be used in low speed and low traffic areas or outside main travel lanes.
- Avoid areas of excessive sediment loading.
- Do not apply sand in winter months, as sand increases need for vacuum sweeping.
- Some permeable pavement surfaces (i.e., pavers) may be damaged by snow removal without modified equipment such as special plow blades.
- Quality control for material production and installation are essential for success.
- Accidental seal-coating or similar surface treatment will result in failure of porous asphalt installations.
- Successful long-term functioning of permeable pavement systems is highly dependent on regular and appropriate maintenance (routine vacuum sweeping).
- Higher material cost than conventional pavement (although ay be offset by reduced stormwater infrastructure costs).

Siting Considerations

- **Potential Locations:** Low traffic areas such as within the roadway outside of the travel way (roadside rights-of-way and emergency access lanes), parking stalls and other low traffic areas of parking lots, driveways for residential and light commercial use, walkways, plazas, bike paths, and patios, where sanding will not occur within the contributing drainage area. Useful in stormwater retrofit applications where space is limited and where additional runoff control is required.
- **Drainage Area:** 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.
- **Slopes:** Locate where pavement slopes do not exceed 5%.
- **General:** Meet the soils, water table, bedrock, and horizontal setback requirements specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems (General Design Guidance for Stormwater Infiltration Systems).

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation guidance.

Design Recommendations

General Considerations

This section addresses design considerations for the most common types of permeable pavement systems.

- **Porous Asphalt:** Porous asphalt consists of a contiguous permeable asphalt surface course installed over a filter course and a base course that serves as a storage reservoir. Stormwater runoff moves vertically through the interconnected void spaces (10-25%) of the surface course and the filter course and temporarily accumulates in the underlying storage reservoir until it is discharged from the system or infiltrated into the underlying soil. The high infiltration rate through the surface course is achieved by eliminating the finer aggregates that are typically used in conventional asphalt. The remaining aggregates are bound together with an asphalt or Portland cement binder.

- **Pervious Concrete:** Like porous asphalt, pervious concrete consists of a contiguous permeable concrete surface course installed over a filter course and a base course that serves as a storage reservoir. Pervious concrete is like conventional concrete except the fine particles are absent from the mix, creating the interconnected void space and high infiltration capacity.

- **Permeable Interlocking Concrete Pavers (PICP):** This system uses concrete pavers that come in a variety of shapes, sizes, and many possible interlocking arrangements. Stormwater infiltrates vertically through the permeable joints between the paver units, or through voids in the permeable concrete units (similar to pervious concrete), then through the bedding layer, choker course, and an underlying storage reservoir.

Figure 13-15. is a typical section of porous asphalt and pervious concrete, and a typical section of permeable interlocking concrete pavers designed for vehicle and non-vehicle loads. Other open course paver systems are available that can be filled with pea gravel or topsoil and seeded with grass, ranging from plastic turf reinforcing grids to concrete grid pavers.

All types of permeable pavement systems can be used with an impermeable liner and underdrain. A liner and underdrain system are required for use with Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems), in locations where contaminated soils exist, where the required vertical separation to SHGT cannot be met, or in locations with unacceptable horizontal

setbacks for infiltration. Such systems are suitable for providing treatment and peak runoff attenuation but do not provide retention credit.

Pretreatment

- Pretreatment is not required for permeable pavement but may be appropriate if system receives stormwater runoff from pervious surfaces.

Inlet

- An inlet structure is not required if porous pavement receives evenly distributed sheet flow. Provide a level spreader or other feature to convert concentrated flow to sheet flow in accordance with the Inlet and Outlet Controls section of this Manual.

- Conveyance to porous pavement is typically overland and must be sheet flow; avoid concentrating flows due to features such as raised islands. Porous pavement receiving concentrated flow is more likely to clog and require additional maintenance.

Sizing and Dimensions

Surface Area and Volume

- Permeable pavement should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- Size the filter and reservoir course to retain the Required Retention Volume (100% or 50% of the Water Quality Volume or WQV) and fully drain within 48 hours after the end of the design storm as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- Assume a porosity of 40% when computing the amount of available storage within the aggregate courses.

- Size the permeable pavement surface area such that the contributing drainage area to the permeable pavement does not exceed three times the surface area of the permeable pavement.

Porous Asphalt and Pervious Concrete

- Surface Course
    - Porous Asphalt:
        - Thickness: 4 to 6 inches
    - Pervious Concrete
        - Thickness: 4 inches (minimum)
    - Design the surface course to support anticipated traffic and other design loads, including additional stresses that may be anticipated at the edges of the installation.

- Choker Course
  - Thickness: 4 to 8 inches

- Filter Course
  - Thickness: 8 to 12 inches; increase to 18 inches if an underdrain is used or there is inadequate separation from SHGT/bedrock.

- Filter Blanket
  - Thickness: 3 inches

- Reservoir Course
  - Thickness (without underdrain): 4 inches minimum
  - Thickness (with underdrain system): 8 inches minimum
  - Thicker reservoir course may be needed to retain the Required Retention Volume (100% or 50% of the WQV) or larger storms for stormwater quantity control
  - Ensure the reservoir course depth is sufficient to prevent winter freeze-thaw and heaving.
    - Combined pavement system and subbase thickness should exceed 0.65 times the design frost depth for the area.

Permeable Interlocking Concrete Pavers

- Surface Course
  - Pavers
    - Thickness: Per manufacturer
    - Gap Width: Per manufacturer
  - Design the surface course to support anticipated traffic and other design loads, including additional stresses that may be anticipated at the edges of the installation.

- Bedding Course
  - Thickness: 2 inches

- Base Reservoir Course
  - Thickness: 6 inches

- Subbase Reservoir Course
  - Thickness (without underdrain): 6 inches (non-vehicle loads), 8 inches (vehicle loads)
  - Thickness (with underdrain system): 8 inches minimum

Underdrain System

- Install an underdrain system when a proposed permeable pavement installation meets one or more of the following conditions:

- Is in native soil that has an infiltration rate less than 0.3 inch per hour (HSG C and D soils)
- Does not meet vertical separation distance to SHGT or bedrock (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) and should be lined
- Does not meet minimum horizontal setback distances (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) and should be lined
- Is within a Land Use with Higher Potential Pollutant Loads (LUHPPL) (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) or area of contaminated soils and should be lined.

- Minimum underdrain pipe diameter: 4 inches
- Minimum underdrain pipe slope: 0.5%
- Install perforated underdrains within a minimum 8-inch-thick reservoir course with a minimum of 2 inches of crushed stone above and below the underdrain.
- For unlined systems, install the perforated underdrain pipe 2 inches below the top of the reservoir course to promote infiltration. For systems that are lined with an impermeable liner to prevent infiltration, install the underdrain pipe 2 inches above the bottom of the reservoir course so the system can drain between storm events.
- Lay underdrain such that perforations are on the bottom of the pipe.
- Use solid (non-perforated) pipe sections and watertight joints wherever the underdrain system passes below berms, extends down steep slopes, connects to a drainage structure, and/or daylights.
- Other considerations when designing/installing underdrains:
  - Provide a marking stake and an animal guard for underdrains that daylight at grade.
  - If designed with laterals, space collection laterals every 25 feet or less.
- Include a minimum of two observation wells/cleanouts for each underdrain, one at the upstream end and one at the downstream end.
  - Cleanouts should be at least 4 inches in diameter, be nonperforated, and extend to the surface (flush with the surface). Cap cleanouts with a watertight removable cap. The cleanout should be highly visible.
  - Provide one cleanout for every 1,000 square feet of surface area (at a minimum) or for every 250 linear feet of total pipe length in larger systems.

Materials

Porous Asphalt and Pervious Concrete

- Porous Asphalt
  - Should conform to the latest version of the University of New Hampshire Stormwater Center Design Specifications for Porous Asphalt Pavement and Infiltration Beds.
- Pervious Concrete
  - Should conform to the latest version of the American Concrete Institute Specification for Pervious Concrete Pavement (ACI SPEC-522.1-13).
- Choker Course
  - Should consist of AASHTO No. 57 clean, washed stone.
- Filter Course
  - Should consist of washed concrete sand (ASTM C33 or AASHTO M-6) or coarse washed sand with a hydraulic conductivity of 10 to 60 feet per day at 95% Standard Proctor.
- Filter Blanket
  - Should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.
- Reservoir Course
  - Should consist of 3/4" AASHTO No. 5 stone. Gravel should be clean (washed and free from dirt and debris), crushed, and angular.

Permeable Interlocking Concrete Pavers

- Pavers
  - PCIP: Concrete pavers should conform to ASTM C936 and have a minimum thickness of 3.125 inches when subject to vehicular traffic.
  - Other open course paver systems should conform to manufacturer guidelines.
- Bedding Course
  - Non-vehicle Loads: washed concrete sand (ASTM C33 or AASHTO M-6)
  - Vehicle Loads: pea gravel, 3/8" AASHTO No. 8 washed crushed stone
- Base Reservoir Course
  - Non-vehicle Loads: pea gravel, 3/8" AASHTO No. 8 washed crushed stone
  - Vehicle Loads: AASHTO No. 57 washed crushed stone
- Subbase Reservoir Course
  - Non-vehicle Loads: 3/4" AASHTO No. 5 washed crushed stone

- Vehicle Loads: 1.5" AASHTO No. 4 washed crushed stone

General

- Filter Fabric
  - Use along sides of excavation; filter fabrics should not be used between aggregate courses or beneath the bottom course.
  - Where reservoir courses extend beneath conventional pavement, use filter fabric at the top of the reservoir course.
  - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

- Underdrain (perforated and non-perforated pipe sections)
  - Polyethylene or polyvinyl pipe.

- Liner
  - If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

Stormwater Quantity Control Design – Adjusted Runoff Curve Number

- Permeable pavement systems reduce the volume of runoff from the paved surface and therefore result in a reduced NRCS Runoff Curve Number (CN), which should be used for stormwater hydrologic and hydraulic routing calculations that are required for stormwater quantity control design.

- Determine adjusted CN values for the permeable pavement surface by the following method:

1. Calculate the volume of stormwater retained by the permeable pavement system as described above.
2. Calculate the stormwater runoff volume for the water quality storm and the 2-, 10-, and 100-year, 24-hour storms as described in Chapter 4 - Stormwater Management Standards and Performance Criteria of this Manual.
3. Subtract the volume of stormwater retained by the permeable pavement system from the stormwater runoff volume for the various storm events. The result is the runoff volume that will be discharged from the permeable pavement during each storm event.
4. Convert the volume of stormwater discharged from the permeable pavement system to an equivalent discharge depth (in inches) by dividing the volume discharged by the area of the permeable pavement surface.
5. Using the calculated discharge depth described above and the precipitation for each design storm event, calculate the adjusted CN values using the equation or graphical

solution (Figure 2-1 from TR-55) presented in Appendix D of this Manual (i.e., Graphical Peak Discharge Method).

- Once the adjusted CN values are determined, also calculate the time of concentration and either follow the remaining steps in the Graphical Peak Discharge Method in Appendix D or use a stormwater hydrologic/hydraulic routing model based on the NRCS Curve Number method (e.g., Hydro CAD or similar software) to calculate peak discharge rates for each design storm event.

Outlet & Overflow

- Permeable pavement should be graded to convey runoff to a properly designed conveyance system for storms greater than the design storm event.
- In addition to underdrains, common overflow outlets include curb cuts, catch basins, or a perimeter stone trench.
- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.

Other Considerations

- The existing native subgrade material under permeable pavement should not be compacted or subject to excessive construction equipment traffic.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to permeable pavement.
    - Adequate vegetative cover should be established over any pervious area adjacent or contributing to the installation before runoff can be accepted.
- Provide terraces and impermeable baffles or graded impermeable berms to maximize storage and prevent lateral reservoir course flow when subgrade slope exceeds 2%.
- In systems where pervious pavement is installed adjacent to conventional pavement, a full-depth barrier (impermeable liner) should be used between the two types of pavements to ensure that structural integrity is maintained and to prevent inadvertent saturation of the adjacent impervious pavement surface course.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.
- The designing qualified professional r should inspect the installation during the following stages of construction, at a minimum:
    - After excavation of the system and scarification of bottom and sidewalls of excavation
    - After placement of each gravel layer and drainpipes (if any)

- After installation of bypass, outlet/overflow, and inlet controls
- Before and during placement of the pavement material (porous asphalt, pervious concrete, or pavers)
- After pavement and pavers have been installed

- The designing qualified professional should provide an as-built plan of the completed permeable pavement system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- Materials testing requirements per the applicable specifications for each type of permeable pavement system.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.

- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed permeable pavement system.

- The system should be fenced off during the construction period to prevent disturbance of the soils.

- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. A hydraulic excavator or backhoe loader, operating outside the limits of the system, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.

- The various gravel layers should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the system and compacted.

- The pavement material should be placed in accordance with the applicable installation requirements, as specified below:

- **Porous Asphalt:** The latest version of the University of New Hampshire Stormwater Center Design Specifications for Porous Asphalt Pavement and Infiltration Beds.[85]
- **Pervious Concrete:** The latest version of the American Concrete Institute Specification for Pervious Concrete Pavement (ACI SPEC-522.1-13)
- **Permeable Interlocking Concrete Pavers:** Manufacturer guidelines.

- For open course paver systems with vegetation, install grass according to the manufacturer's guidelines and in accordance with these general recommendations:
  - At least 1/8" to 1/4" of the paver must remain above the soil to bear the traffic load.
  - Sod or seeding method may be used.
  - If sod is used, the depth of backfill required will depend on the depth of the sod. Sod is laid over the pavers, watered thoroughly, and then compressed into the cells of the pavers.
  - If grass is planted from seed, the appropriate soil should be placed in the cells, tamped into the cells, and then watered thoroughly so that the appropriate amount of paver is exposed. The soil is then ready for planting with a durable grass seed.
  - Traffic should be excluded from the area for at least a month to allow for establishment of grass.

Maintenance Needs

- Permeable pavement systems should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.

- Maintenance must be performed by properly trained personnel trained in the use of the special equipment necessary in accordance with industry or manufacturer's requirements such as vacuum sweeping, specialized snow plowing accessories, etc.

- Maintenance should be detailed in a legally binding maintenance agreement.

[85] https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/unhsc_pa_spec_10_09.pdf

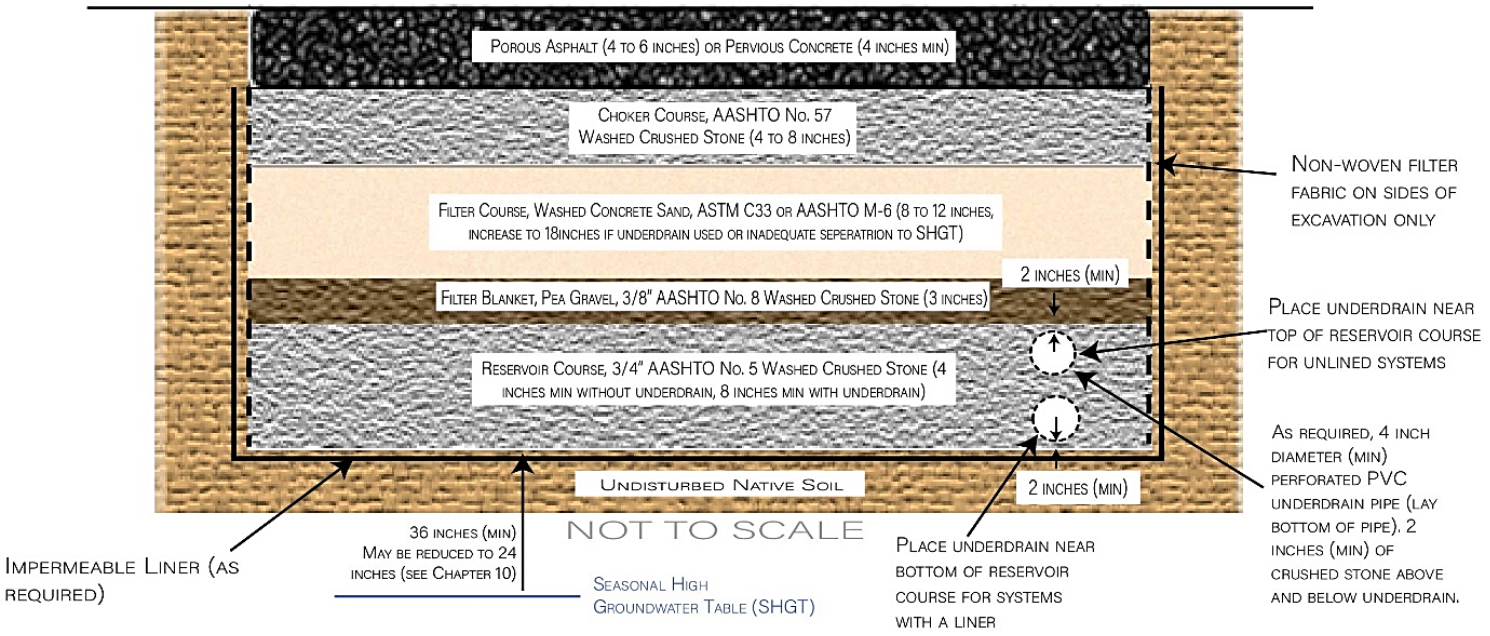
- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the bioretention soil media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the bioretention system. Heavy construction equipment should not be allowed within the limits of the bioretention system for maintenance purposes.

Recommended Maintenance Activities

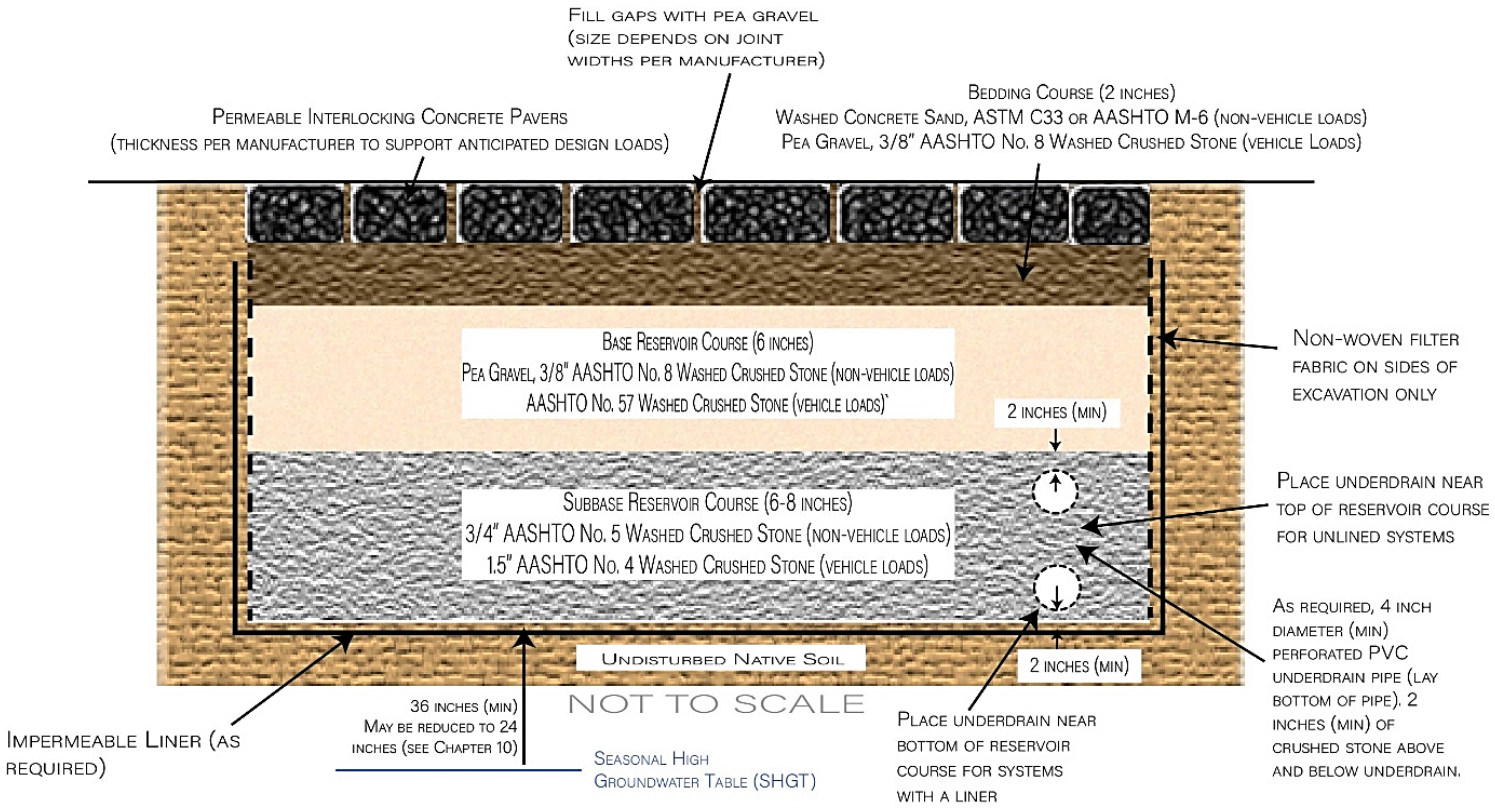
- Inspect surface course after major storms (1 inch or more of precipitation) in the first year following construction.
- Inspect surface course annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.
- Vacuum sweep and air blow (using a leaf blower or equipment recommended by the manufacturer) the permeable pavement surface quarterly.
- Regularly remove tracked mud or sediment and leaves. Power washing can be effective for cleaning clogged areas.
- Do not apply sand during winter operations.
- Minimize use of deicing chemicals. Only use as necessary based on site-specific drainage and icing conditions.
- Do not use deicing chemicals on pervious concrete less than one year old. Never use deicers containing magnesium chloride, calcium magnesium acetate or potassium acetate on pervious concrete.
    - Use caution when removing snow from the surface course. Some permeable paving surface courses such as pavers may be damaged by snowplows or loader buckets not equipped with a rubber blade guard to avoid catching on the paver units.
    - Under no circumstances may any sealants or coatings be applied to permeable paving systems, except for those approved by the manufacturer to improve surface course resistance to deicing chemicals or refresh traffic striping.
    - Take corrective action if the system fails to drain the design storm volume within 48 hours after the end of a storm.

Figure 13-15.. Permeable Pavement – Typical Sections

Porous Asphalt or Pervious Concrete



Permeable Interlocking Concrete Pavers



Bioretention

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	■
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Low**
Bacteria	**High**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**Varies**

Description

Bioretention systems are shallow, vegetated depressions that capture, temporarily store, and filter stormwater runoff. Bioretention systems have an engineered soil[86] media below the surface of the system that facilitates stormwater filtration and vegetative growth. Bioretention systems are frequently designed to infiltrate, commonly referred to as "infiltration" or "exfiltration" bioretention systems but can be designed with an underdrain to capture filtered water and assist with drainage from the system, typically referred to as "flow-through" bioretention systems. In certain situations, bioretention systems can also be designed with impermeable liners to prevent infiltration into the underlying soil.

Bioretention systems remove pollutants through a variety of physical, chemical, and biological processes including filtration, pollutant uptake, and adsorption. Vegetation in the soil bed provides uptake of pollutants and runoff, and the root system helps maintain the infiltration rate in the soil bed. If not designed with an impermeable liner, bioretention systems can provide retention of stormwater and reduce runoff volumes through infiltration and groundwater recharge. Bioretention systems may also be used to provide stormwater quantity control when designed as on-line facilities.

Bioretention systems can be implemented on most sites as part of the urban, suburban, or rural landscape. Given their versatility, many design variants of bioretention systems exist, including bioretention basins, stormwater planters, bioswales, tree filters (see Tree Filter section), and

[86] Engineered soil is a manufactured soil consisting of specified ratios of sand, silt, clay, and organic amendments such as compost and designed for a specific application.

other systems that vary based on shape, location, and configuration. The following photographs are examples of common types of bioretention systems.

Bioretention basin at the edge of a parking lot.

Rain garden on a residential lot.

Roadside bioswale in urban residential setting.

Bioretention planter in urban downtown setting.

Advantages

- Applicable to small drainage areas.
- Can be applied to most sites due to relatively few constraints and many design variations (i.e., highly versatile).
- Ideal for stormwater retrofits and highly developed sites.
- High pollutant removal efficiency and water quality benefits.
- Can provide stormwater retention, runoff volume reduction, and groundwater recharge if designed for infiltration.
- Vegetation can also provide aesthetic, ecological, and other green infrastructure benefits, like cooling the urban heat island effect.

Limitations

- Limited to smaller drainage areas.
- Frequent maintenance required.
- Infiltration bioretention systems generally have higher relative construction costs than other stormwater infiltration systems due to cost of bioretention soil media.

Siting Considerations

- **Potential Locations:** Within parking lot islands, along borders of parking lots, roundabouts, planted islands, medians, streetscapes (e.g., between the curb and sidewalk), wide roadway shoulders, and along shared-use paths. Bioretention systems such as small-scale rain gardens are also well-suited to residential areas because of the co-benefits they provide

- **Drainage Area:** Small-scale bioretention systems should have a contributing drainage area of 1 acre or less. The recommended maximum contributing drainage area for bioretention systems is 5 acres. For larger sites, multiple bioretention systems should be distributed throughout the site or off-line designs should be used to bypass larger flows. For curb inlet planters, the recommended maximum ratio of contributing impervious drainage area to planter bed area is 10:1.

- **Soils:** Bioretention systems that return filtered runoff to the conveyance system and do not infiltrate into the ground can be used in almost any soil type. Bioretention designs that rely on infiltration should be used only when the soil infiltration characteristics are appropriate (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for design guidance for stormwater infiltration systems).

- **Land Use:** Bioretention systems can be used in most land use settings where space is available.

- **Water Table and Bedrock:** For bioretention systems designed for infiltration (unlined systems), meet the minimum required vertical separation distances from the top and bottom of the filtering system to the seasonal high groundwater table (SHGT) and bedrock, as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- **Horizontal Setbacks:** For bioretention systems designed for infiltration (unlined systems), meet the minimum horizontal setback distances in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 –

General Design Guidance for Stormwater Infiltration Systems, for soil evaluation guidance.

Design Recommendations

General Considerations

This section addresses three types of bioretention system designs (Table 13-5):

- **Bioretention System with Underdrain (Partial Infiltration Bioretention System):** Most bioretention systems should be designed with an underdrain to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall. Underdrained bioretention systems can be used with any soil type or soil infiltration rate, ,although bioretention systems in HSG C or D soils an underdrain is necessary. The underdrain should be raised above the bottom of the system to maximize infiltration and enhance nitrogen removal. Underdrained bioretention systems (without a liner) are suitable for providing stormwater retention, although only the infiltrated volume (not the volume discharged via the underdrain) can be credited toward the Standard 1 retention requirement.

- **Bioretention System with Underdrain and Liner (Flow-Through Bioretention System):** An underdrain and impermeable liner are required for use with Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems), in locations where contaminated soils exist, where the required vertical separation to SHGT cannot be met, or in locations with unacceptable horizontal setbacks for infiltration. Such systems are suitable for providing treatment but do not provide retention credit.

- **Bioretention System with No Underdrain (Infiltration Bioretention System):** Bioretention systems can be designed to fully infiltrate into the native soil without an underdrain. Such systems are best suited for use with Hydrologic Soil Group (HSG) A and B soils. Bioretention systems have higher relative construction costs than other surface infiltration systems presented in this Manual (infiltration basins and trenches) due to the cost of the engineered bioretention soil, plantings, etc. Therefore, infiltration bioretention systems tend to be less cost-effective than other surface infiltration practices.

Figure 13-16. and Figure 13-17. are schematics of these bioretention system designs.

Table 13-2. Bioretention System Design Types

Type of System	Underdrain Type	Infiltration or Filtration Design?	Suitable for Retention?	Suitable for Treatment?	General Conditions for Use
Bioretention System with Underdrain Partial Infiltration Bioretention System	Raised Underdrain	Infiltration and Filtration (partial infiltration)	Yes (infiltration volume only)	Yes	All HSG Soil types Underdrain required for HSG C and D Soils
Bioretention System with Underdrain and Liner Flow-Through Bioretention System	Underdrain and Impermeable Liner	Filtration Only	No	Yes	Land Uses with Higher Potential Pollutant Loads Contaminated sites Where required vertical separation to SHGT cannot be met Sites with unacceptable setback distances for infiltration
Bioretention System Without Underdrain Infiltration Bioretention System	No Underdrain	Infiltration and Filtration (Full infiltration)	Yes	Yes	HSG A and B Soils

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the bioretention system in accordance with the Pretreatment BMPs section of this Manual.
- Acceptable pretreatment measures include vegetative filter strips, sediment forebays, pretreatment swales, deep sump hooded catch basins,[87] oil grit separators, and proprietary pretreatment devices.
- Sediment forebays should have a minimum storage volume of 25% of the Water Quality Volume (WQV), while flow-through Pretreatment BMPs should treat at least the equivalent Water Quality Flow (WQF). A minimum sediment forebay storage volume of 10% of the WQV may be used in urban settings, space constrained sites, and as retrofits, with the approval of the review authority.

Sizing and Dimensions

- Bioretention Filter Bed (Bottom) Area
  - Bioretention system should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
  - Bioretention system should completely drain in 48 hours or less after the end of the design storm as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
  - For unlined systems, the design infiltration rate used for system sizing and drain time analysis should be equal to 50% of the slowest observed field infiltration rate of the underlying soils or 0.5 inches per hour (1.0 feet per day) for the bioretention soil media, whichever value is lower.
  - For lined systems, use the coefficient of permeability of the bioretention soil media (0.5 inches per hour or 1.0 feet per day or) in the drain time analysis.
- Bioretention Soil Depth
  - Engineered bioretention soil media should have a depth of 24 to 48 inches as necessary to accommodate the required sizing, vegetation species and root establishment, and subsurface conditions.
  - Bioretention systems with trees should have a minimum soil depth of 30 inches.
  - Soil depth may be limited by the requirement to maintain adequate separation to groundwater and bedrock as specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
- Ponding Depth
  - Maximum for water quality storm: 12 inches

[87] Only recommended for space constrained sites where no other Pretreatment BMPs are feasible.

- Maximum for overflow events: 36 inches

- Freeboard Depth
  - Minimum freeboard depth: 3 to 6 inches
  - As measured from the elevation of the maximum ponding depth to the facility's overflow elevation or to the invert of the inlet to the facility, whichever is lower.

- Bottom Width
  - Minimum: 4 feet (ideal). For bioretention planters, narrower widths may be allowed, with a minimum width of 2.5 feet. The design should consider plant health, water quality performance, and implementation costs.

- Bottom Slope
  - Design bottom of infiltration bioretention systems to be level or have a maximum slope of 0.5% to promote infiltration and even distribution.
  - Flow-through bioretention systems with bottom slopes greater than 0.5% should be designed with impermeable check dams (e.g., constructed from granite or concrete curbing) or as a terraced system with relatively flat bottoms in each cell to promote infiltration throughout the bottom of the entire system.

- Side Slopes
  - 3(H):1(V) slopes or flatter are preferred especially on grassed slopes where mowing is required.
  - In ultra-urban locations or space constrained areas; side slopes of 2(H):1(V) may be utilized if properly designed to account for erosion and slope stability. Stabilize the slope with turf reinforcement matting or equivalent if the slope could potentially erode.
  - If site topography does not allow for 3(H):1(V) slopes or adequately stabilized 2(H):1(V) slopes, vertical concrete walls with a maximum height of 30 inches can be used. Drop curbs or similar precast structures can also be used to create stable, vertical bioretention side walls.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Runoff can be introduced to the bioretention system through overland flow, curb cuts, inlet structures, swales/channels, and/or pipes.

- Design the bioretention system in an off-line configuration to the extent feasible if runoff is delivered by a storm drain pipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Outlets are typically a stabilized spillway, gabion berm, concrete weir, curb cut opening, precast concrete structure, or polyethylene/polyvinyl chloride riser structure.
- On-line systems should have a primary outlet sized to convey the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event (assuming the primary outlet is not designed to pass the 100-year storm event).
- Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm.

Underdrain System

- Install an underdrain system when a proposed bioretention system meets one or more of the following conditions:
  - Is in native soil that has an infiltration rate less than 0.3 inch per hour (HSG C and D soils)
  - Does not meet vertical separation distance to SHGT or bedrock (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) and should be lined
  - Is within a Land Use with Higher Potential Pollutant Loads (LUHPPL) (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) or area of contaminated soils and should be lined.
- An underdrain is also recommended, but not required, for other bioretention systems to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall.
- Minimum underdrain pipe diameter: 4 inches
- Minimum underdrain pipe slope: 0.5%
- Use two layers of gravel with the underdrain system. Both layers of gravel should be located below and extend across the entire bottom of the bioretention system. The upper gravel layer should consist of 3 inches of pea gravel, and the lower layer should consist of a 12-inch thick gravel sump.
- For unlined bioretention systems, install the perforated underdrain pipe 2 inches below the top of the gravel sump to promote infiltration. For systems that are lined with an impermeable liner to prevent infiltration, install the underdrain pipe 2 inches above the bottom of the gravel sump so the system can drain between storm events.
- For enhanced removal of nitrogen, use an upturned underdrain in combination with a low permeability native soil (HSG C or D soils) or liner to create a thicker saturated zone (also called an Internal Water Storage zone or Internal Storage Reservoir) that extends up to a maximum of 6 inches into the bottom of the bioretention soil media. This type of

underdrain configuration is recommended for bioretention systems that discharge to coastal, estuarine, and nitrogen impaired waters where enhanced nitrogen removal is desired.

- If the bioretention system is designed without an underdrain, pea gravel and gravel sump are optional.
- Lay underdrain such that perforations are on the bottom of the pipe.
- Use solid (non-perforated) pipe sections and watertight joints wherever the underdrain system passes below berms, extends down steep slopes, connects to a drainage structure, and/or daylights.
- Place filter fabric along sidewalls of excavation and above the pea gravel (below the bioretention soil layer) for a distance of 1 to 2 feet on both sides of the underdrain. Filter fabric shall not be placed across the entire width of the bioretention system.
- Other considerations when designing/installing underdrains:
    - Provide a marking stake and an animal guard for underdrains that daylight at grade.
    - If designed with laterals, space collection laterals every 25 feet or less.
- Include a minimum of two observation wells/cleanouts for each underdrain, one at the upstream end and one at the downstream end.
    - Cleanouts should be at least 4 inches in diameter, be nonperforated, and extend to the surface. Cap cleanouts with a watertight removable cap. The cleanout should be highly visible.
    - Provide one cleanout for every 1,000 square feet of surface area (at a minimum) or for every 250 linear feet of total pipe length in larger systems.

Materials

- Surface Cover
- Grass or river stone are the preferred surface cover types for bioretention systems to minimize required maintenance. Mulch may be used directly around the plants, but mulch should NOT be used to cover the entire bottom of the bioretention system.
- If mulch is used, use 2 to 4 inches of shredded hardwood bark mulch, aged for 6 months minimum.
    - Alternative surface covers such as pea gravel may be used if allowed by the review authority.
- Vegetation
    - Select bioretention plantings/vegetation and develop a planting plan with guidance provided in Appendix F of this Manual.

- A native grass/wildflower seed mix can be used as an alternative to groundcover plantings.
- Establish a dense vegetative cover or adequately stabilized surface throughout the bioretention system and any upgradient areas disturbed by construction before runoff can be accepted into the facility.
- Plant layout should be random and natural.
- Trees should be planted primarily along the perimeter of the facility and with 15 feet of separation from underdrain piping.
- Trees should not be planted in lined bioretention systems.
- Do not plant trees, shrubs, or grasses with a mature vegetation height exceeding 24 inches above the surrounding sidewalk or pavement surface in bioretention systems within medians, near intersections, or near pedestrian crossings to avoid obstruction of sight lines.

➢ Engineered Bioretention Soil Media

- The engineered soil media in bioretention systems is designed to filter/treat runoff and to provide sufficient organic material to support plan establishment and growth.

- The engineered bioretention soil media should be a homogeneous soil mix of (by volume):
  - 60–85% Sand
  - 15–25% Topsoil
  - 3–8% Organic Matter

- **Sand** should be washed concrete sand (ASTM C33 or AASHTO M-6) or coarse washed sand that meets the gradation schedule as shown in State of Connecticut Department of Transportation Standard Specifications, Section M.01 (Aggregates), Table M.01.04-1 for Fine Aggregate Gradations.

- **Topsoil** should contain 5–20% organic material, have a pH range of 5.5 to 7.0, and be a sandy loam, loamy sand, or loam per USDA soil texture with less than 5% clay content. Topsoil that meets the State of Connecticut Department of Transportation Standard Specifications, Section M.13.01 (Roadside Development) for Topsoil may also be used, except it should contain less than 5% clay content.

- **Organic matter** should consist of one of the following materials
  - Sphagnum Peat: Partially decomposed sphagnum peat moss, finely divided or of granular texture with 100 percent passing through a 1/2-inch (13-mm) sieve, a pH of 3.4 to 4.8.
  - Wood Derivatives: Shredded wood, wood chips, ground bark, or wood waste; of uniform texture and free of stones, sticks, soil, or toxic materials.

- Compost shall NOT be used as organic matter since the use of compost in bioretention soil media can result in nutrient export from the system.

- **Other soil amendments** such as zerovalent iron and/or processed drinking water treatment residuals (alum) may be used to further enhance phosphorus sorption as specified by the designer. Processed drinking water treatment residuals should have a minimum of 30% solids. Drinking water treatment residuals are typically processed and dried using a belt filter press.

- Bioretention soil media should meet the following particle size distribution according to ASTM D422 (Standard Test Method for Particle-Size Analysis of Soils) as specified in Table 13-6.

Table 13-3. Acceptable Particle Size Distribution of Bioretention Soil Media

Media Type	Sieve #	Size (inches)	Size (mm)	% Passing
Coarse Sand	4	0.187	4.76	100
Medium Sand	10	0.079	2.00	95
Fine Sand	40	0.017	0.42	10-20
Silt/Clay	200	0.003	0.075	0-5

- Bioretention soil media should also meet the following specifications:
  - pH (soil reaction): 5.5 to 7.5
  - Cation Exchange Capacity (CEC): minimum of 10 milliequivalents per 100 grams of soil (meq/100 g) at pH of 7.0
  - Organic Matter (percentage by volume): 3% to 10%
  - Total Phosphorus: <100 mg/kg

- Bioretention soil media should NOT contain any of the following materials: stones, clods, roots, clay lumps, and pockets of coarse sand exceeding 0.187 inches (4.76 mm) in any dimension; plants, sod, concrete slurry, concrete layers or chunks, cement, plaster, building debris, asphalt, bricks, oils, gasoline, diesel fuel, paint thinner, turpentine, tar, roofing compound, acid, solid waste, and any other extraneous materials that are harmful to plant growth.

➢ Pea Gravel
- Should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.

➢ Gravel Sump
- Should consist of 3/4" AASHTO No. 5 stone. Gravel should be clean (washed and free from dirt and debris), crushed, and angular.

- Filter Fabric
  - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

- Poured-in-place Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section 6.01 (Concrete for Structures).
  - Underdrain (perforated and non-perforated pipe sections)
  - Polyethylene or polyvinyl pipe.

- Liner
  - If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

- Curbing (for Overflow Weirs or Check Dams)
  - If used for check dams, granite or concrete curbing shall conform to State of Connecticut Department of Transportation Standard Specifications, Section M.12.06 (Stone Curbing) and Section 8.11 (Concrete Curbing).

- Turf Reinforcement Matting (TRM)
  - Stabilize the side slopes of the bioretention system with TRM to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.
  - If used, shall be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Other Considerations

- If designing a lined system in a location where 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.

- For lined bioretention systems within LUHPPLs, a shutoff valve can be installed on the underdrain outlet to capture and contain accidental spills or releases that reach the bioretention system.

- Roadway stability can be a design issue when installing bioretention systems along roadways. It may be necessary to provide a vertical impermeable barrier to keep water from saturating the road's sub-base. The barrier should be capable of supporting H-20 loads.

- Non-woven filter fabric should be placed along the sidewalls of the bioretention system to help direct the water flow downward, reduce lateral flows, and to reduce lateral soil migration. Non-woven filter fabric should also be placed above the pea gravel layer (below the bioretention soil layer) for a distance of 1 to 2 feet on both sides of the underdrain pipe. Filter fabric should NOT be placed across the entire width of the bioretention system because filter fabric installed in this manner can result in clogging and system failure.

Winter Operations

- Bioretention systems should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Requirements

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
    - After excavation of the bioretention system and scarification of bottom and sidewalls of excavation
    - After placement of gravel layer
    - After placement of underdrain before covering by the pea gravel layer
    - After placement of bioretention soil media
    - After installation of bypass, outlet/overflow, and inlet controls
    - After plants have been installed

- The designing qualified professional should provide an as-built plan of the completed bioretention system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- The bioretention soil mix should be tested prior to placement according to the specifications in this section (at least one test per bioretention system). The designing qualified professional should certify that the bioretention soil mix meets the specifications in the previous section based on soil testing results.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the bioretention system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed bioretention system.
- The bioretention system should be fenced off during the construction period to prevent disturbance of the soils.
- The bioretention system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the bioretention system. A hydraulic excavator or backhoe loader, operating outside the limits of the bioretention system, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the bioretention system.
- The gravel, pea gravel, and bioretention soil media should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the bioretention system and then hand-raked to the desired elevation.
- Place the bioretention soil in 6 to 12-inch lifts. The bioretention soil needs to settle before planting. Lightly tamp or spray the surface of the bioretention soil with water until saturated. The elevation of the bioretention soil can be a couple of inches higher at installation than the design elevation in anticipation of settling. Bring bioretention soil levels back to the design elevation if necessary.
    - Install vegetation (plants, grass, etc.) in the bioretention system in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established. The bioretention soil mix provides enough organic material to adequately supply nutrients from natural cycling.

Maintenance Needs

- Bioretention systems should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.

- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the bioretention soil media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the bioretention system. Heavy construction equipment should not be allowed within the limits of the bioretention system for maintenance purposes.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect bioretention system annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.
- Remove accumulated sediment from the bioretention system when the sediment accumulation exceeds 1 inch or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the soil media is clogged. Replace with fresh bioretention soil media that conforms to the specifications in this section.
- Maintain vegetated filter strips or grassed side slopes of bioretention system in accordance with maintenance recommendations in Pretreatment BMPs section of this Manual.
- Periodically remove grass clippings to prevent clogging of the surface of the bioretention system.
- Mowing should not be performed when the ground is soft to avoid the creation of ruts and compaction, which can reduce infiltration.
- Bioretention systems require other seasonal landscape maintenance, including:
    - Watering plants as necessary during first growing season
    - Watering as necessary during dry periods
    - Replacing dead or dying plants, or pruning plants, as necessary
    - Inspection of soil and repairing eroded areas
    - Removal of litter and debris

Figure 13-16. Bioretention System Schematic (Plan View and Elevation)

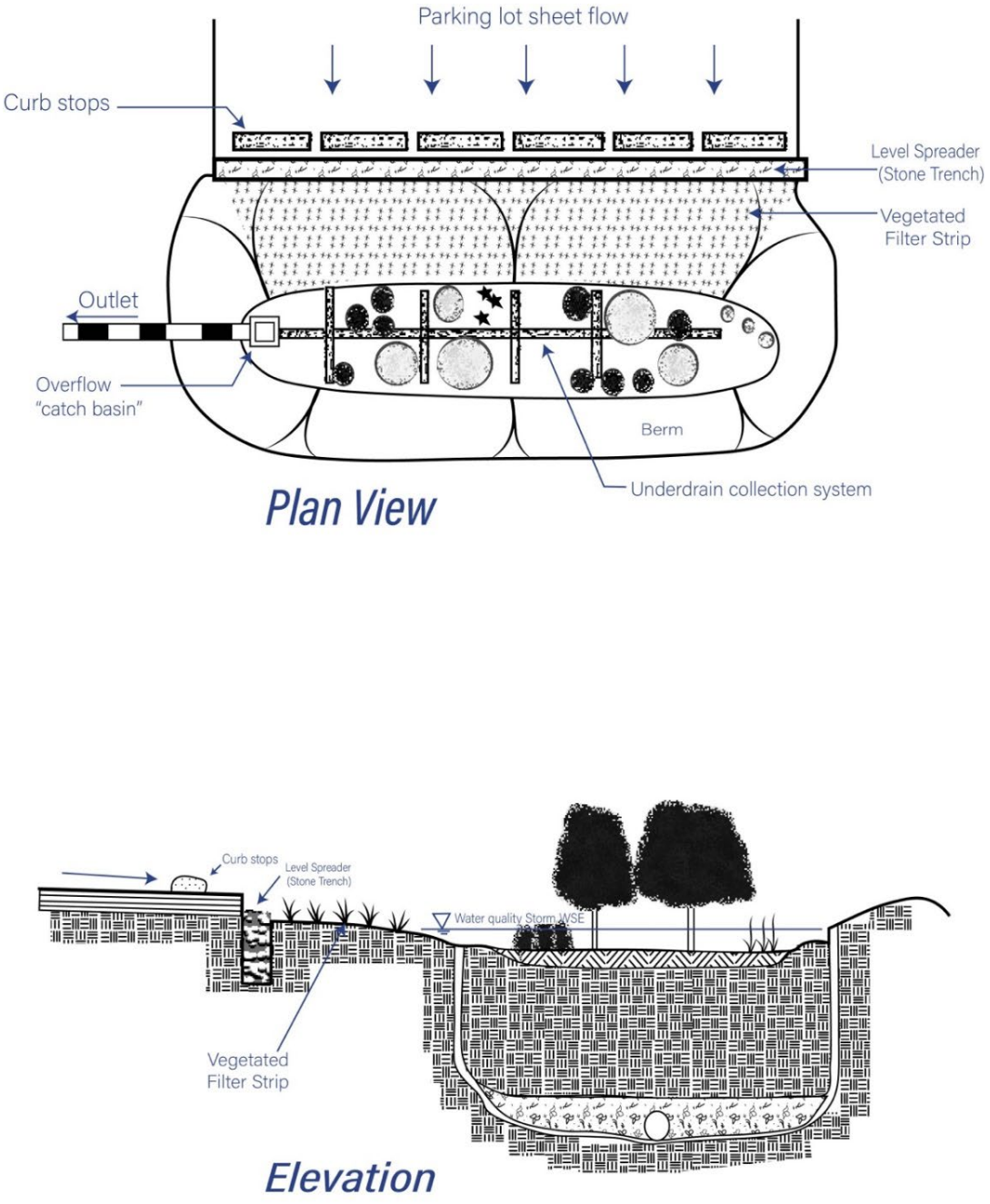
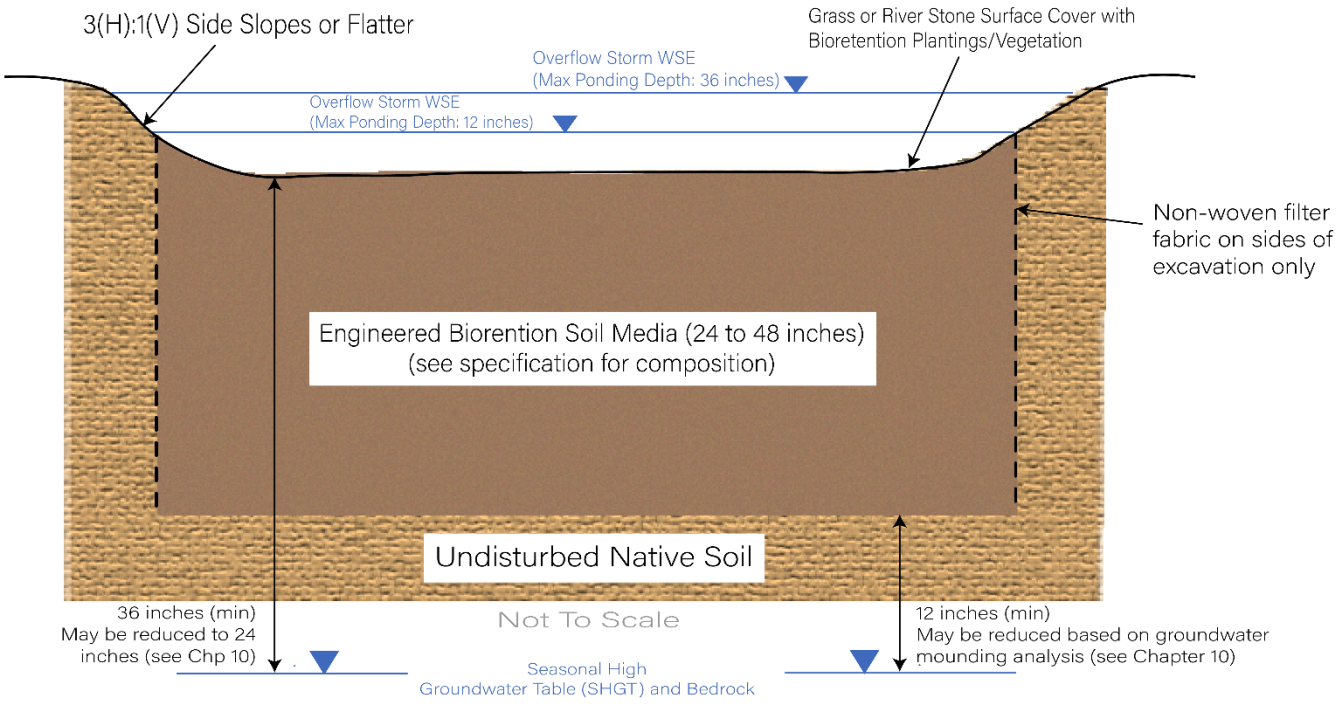


Figure 13-17. Bioretention System without and with Underdrain Schematic

Without Underdrain



With Underdrain

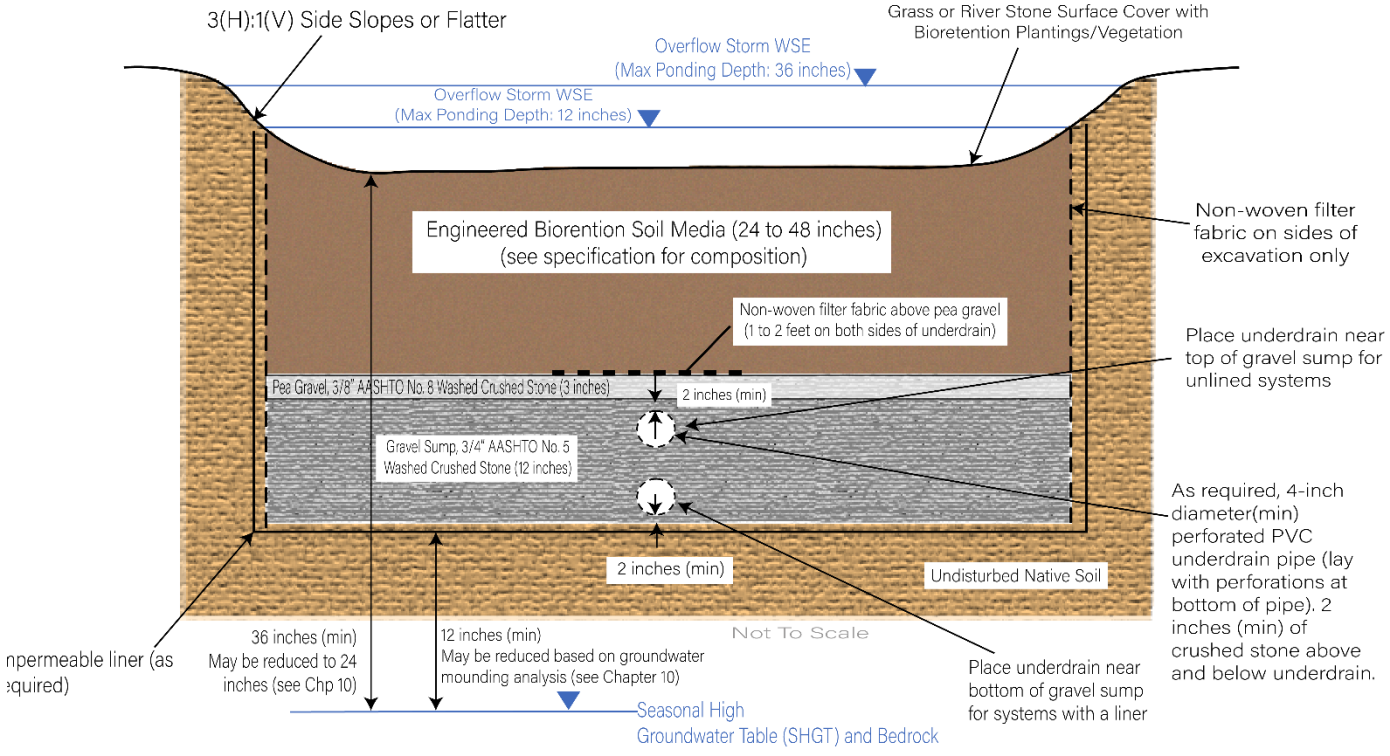
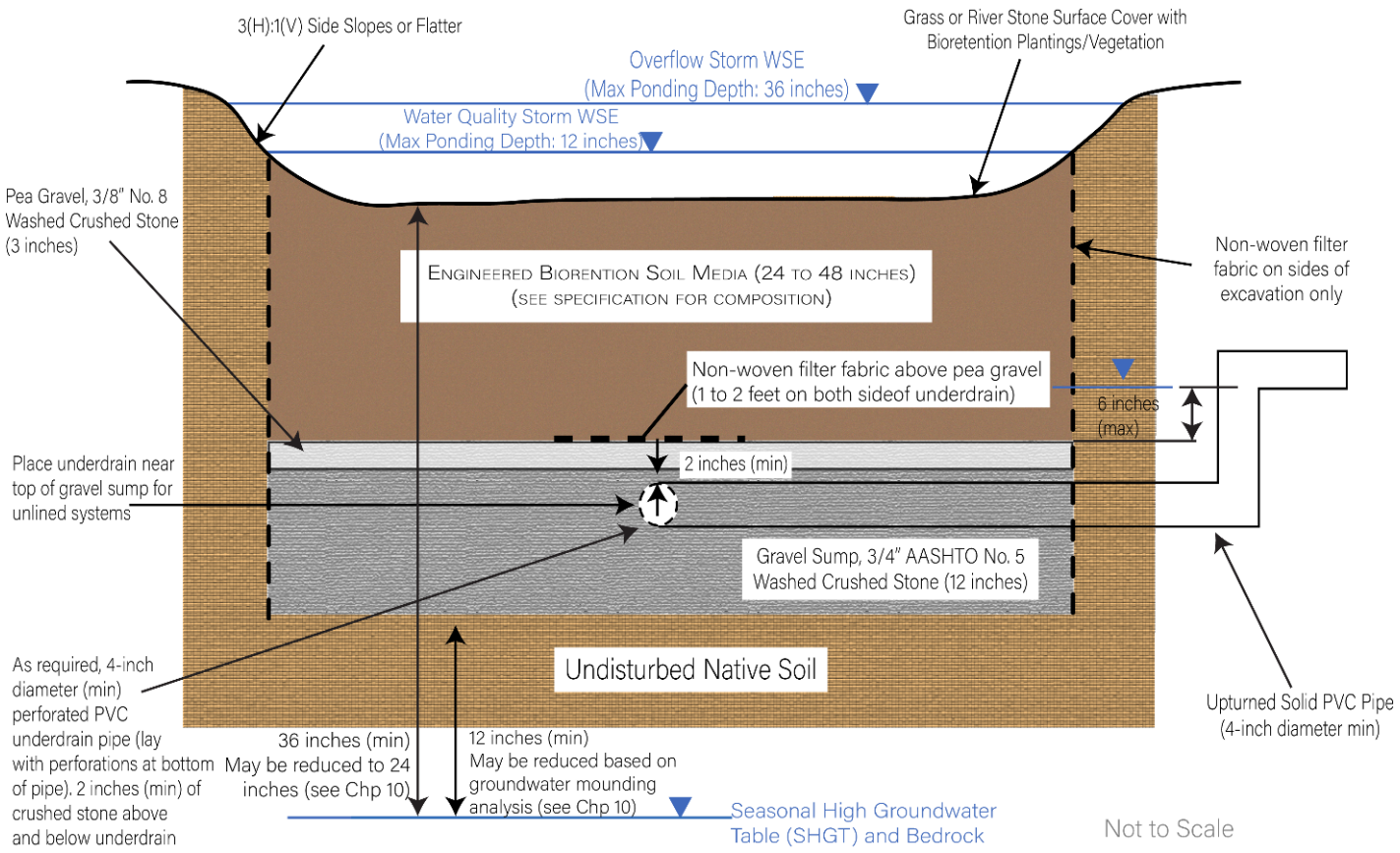


Figure 13-18. Bioretention System with Underdrain and Internal Water Storage Zone



Tree Filter

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	■
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention*	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	□

*Exfiltration systems only

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Moderate**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**High**
Maintenance Burden	**Medium**
Land Requirement	**Low**

Description

Tree filters are compact bioretention systems consisting of an open-bottomed chamber with one or more trees and filled with engineered soil media. Tree filters collect, temporarily store, and filter stormwater runoff through the engineered soil media, and the tree provides pollutant uptake. Tree filters are particularly well suited to urban or built-out areas where they can easily fit into small footprints and/or work as retrofits. Tree filters often work in tandem with existing stormwater networks allowing less frequent, high-intensity storm events to bypass the system.

Tree filters consist of three main parts: the tree, soil media, and chamber. The chamber is typically filled with engineered soil media that is designed for rapid infiltration. The system is planted with non-invasive trees or shrubs. The top of the chamber typically has a tree grate to protect the base of the tree, soil, and root system, as well as for pedestrian safety. The grate also serves to keep trash and debris from entering the top of the chamber. Most of the stormwater enters the system through a curb cut under the grate. Within the chamber there is typically storage for ponded stormwater runoff above the soil media. The engineered soil media filters the stormwater runoff as it flows downward through the system. The filtered runoff is collected in an underdrain and returned to the storm drainage system or infiltrates into the underlying soil. Tree filters provide pollutant removal via filtration, infiltration, pollutant uptake, and adsorption.

Advantages

- Applicable to small drainage areas and narrow right-of-way areas where space is limited.

- Ideal for stormwater retrofits and highly developed sites.
- Requires less space than other forms of bioretention.
- Can provide stormwater retention, runoff volume reduction, and groundwater recharge if designed for infiltration.
- Can provide aesthetic benefits by enhancing the streetscape like standard street trees.
- Provides other non-stormwater benefits of trees including cleaner air, reduction of heat island effect, carbon sequestration, reduced noise pollution, reduced pavement maintenance needs, and cooler cars in shaded parking lots.
- Available with pre-cast concrete or proprietary (i.e., manufactured) designs or non-proprietary designs for reduced cost.

Limitations

- Limited to smaller drainage areas.
- Frequent maintenance required.
- Should not be used in areas of heavy sediment loads (i.e., unstabilized construction sites).
- Generally, less cost-effective than other stormwater infiltration systems in terms of cost per cubic foot of runoff treated due to cost of bioretention soil media and subsurface structural components.

Siting Considerations

- **Drainage Area:** The maximum contributing drainage area for one individual tree filter is between 0.25 and 0.5 acre. Larger drainage areas can be managed with the use of multiple tree filters; however, there may be more cost-effective solutions for larger drainage areas.

- **Soils:** Tree filters that return filtered runoff to the conveyance system and do not infiltrate into the ground can be used in almost any soil type. Tree filters that rely on infiltration should be used only when the soil infiltration characteristics are appropriate (see Chapter 10 for design guidance for stormwater infiltration systems).

- **Land Use:** Tree filters are suitable in ultra-urban settings where space is limited as well as residential and suburban areas. Potential locations include medians, streetscapes (e.g., between the curb and sidewalk), roadway shoulders, and along shared-use paths. Locate where the structural integrity of the roadbed material will not be compromised and where snow storage will not occur atop the tree filter.

- **Water Table and Bedrock:** For tree filters designed for infiltration (unlined systems), meet the minimum required vertical separation distances from the top and bottom of the filtering system to the seasonal high groundwater table (SHGT) and bedrock, as described in Chapter 10.

- **Horizontal Setbacks:** For bioretention systems designed for infiltration (unlined systems), meet the minimum horizontal setback distances in Chapter 10.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 for soil evaluation guidance.

Design Recommendations

General Considerations

This section addresses three types of tree filter designs (Table 13-7. Tree Filter Design Types

Type of System	Underdrain Type	Infiltration or Filtration Design?	Suitable for Retention?	Suitable for Treatment?	General Conditions for Use
Tree Filter with Underdrain Partial Infiltration System	Raised Underdrain	Infiltration and Filtration (partial infiltration)	Yes (infiltration volume only)	Yes	All HSG Soil types Underdrain required for HSG C and D Soils
Tree Filter with Underdrain and Liner Flow-Through System	Underdrain and Impermeable Liner	Filtration Only	No	Yes	Land Uses with Higher Potential Pollutant Loads Contaminated sites Where required vertical separation to SHGT cannot be met Sites with unacceptable setback distances for infiltration
Tree Filter Without Underdrain Infiltration System	No Underdrain	Infiltration and Filtration (Full infiltration)	Yes	Yes	HSG A and B Soils

):

- **Tree Filter with Underdrain (Partial Infiltration System):** Tree filters are commonly designed with an underdrain to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall. Underdrained systems can be used with any soil type or soil infiltration rate. The underdrain should be raised above the bottom of the system to maximize infiltration and enhance nitrogen removal. Underdrained systems (without a liner) are suitable for providing stormwater retention, although only the infiltrated volume (not the volume discharged via the underdrain) can be credited toward the Standard 1 retention requirement.

- **Tree Filter with Underdrain and Liner (Flow-Through System):** An underdrain and impermeable liner are required for use with Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10), in locations where contaminated soils exist, where the required vertical separation to SHGT cannot be met, or in locations with unacceptable horizontal setbacks for infiltration. Such systems are suitable for providing treatment but do not provide retention credit.

- **Tree Filter with No Underdrain (Infiltration System):** Tree filters can be designed to fully infiltrate into the native soil without an underdrain. Such systems, also called "treewells," are best suited for use with Hydrologic Soil Group (HSG) A and B soils. Tree filters can have higher relative construction costs than other surface infiltration systems presented in this Manual (infiltration basins and trenches) due to the cost of the engineered bioretention soil, plantings, subsurface structural components, etc. Infiltration tree filters (tree wells) can be designed without pre-cast or proprietary concrete chambers at reduced construction cost.

Table 13-4. Tree Filter Design Types

Type of System	Underdrain Type	Infiltration or Filtration Design?	Suitable for Retention?	Suitable for Treatment?	General Conditions for Use
Tree Filter with Underdrain Partial Infiltration System	Raised Underdrain	Infiltration and Filtration (partial infiltration)	Yes (infiltration volume only)	Yes	All HSG Soil types Underdrain required for HSG C and D Soils
Tree Filter with Underdrain and Liner Flow-Through System	Underdrain and Impermeable Liner	Filtration Only	No	Yes	Land Uses with Higher Potential Pollutant Loads Contaminated sites Where required vertical separation to SHGT cannot be met Sites with unacceptable setback distances for infiltration
Tree Filter Without Underdrain Infiltration System	No Underdrain	Infiltration and Filtration (Full infiltration)	Yes	Yes	HSG A and B Soils

Pretreatment

- Commonly incorporate pretreatment measures at locations where runoff enters the tree filter in accordance with the Pretreatment BMPs section of this Manual.

- Acceptable pretreatment measures include interior concrete sediment collection chambers and exterior deep sump hooded catch basins.

- Interior Concrete Sediment Collection Chambers
    - Should be designed to overflow directly into the tree filter via a level overflow weir wall.
        - Elevation of overflow weir wall should be sufficiently lower than gutter line to at least pass the applicable Water Quality Volume (WQV) or Water Quality Flow (WQF) below the elevation of the gutter line.
    - Should be equipped with a cover or with an overall tree filter grate.
    - Minimum depth: 4 feet from top of overflow weir wall.
    - Minimum bottom surface area: 6 square feet with no individual dimension (length or width) less than 2 feet.
    - Provide two 2-inch diameter seep holes (the lowest being 2 feet above interior bottom of collection chamber) along the weir wall.

- Deep Sump Hooded Catch Basin
    - Typically requires the tree filter surface to be at least 24 inches below the top of curb/sidewalk due to the depth of the catch basin outlet pipe.
    - If constructing a new catch basin, use a square catch basin structure, which should directly abut the tree filter. The width of the outlet should extend the full inside width of the catch basin structure. Outlet opening height should be sufficient to convey the applicable WQV or WQF but should not be less than 4 inches.
    - Minimum sump depth: 4 feet
    - If utilizing an existing round deep sump hooded catch basin structure, runoff can be conveyed to the tree filter via a pipe (see deep sump hooded catch basin design in the Pretreatment BMPs section of this Manual).

Sizing and Dimensions

- Tree Filter Bed (Bottom) Area
    - Tree filters should be designed by either the Static or Dynamic Methods as described in Chapter 10.
    - Tree filters should completely drain in 48 hours or less after the end of the design storm as described in Chapter 10.
    - For unlined systems, the design infiltration rate used for system sizing and drain time analysis should be equal to 50% of the slowest observed field infiltration rate of the underlying soils or 0.5 inches per hour (1.0 feet per day) for the bioretention soil media, whichever value is lower.

- For lined systems, use the coefficient of permeability of the bioretention soil media (0.5 inches per hour or 1.0 feet per day or) in the drain time analysis.
- Multiple tree filters can be combined to meet water quality goals.

- Bioretention Soil Depth
  - Engineered bioretention soil media should have a depth of 24 to 48 inches ,or as necessary to accommodate the required sizing, vegetation species and root establishment/growth, and subsurface conditions. The volume should be adequate to ensure root systems and thereby the tree will be viable and able to grow.
  - Bioretention systems with trees should have a minimum soil depth of 30 inches.
  - Soil depth may be limited by the requirement to maintain adequate separation to groundwater and bedrock as specified in Chapter 10.

- Ponding Depth
  - Maximum for water quality storm: 6 inches
  - Maximum for overflow events: 9 inches (preferred) to 12 inches (absolute maximum)

- Freeboard Depth
  - Minimum freeboard depth: 3 to 6 inches
  - As measured from the elevation of the maximum ponding depth to the facility's overflow elevation or to the invert of the inlet to the facility, whichever is lower.

- Bottom Width
  - Minimum: 5 feet

- Bottom Slope
  - Design bottom of tree filter to be level.

- Concrete Tree Filter Chamber
  - Should be a minimum of 18 inches deep below top of curb/sidewalk and should be designed to support adjacent structures.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Runoff can be introduced via a curb cut or drop inlet. Runoff can be introduced via a pipe from an upstream structure such as a catch basin, although this option is limited as it requires either a shallow upstream structure and/or deeper tree filter .

- Design the bioretention system in an off-line configuration to the extent feasible if runoff is delivered by a storm drain pipe or is along the main storm conveyance system.

- Depth between inlet and top of engineered soil media should be 2 inches or less and should be designed to minimize erosion within the tree filter.

Outlet & Overflow

- Tree filters designed off-line are typically sized to handle only the Water Quality Volume.
  - If the tree filter is designed to infiltrate and meets the infiltration criteria, an outlet is not required. Once the system has reached its capacity (i.e., once the system is full), additional flow will bypass the tree filter. The designer should confirm that the bypassed flow is managed downstream and does not worsen flooding.

- Tree filters designed in an on-line configuration must have an outlet sized to convey the 10-year, 24-hour storm event, at a minimum.
  - Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.
  - Outlets are typically an overflow riser that discharges to a storm drainage system.
  - Outlets must be designed such that stormwater does not overflow from the tree filter onto adjacent roadway surfaces.

- If used, underdrains can connect to a downstream drainage system or daylight at an approved discharge point.

Underdrain System

- Use an underdrain system when a proposed tree filter meets one or more of the following conditions:
  - Is in native soil that has an infiltration rate less than 0.3 inch per hour (HSG C and D soils)
  - Does not meet vertical separation distance to SHGT or bedrock (Chapter 10) and should be lined
  - Does not meet minimum horizontal setback distances (Chapter 10) and should be lined
  - Is within a Land Use with Higher Potential Pollutant Loads (LUHPPL) (Chapter 10) or area of contaminated soils and should be lined.

- An underdrain is also recommended, but not required, for other tree filter installations to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall.

- Minimum underdrain pipe diameter: 4 inches

- Minimum underdrain pipe slope: 0.5%

- Use two layers of gravel with the underdrain system. Both layers of gravel should be located below and extend across the entire bottom of the tree filter chamber. The upper gravel layer should consist of 3 inches of pea gravel, and the lower layer should consist of a 12-inch thick gravel sump.
- For unlined systems, install the perforated underdrain pipe at the top of the 12-inch gravel sump. For systems that are lined with an impermeable liner to prevent infiltration, install the underdrain pipe at the bottom of the 12-inch gravel sump so the system can drain completely between storm events.
- If the tree filter is designed without an underdrain, pea gravel and gravel sump are optional.
- Lay underdrain such that perforations are on the bottom of the pipe.
- Use solid (non-perforated) pipe sections and watertight joints outside the BMP.
- If an underdrain is used, place non-woven filter fabric above the pea gravel (below the bioretention soil layer) for a distance of 1 to 2 feet on both sides of the underdrain. Filter fabric should not be placed across the entire width of the chamber. If gravel storage/underdrain layers extend below the concrete chamber, place filter fabric along sidewalls of excavation below the chamber.
- Other considerations when designing/installing underdrains:
    - Provide a marking stake and an animal guard for underdrains that daylight at grade.
- Include a minimum of one observation well/cleanout for each underdrain.
    - Cleanouts should be at least 4 inches in diameter, be nonperforated, and extend to the surface. Cap cleanouts with a watertight removable cap. The cleanout should be highly visible at the ground surface or below the grate when the grate is removed.

Materials

- Surface Cover
    - If a tree filter grate is used, no surface cover is required over the bioretention soil media.
    - If a tree filter grate is not used, a minimum 3-inch thick layer of river stone may be used on top of the bioretention soil media.
    - Mulch may be used directly around the base of the tree, but mulch should NOT be used to cover the entire surface of the tree filter.
    - If mulch is used, use 2 to 4 inches of shredded hardwood bark mulch, aged for 6 months minimum.

- Vegetation
  - Select tree/shrub species with guidance provided in Appendix F of this Manual. Use of native species is recommended.
  - Location of tree filter and species should be selected to avoid obstruction of sight lines.

- Engineered Bioretention Soil Media

  - The engineered bioretention soil media in tree filters systems is designed to filter/treat runoff and to provide sufficient organic material to support plan establishment and growth.

  - The engineered bioretention soil media should be a homogeneous soil mix of (by volume):
    - 60–85% Sand
    - 15–25% Topsoil
    - 3–8% Organic Matter

  - **Sand** should be washed concrete sand (ASTM C33 or AASHTO M-6) or coarse washed sand that meets the gradation schedule as shown in State of Connecticut Department of Transportation Standard Specifications, Section M.01 (Aggregates), Table M.01.04-1 for Fine Aggregate Gradations.

  - **Topsoil** should contain 5–20% organic material, have a pH range of 5.5 to 7.0, and be a sandy loam, loamy sand, or loam per USDA soil texture with less than 5% clay content. Topsoil that meets the State of Connecticut Department of Transportation Standard Specifications, Section M.13.01 (Roadside Development) for Topsoil may also be used, except it should contain less than 5% clay.

  - **Organic matter** should consist of one of the following materials
    - Sphagnum Peat: Partially decomposed sphagnum peat moss, finely divided or of granular texture with 100 percent passing through a 1/2-inch (13-mm) sieve, a pH of 3.4 to 4.8.
    - Wood Derivatives: Shredded wood, wood chips, ground bark, or wood waste; of uniform texture and free of stones, sticks, soil, or toxic materials.

  - Compost shall NOT be used as organic matter since the use of compost in bioretention soil media can result in nutrient export from the system.

  - Soil amendments such as zerovalent iron and/or drinking water treatment residuals (alum) may be used to further enhance phosphorus sorption.

  - Bioretention soil mix should have a pH of 5.2 to 7.0 and meet the particle size distribution defined in Table 13-8.

Table 13-5. Acceptable Particle Size Distribution of Final Bioretention Soil Mix

Media Type	Sieve #	Size (inches)	Size (mm)	% Passing
Coarse Sand	4	0.187	4.76	100
Medium Sand	10	0.079	2.00	95
Fine Sand	40	0.017	0.42	40-15
Silt	200	0.003	0.075	10-20
Clay	<200	Pan	Pan	0-5

  - Bioretention soil mix should NOT contain any of the following materials: stones, clods, roots, clay lumps, and pockets of coarse sand exceeding 0.187 inches (4.76 mm) in any dimension; plants, sod, concrete slurry, concrete layers or chunks, cement, plaster, building debris, asphalt, bricks, oils, gasoline, diesel fuel, paint thinner, turpentine, tar, roofing compound, acid, solid waste, and any other extraneous materials that are harmful to plant growth.

- Pea Gravel
  - Should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.

- Gravel Sump
  - Should consist of 3/4" AASHTO No. 5 stone. Gravel should be clean (washed and free from dirt and debris), crushed, and angular.

- Filter Fabric
  - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

- Poured-in-place Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section 6.01 (Concrete for Structures).

- Underdrain (perforated and non-perforated pipe sections)
  - Polyethylene or polyvinyl pipe.

- Liner
  - If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 with the approval of the review authority.

Other Considerations

- If tree filter is located adjacent to a sidewalk or in an area subject to high pedestrian traffic, consider the use of curb around the perimeter of the tree filter, or the use of a grate over the tree filter to reduce trip hazard and prevent pet waste and trampling.
    - If height from top of tree filter media to sidewalk elevation is greater than 12 inches, use a grate.

- Where existing sidewalks are modified to incorporate tree filters, the sidewalk should comply with meet accessibility requirements.
    - Grates can be used over tree filters to meet sidewalk width accessibility requirements.

- If designing a lined system in a location where 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.

- For lined systems within LUHPPLs, a shutoff valve can be installed on the underdrain outlet to capture and contain accidental spills or releases that reach the bioretention system.

- Roadway stability can be a design issue when installing tree filters along roadways. It may be necessary to provide a vertical impermeable barrier to keep water from saturating the road's sub-base. The barrier should be capable of supporting H-20 loads.

Winter Operations

- Tree filters should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. If unavoidable, use grates and tree protection barriers to minimize potential damage to the system. Refer to Chapter 7 for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
    - After excavation of the system and installation of the concrete chamber
    - After placement of gravel layer
    - After placement of underdrain before covering by the pea gravel layer
    - After placement of bioretention soil media
    - After installation of bypass, outlet/overflow, and inlet controls
    - After tree has been installed

- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The bioretention soil mix should be tested prior to placement according to the specifications in this section (at least one test per bioretention system). The designing qualified professional should certify that the bioretention soil mix meets the specifications in the previous section based on soil testing results.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the bioretention system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed tree filter.
- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The system should be excavated to the dimensions and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. Excavation equipment should not be allowed within the limits of the system.
- The gravel, pea gravel, and bioretention soil media should be placed in the excavation by a hydraulic excavator located outside the limits of the system and then hand-raked to the desired elevation.
- Place the bioretention soil in 6 to 12-inch lifts. The bioretention soil needs to settle before planting. Lightly tamp or spray the surface of the bioretention soil with water until saturated. The elevation of the bioretention soil can be a couple of inches higher at installation than the design elevation in anticipation of settling. Bring bioretention soil levels back to the design elevation if necessary.
- Install tree or shrub(s) in the tree filter. Water tree/shrubs thoroughly immediately after planting and as necessary until fully established. The bioretention soil mix provides enough organic material to adequately supply nutrients from natural cycling.

Maintenance Needs

- Tree filters should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintenance activities such as sediment removal and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the bioretention soil media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

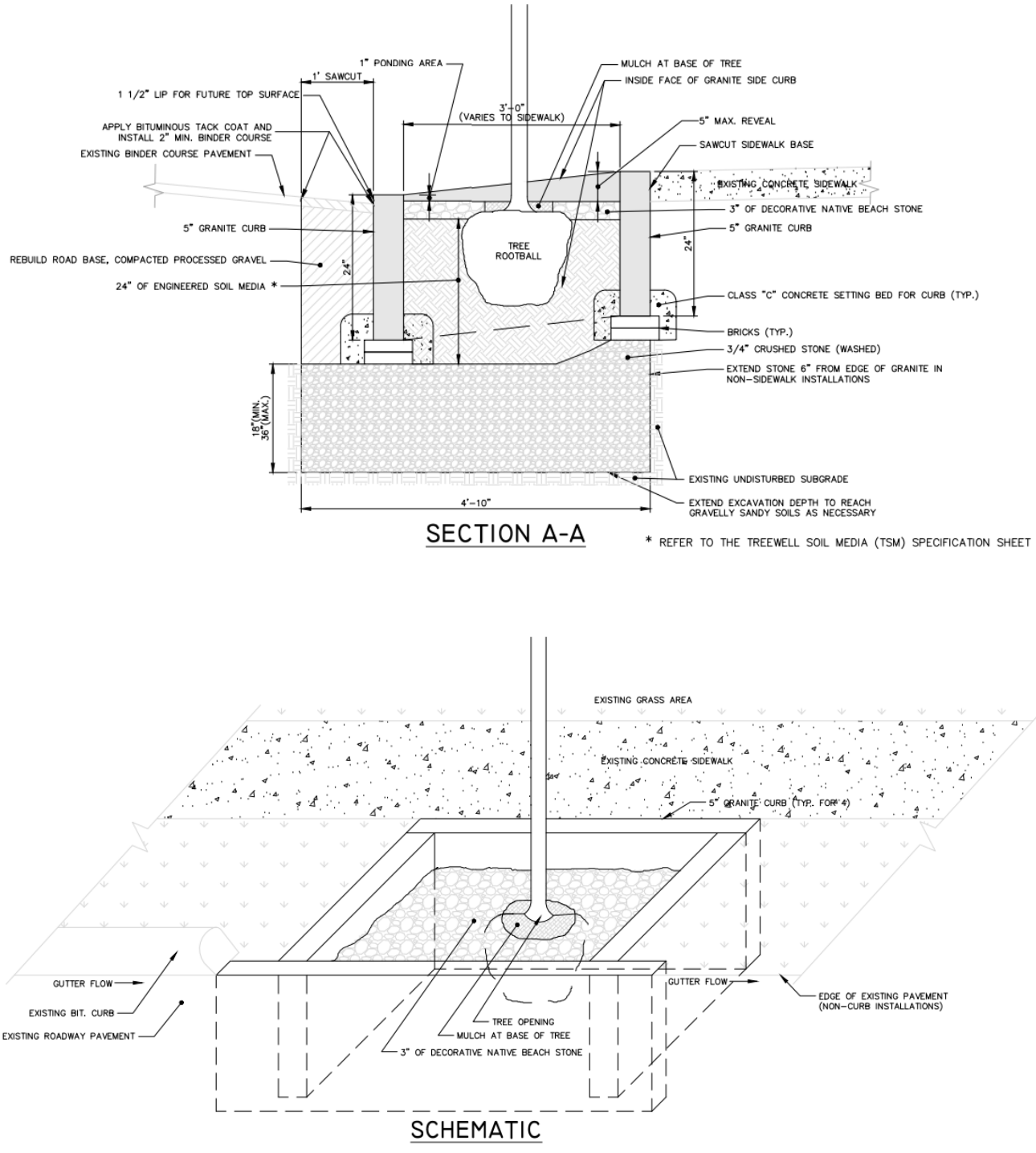
Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect tree filter annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment chamber or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.
- Remove accumulated sediment from the tree filter when the sediment accumulation exceeds 1 inch or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the soil media is clogged. Replace with fresh bioretention soil media that conforms to the specifications in this section.
- Tree filters require seasonal landscape maintenance, including:
    - Watering trees and shrubs as necessary during first growing season
    - Watering as necessary during dry periods
    - Treating diseased trees and shrubs as necessary
    - Inspection of soil and repairing eroded areas around the tree filter

- Removal of litter and debris from the tree filter surface and/or grate

Figure 13-19. Tree Filter with Underdrain Schematic

Figure 13-20. Tree Filter without Underdrain (Treewell) Schematic



Source: Niantic Treewell Design, Town of East Lyme Engineering Department.

Sand Filter

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	■
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**High**

*Includes sediment-bound pollutants and floatables (with pretreatment)

/mplementation

Capital Cost	**Medium**
Maintenance Burden	**High**
Land Requirement	**Medium**

Description

Sand filters are sand-filled basins or trenches that capture, temporarily store, and filter stormwater runoff. Sand filters can be designed as surface filters or underground filters. The design guidelines in this section focus on surface sand filters. Sand filters require less space than other filtering practices but must be in locations with adequate elevation to provide the necessary hydraulic head. Sand filters have higher longevity than other filtering practices and generally have a lower land requirement than bioretention basins.

Sand filters are frequently designed to infiltrate but are always equipped with an underdrain to capture filtered water and assist with drainage from the system. Following pretreatment, stormwater is temporarily stored above the surface of the sand filter and flows downward through a layer of sand that filters the runoff before discharging from the system through an underdrain or into the underlying soil via infiltration. Pollutants in runoff are treated in sand filters through the processes of settling, filtration, and adsorption. Surface sand filters may also be used to provide stormwater quantity control when designed as on-line facilities.

Sand filters are better suited for impervious drainage areas. They are not recommended for use in pervious drainage areas where high sediment loads, and organic material can clog the sand bed.

Advantages

- Applicable to small drainage areas.
- May require less space than other BMPs.

- Ideal for stormwater retrofits and highly developed sites.
- High solids, metals, and bacteria removal efficiency.
- High longevity.

Limitations

- Limited to smaller drainage areas.
- Frequent maintenance required.
- Typically require a minimum head difference of approximately 5 feet between the allowable pool elevation above the filter and outlet of the filter.
- Not feasible in areas of high-water tables.
- Should not be used in areas of heavy sediment loads (i.e., unstabilized construction sites).
- Can be unattractive without grass or vegetative cover. Bioretention may be a more aesthetically pleasing alternative due to incorporation of more diverse selection of plants.

Siting Considerations

- **Drainage Area and Head:** The maximum contributing drainage area for surface sand filters is 5 acres. Sand filters are best located where there is adequate surface area to temporarily store stormwater and enough elevation difference (2 to 6 feet) between the design pool elevation and the outlet of the sand filter (underdrain or underlying soil).

- **Slopes:** Sand filters can be used on sites with slopes of approximately 6 percent or less. Locate sand filters where the topography allows the design of the sand filter bottom to be level.

- **Soils:** Sand filters that return filtered runoff to the conveyance system and do not infiltrate into the ground can be used in almost any soil type. Sand filters that rely on infiltration should be used only when the soil infiltration characteristics are appropriate (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for design guidance for stormwater infiltration systems).

- **Land Use:** Sand filters are suitable in urban and rural settings. Sand filter systems are generally applicable to highly impervious sites. Potential locations include along shared-use paths, along borders of parking lots, and within available open space/pervious areas. Sand filters should be sited in locations that will not be used as dedicated snow storage areas and which have low likelihood for pedestrian traffic.

- **Water Table and Bedrock:** For sand filters designed for infiltration (unlined systems), at least 3 feet of separation is recommended between the bottom of the sand and the seasonal high groundwater table (SHGT) and bedrock to maintain adequate drainage, prevent structural damage to the filter, and minimize the potential for interaction with groundwater. The vertical separation distance to the SHGT or bedrock may be reduced to 2 feet as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation guidance.

Design Recommendations

General Considerations

This section addresses two types of surface sand filter designs. Figure 13-21 is a schematic of a surface sand filter design. (See Table 13-9):

- **Surface Sand Filter with Underdrain - Unlined (Partial Infiltration System):** All surface sand filters should be designed with an underdrain to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall. Underdrained systems can be used with any soil type or soil infiltration rate. The underdrain should be raised above the bottom of the system to maximize infiltration. Underdrained sand filter systems (without a liner) are suitable for providing stormwater retention, although only the infiltrated volume (not the volume discharged via the underdrain) can be credited toward the Standard 1 retention requirement.

- **Surface Sand Filter with Underdrain and Liner (Flow-Through System):** An underdrain and liner are required for use with Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems), in locations where contaminated soils exist, where the required vertical separation to SHGT cannot be met, or in locations with unacceptable horizontal setbacks for infiltration. Such systems are suitable for providing treatment but do not provide retention credit.

Figure 13-21 is a schematic of a surface sand filter design.

Table 13-6. Surface Sand Filter Design Types

Type of System	Underdrain Type	Infiltration or Filtration Design?	Suitable for Retention?	Suitable for Treatment?	General Conditions for Use
Surface Sand Filter with Underdrain – Unlined Partial Infiltration System	Raised Underdrain	Infiltration and Filtration	Yes (infiltration volume only)	Yes	All HSG Soil types
Surface Sand Filter with Underdrain and Liner Flow-Through System	Underdrain and Impermeable Liner	Filtration Only	No	Yes	Land Uses with Higher Potential Pollutant Loads Contaminated sites Where required vertical separation to SHGT cannot be met Sites with unacceptable setback distances for infiltration

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the sand filter in accordance with the Pretreatment BMPs section of this Manual.
- Acceptable pretreatment measures include vegetative filter strips, sediment forebays, pretreatment swales, deep sump hooded catch basins, and proprietary pretreatment devices.
- Sediment forebays should have a minimum storage volume of 25% of the Water Quality Volume (WQV) and release it to the filter media over a 24-hour period, while flow-through Pretreatment BMPs should treat at least the equivalent Water Quality Flow (WQF).

Sizing and Dimensions

- Surface Sand Filter Bed (Bottom) Area
  - Sand filter should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.
  - Sand filter should completely drain in 48 hours or less after the end of the design storm as described in Chapter 10.
  - For the drain time analysis, use the coefficient of permeability of the filter media (3.5 feet per day or 1.75 inches per hour for sand). If the sand filter is designed

with a loam surface, use a coefficient of permeability value of 1.0 feet per day or 0.52 inches per hour.

- Sand Filter Bed Thickness
  - 18 inches (minimum)
  - Filter bed thickness may be limited by the requirement to maintain adequate separation to groundwater and bedrock as specified in Chapter 10.

- Ponding Depth
  - Maximum for water quality storm: 24 inches
  - Maximum for overflow events: 36 inches

- Bottom Width
  - Minimum: 4 feet

- Bottom Slope
  - Design the top and bottom of sand filter bed to be level.

- Side Slopes
  - Maximum: 3(H):1(V) slopes. If site topography does not allow for 3(H):1(V) slopes, vertical concrete walls with a maximum height of 30 inches can be used.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Runoff can be introduced to the sand filter through overland flow, curb cuts, inlet structures, swales/channels, and/or pipes.

- Design the sand filter in an off-line configuration to the extent feasible if runoff is delivered by a storm drain pipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Outlets are typically a stabilized spillway, gabion berm, concrete weir, precast concrete structure, or polyethylene/polyvinyl chloride riser structure.

- On-line systems should be designed to avoid erosion of the sand filter bed and have a primary outlet sized to convey the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event (assuming the primary outlet is not designed to pass the 100-year storm event).

- Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm

Underdrain System

- Minimum underdrain pipe diameter: 4 inches
- Minimum underdrain pipe slope: 0.5%
- Use two layers of gravel with the underdrain system. Both layers of gravel should be located below and extend across the entire bottom of the sand filter. The upper gravel layer should consist of 3 inches of pea gravel, and the lower layer should consist of a 12-inch thick gravel sump.
- For unlined systems, install the perforated underdrain pipe 2 inches below the top of the gravel sump to promote infiltration. For systems that are lined with an impermeable liner to prevent infiltration, install the underdrain pipe 2 inches above the bottom of the gravel sump so the system can drain between storm events.
- Lay underdrain such that perforations are on the bottom of the pipe.
- Use solid (non-perforated) pipe sections and watertight joints wherever the underdrain system passes below berms, extends down steep slopes, connects to a drainage structure and/or daylights.
- Place filter fabric along sidewalls of excavation and above the pea gravel (below the sand layer) for a distance of 1 to 2 feet on both sides of the underdrain. Filter fabric shall not be placed across the entire width of the sand filter.
- Other considerations when designing/installing underdrains:
    - Provide a marking stake and an animal guard for underdrains that daylight at grade.
    - If designed with laterals, space collection laterals every 25 feet or less.
- Include a minimum of two observation wells/cleanouts for each underdrain; one at the upstream end and one at the downstream end.
- Cleanouts shall be at least 4 inches in diameter, be non-perforated and extend to the surface. Cap cleanouts with a watertight removable cap. The cleanout should be easily visible.
- Provide one cleanout for every 1,000 square feet of surface area (at a minimum) or for every 250 linear feet of total pipe length in larger systems.

Materials

- Surface Cover
    - The side slopes and surface of the sand filter bed should consist of 3 to 6 inches of loam/topsoil and grass. If a loam/topsoil and grass surface layer is selected for

the surface of the sand filter bed, use a hydraulic conductivity value of 1.04 feet per day (0.52 inches per hour) for system sizing.
    - To minimize maintenance, no additional cover material is required over the surface of the sand filter bed. Pea gravel or river stone may also be placed on top of the sand layer as an alternative to the exposed sand layer.
    - Filter fabric should not be used between the surface cover layer (if any) and the sand layer.

- Vegetation
    - Specify vegetation (e.g., drought tolerant grass) for the sand filter side slopes and on top of the sand filter bed (vegetation on the filter bed is optional) with the guidance provided in Appendix F of this Manual.

- Sand
    - Should be washed concrete sand (ASTM C33 or AASHTO M-6) or coarse washed sand that meets the gradation schedule as shown in State of Connecticut Department of Transportation Standard Specifications, Section M.01 (Aggregates), Table M.01.04-1 for Fine Aggregate Gradations.

- Pea Gravel
    - Should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.

- Gravel Sump
    - Should consist of 3/4" AASHTO No. 5 stone. Gravel should be clean (washed and free from dirt and debris), crushed, and angular.

- Filter Fabric
    - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

- Underdrain (perforated and non-perforated pipe sections)
    - Polyethylene or polyvinyl pipe.

- Liner
    - If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

- Turf Reinforcement Matting (TRM)
    - Stabilize the side slopes of the sand filter with TRM to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.

- If used, shall be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Other Considerations

- If designing a lined system in a location where 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.

- For lined sand filters within LUHPPLs, a shutoff valve can be installed on the underdrain outlet to capture and contain accidental spills or releases that reach the bioretention system.

- Non-woven filter fabric should be placed along the sidewalls of the excavation to help direct the water flow downward, reduce lateral flows, and to reduce lateral soil migration. Place filter fabric along sidewalls of excavation and above the pea gravel (below the sand layer) for a distance of 1 to 2 feet on both sides of the underdrain. Filter fabric shall not be placed across the entire width of the sand filter.

Winter Operations

- Surface sand filters should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the sand filter and scarification of bottom and sidewalls of excavation
  - After placement of gravel layer
  - After placement of underdrain before covering by the pea gravel layer
  - Inspection of sand material prior to placement
  - After placement and leveling of sand layer
  - After installation of bypass, outlet/overflow, and inlet controls
  - After grass and/or pea gravel surface cover have been installed

- The designing qualified professional should provide an as-built plan of the completed sand filter along with a certification that the system was designed in accordance with the

guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- Sand filters should not be used as temporary sediment traps for construction erosion and sediment control.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.
- The sand filter should be fenced off during the construction period to prevent disturbance of the soils.
- The sand filter should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the system. A hydraulic excavator or backhoe loader, operating outside the limits of the sand filter, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the sand filter.
- The gravel, pea gravel, and sand layers should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the sand filter and then hand-raked to the desired elevation.
- Place the sand in 6 to 12-inch lifts. Lightly tamp or spray the surface of the sand with water. The sand can be expected to settle, especially after becoming saturated. For this reason, the elevation of the sand layer can be a couple of inches higher at installation than the design elevation in anticipation of settling. Sand should be carefully placed to avoid formation of voids and short-circuiting.
- Install vegetation (e.g., drought tolerant grass) on the side slopes and surface of the sand filter in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.

Maintenance Needs

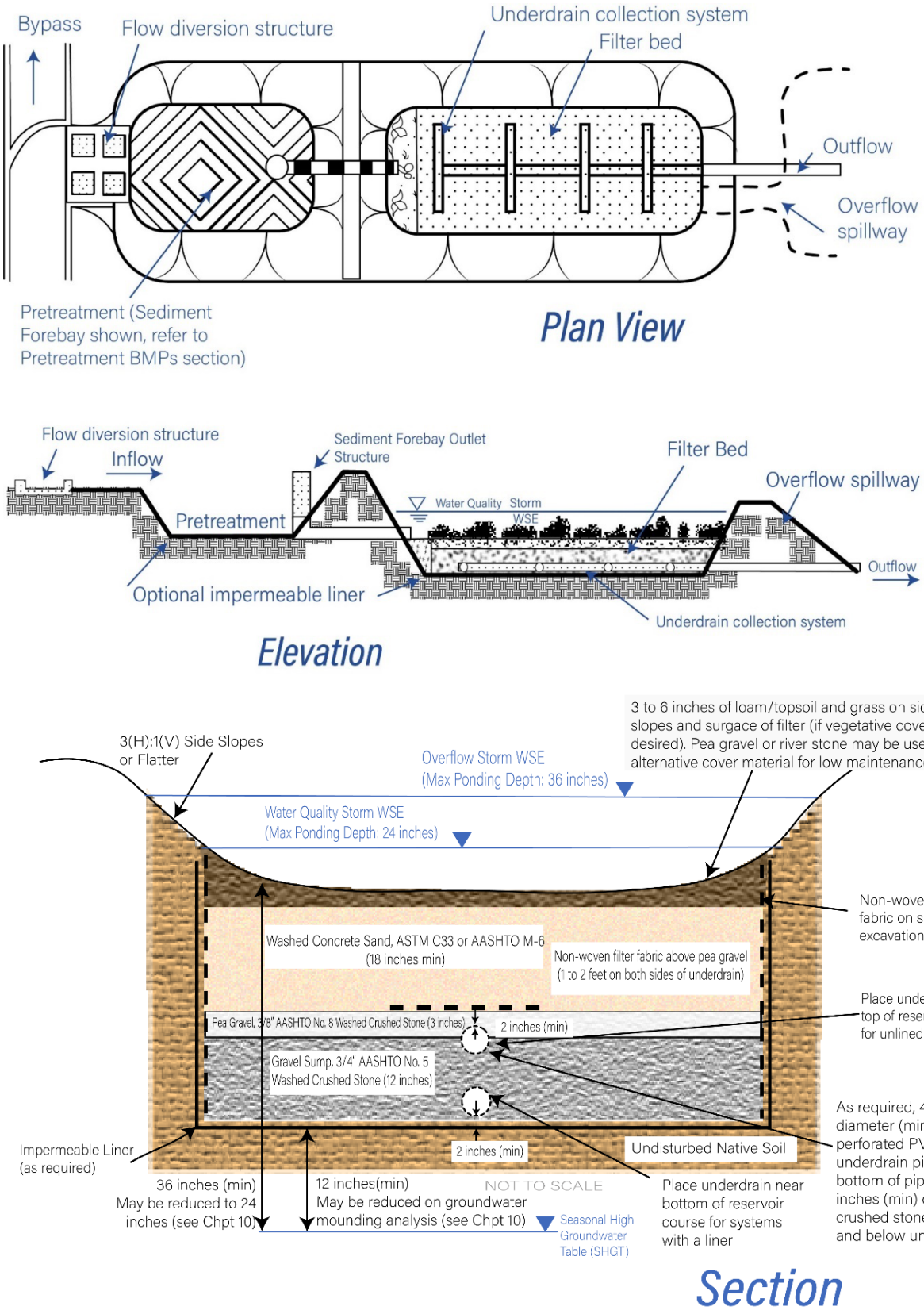
- Surface sand filters should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the filter media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect the sediment forebay or other pretreatment area twice a year.
- Inspect the remainder of the sand filter annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.
- Remove sediment from the sand filter when the sediment accumulation exceeds 2 inches or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the filter is clogged. Replace with fresh washed concrete sand that conforms to the specifications in this section.
- Weed as necessary. Mow grass within sand filter to a height of 6 inches or more. Maintain a healthy, vigorous stand of grass cover; re-seed as necessary.
- Periodically remove grass clippings to prevent clogging of the surface of the sand filter.
- Mowing should not be performed when the ground is soft to avoid the creation of ruts and compaction, which can reduce infiltration.

Figure 13-21. Surface Sand Filter Schematic



Stormwater Pond

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	■
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Moderate**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**High**

Description

Stormwater ponds are designed to retain a permanent pool of water that provides treatment for the water quality storm event and peak runoff attenuation for larger storms. This section addresses four types of stormwater ponds:

- Wet Pond
- Micro pool Extended Detention Pond
- Wet Extended Detention Pond
- Multiple Pond System

Stormwater is treated primarily through sedimentation, as suspended particles and attached pollutants settle to the bottom of the pond. Stormwater ponds can also reduce soluble pollutants in stormwater discharges by adsorption to sediment, bacterial decomposition, and the biological processes of aquatic and fringe wetland vegetation.

The key to maximizing the pollutant removal effectiveness of stormwater ponds is maintaining a permanent pool of water. To achieve this, the bottom of stormwater ponds should be located below the seasonal high groundwater table or should have a sufficiently large contributing drainage area and an impermeable liner if located in permeable soils. The pool typically operates on the instantaneously mixed reservoir principle where incoming water mixes with the existing pool and undergoes treatment through sedimentation and other processes. When the existing pool is at or near the pond outlet or when the primary flow path through the pond is highly linear, the pond may act as a plug flow system in which incoming water displaces the permanent pool, which is then discharged from the pond. In this process, a portion of the "new" polluted runoff enters the pond as the "old" treated water is discharged from the pond, thereby allowing treatment of the Water Quality Volume (WQV). When designed in an on-line

configuration, stormwater ponds can also be sized to treat and provide peak runoff attenuation for storms larger than the water quality storm event.

The permanent pool of a stormwater pond reduces the velocity of incoming water to prevent resuspension of particles and promote settling of newly introduced suspended solids. The energy dissipating and treatment properties of the permanent pool are enhanced by aquatic vegetation, which is an essential part of the stormwater pond design. In contrast, a dry extended detention basin, which has no permanent pool, is not suitable for stormwater treatment due to the potential for resuspension of accumulated sediment by incoming storm flows during the early portion of a storm event when the basin is empty.

Stormwater ponds do not provide sufficient retention or runoff volume reduction through infiltration or other processes and therefore cannot be used to meet the Standard 1 retention performance criterion of this Manual.

Advantages

- Effective for removal of particulate and soluble pollutants.
- Can provide an aesthetic benefit if open water is desired as part of an overall landscaping plan.
- Can provide wildlife habitat with appropriate design elements.
- Can provide peak runoff attenuation.

Limitations

- Do not provide infiltration or sufficient runoff volume reduction, and therefore cannot be used to meet the Standard 1 retention performance criterion.
- Unlined ponds that intercept groundwater have potential to impact groundwater quality if dissolved pollutants are present in the runoff.
- Lined ponds typically require a minimum drainage area in order to maintain a permanent pool, which may become difficult during extended dry periods.
- Require a relatively large land area.
- May cause thermal impacts to receiving waters and therefore should not discharge directly to Coldwater streams or other receiving water environments that are sensitive to thermal loads.
- Ponds with steep side slopes and/or deep wet pools may present a safety risk in residential areas and areas with public access.
- Stormwater ponds can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools. If amphibians deposit their eggs in these artificial ponds, they rarely survive due to the sediment and pollutant loads, as well as fluctuations in water quality, quantity, and temperature.

Siting Considerations

- **Drainage Area:** Stormwater ponds that utilize a liner system should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, the minimum contributing drainage area for lined ponds is 10 acres. Smaller drainage areas may be suitable if intercepting groundwater or with sufficient surface runoff to support a permanent pool. A water budget analysis should be performed to demonstrate that sufficient groundwater flow and/or surface runoff is available to maintain the permanent pool depth.

- **Groundwater:** Stormwater ponds should intercept groundwater or have an impermeable liner to maintain a permanent pool if located in permeable soils. The elevations of unlined ponds should be established such that the groundwater elevation is equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered.

- Land Uses: Land uses will dictate potential pollutants-of-concern and potential safety risks. A liner is required for stormwater ponds that receive runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) or on contaminated sites. The pond's permanent pool may pose a safety risk in residential areas and areas with public access, sometimes requiring fencing to limit access to the pond.

- Baseflow: A small amount of baseflow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer. This baseflow can be provided by groundwater discharge to the pond or the drainage system that feeds the pond.

- **Site Slopes:** Site slopes greater than 6% may result in the need for an embankment greater than 4 feet above existing grade to provide the desired storage volume, which would be subject to CT DEEP dam safety regulatory requirements. Steep slopes may also present design and construction challenges, and significantly increase the cost of earthwork.

- **Receiving Waters:** Stormwater ponds should not be used for sites that discharge within 200 feet of coldwater streams, 200 feet from a public water supply reservoir, or 100 feet from streams tributary to a public water supply reservoir.

- **Natural Wetlands/Vernal Pools:** Natural wetlands and vernal pool depressions should not be used, either temporarily or permanently, as a stormwater pond. Stormwater ponds should be located at least 750 feet from a vernal pool. They should not be sited between vernal pools, or in areas that are known primary amphibian overland migration routes.

Soil Evaluation and Water Budget Analysis

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, and depth to bedrock. Perform test pits or soil borings in accordance with the soil evaluation guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- A water budget analysis should be performed for stormwater pond designs. The water budget consists of calculations, on a daily basis, of the inflows to and outflows from the pond to show that the required depth of water in the pond is maintained throughout the year. The analysis should be performed for a wet year, a dry year, and an average year. The analysis should demonstrate that the permanent pool of the stormwater pond meets the minimum requirements of this section for all of the days in each of the three analyses. All of the inputs to and outputs from the pond should be considered, including direct precipitation, runoff, flooding, groundwater inflow, evapotranspiration, groundwater outflow, and anu reuse of the pond water such as irrigation.

Design Recommendations

General Considerations

This section addresses the following types of stormwater pond designs:

- **Wet Pond:** A wet pond typically consist of two major components - a forebay and a permanent wet pool. The forebay provides pretreatment by capturing coarse sediment particles to minimize the need to remove the sediments from the primary wet pool. The wet pool serves as the primary treatment mechanism and where much of the storage capacity exists. Wet ponds can be sized for a wide range of watershed sizes, if adequate space exists. For example, a variation on the conventional wet pond, sometimes referred to as a "pocket pond", is intended to serve relatively small drainage areas (between one and five acres). Because of these smaller drainage areas and the resulting lower hydraulic loads of pocket ponds, outlet structures can be simplified and often do not have safety features such as emergency spillways and low-level drains. Figure 13-22 depicts a typical schematic design of a conventional wet stormwater pond, while Figure 13-23 shows a typical schematic design of a modified wet pond or "pocket pond."

Several adaptations of this basic design have been developed to achieve the specific treatments goals of various watershed or site conditions. These wet pond design variations are described below.

- **Micropool Extended Detention Pond:** Micropool extended detention ponds are primarily used for peak runoff control and utilize a smaller permanent pool than conventional wet ponds. While micropool extended detention ponds are not as efficient as wet ponds for the removal of pollutants, they should be considered when a large open pool might be undesirable or unacceptable. Undesirable conditions could include thermal

impacts to receiving streams from a large open pool, safety concerns in residential areas, or where maintaining a large open pool of water would be difficult due to a limited drainage area or deep groundwater.

Micropool extended detention ponds are also efficient as a stormwater retrofit to improve the treatment performance of existing dry detention basins. Figure 13-24 depicts a typical schematic design of a micropool extended detention pond.

- **Wet Extended Detention Pond:** These ponds are very similar to wet ponds with the exception that their design is more focused on attenuating peak rates of runoff. As a result, more storage volume is committed to managing peak flows as opposed to maximizing the wet pool depth. The configuration of the outfall structure may also differ from typical wet pond designs to provide additional storage volume above the level of the permanent pool. Figure 13-25 depicts a typical schematic design of a wet extended detention pond.

- **Multiple Pond System:** Multiple Pond systems consist of several wet pools that are constructed in a series following a forebay. The advantage of these systems is that they can improve treatment efficiency by better simulating plug flow conditions as compared to a single large wet pool. Also, these systems can reduce overall maintenance needs since more frequent maintenance would be performed within the first pool cells as opposed to the large, primary pool. The disadvantage of these systems is that they typically require more land area to treat the WQV. Figure 13-26 depicts a typical schematic design of a multiple pond system.

Pretreatment – Sediment Forebay

- A sediment forebay is recommended for all wet pond systems, although other forms of pretreatment may be used at locations where runoff enters the stormwater pond.

- The sediment forebay and other pretreatment measures should be designed in accordance with the Pretreatment BMPs section of this Manual.

- The sediment forebay should be sized to contain at least 10% of the WQV. The forebay storage volume may be used to fulfill the WQV requirement of the overall stormwater pond. The forebay should also include additional sediment storage volume that may not be used for WQV calculations.

Sizing and Dimensions

- The pond volume, including the volume of the sediment forebay, permanent pool, and extended detention area, should be equal to or exceed the WQV. A larger volume should be used to achieve greater pollutant removal when it is necessary to meet specific water quality standards. The recommended division of storage between the forebay, permanent pool, and extended detention is outlined in Table 13-10.

Table 13-7. Water Quality Volume Distribution in Stormwater Pond Designs

Design Variant	Percent of Water Quality Volume (WQV)		
	Sediment Forebay	Permanent Pool	Extended Detention
Wet Pond	10%	90%	0%
Micropool Extended Detention Pond	10%	10%	80%
Wet Extended Detention Pond	10%	40%	50%
Multiple Pond System	10%	40%	50%
Pocket Pond	10%	40%	50%

Source: NYDEC, 2001.

- Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, extended detention, and marsh).
- The extended detention storage volume (storage volume above the permanent pool provided for additional water quality and stormwater quantity control) should drain out of the pond over a minimum of 24 hours, after which the water surface elevation in the pond will return to the permanent pool elevation.
- Underwater or marsh berms may be incorporated in the design to lengthen the flow path through the pond.
- Thermal impacts of stormwater ponds may be mitigated by implementing one or more of the following design measures:
  - Use of a smaller permanent pool with more extended detention storage and an extended detention time of 24 hours or less
  - Planting of shade trees around the perimeter of the pond (but at least 25 feet away from inlet/outlet structures and the pond embankment) to reduce solar warming of the pool
  - Designing the pond with a series of pools, as opposed to a single pool, to allow cooling prior to discharge
  - Use of an outlet structure designed to draw water from near the bottom of the pond where water temperatures may be cooler
  - Use of an underdrained gravel trench outlet.
- The pond should have a curvilinear shape and a minimum length: width ratio of 3:1 from the pond inlet to outlet.

- Upper stages of the pond should provide temporary storage of larger storms (2-year, 10-year, and 100-year, 24-hour events) to control peak discharge rates.
- Provide variable pond depths of 4 to 6 feet but not exceeding depths of 8 feet. Maintaining pond water depths in excess of 4 feet precludes invasive emergent vegetation such as cattails. Emergent vegetation provides mosquito larvae with refuge from predators and increases nutrient availability.
- Maintain pond water quality sufficient to support mosquito-feeding fish. Stormwater ponds often develop mini ecosystems where birds, frogs, and other insects feed, many of which are natural predators of mosquitoes and nuisance insects. Ponds can also be stocked with predatory fish native to Connecticut that feed on mosquito larvae such as banded sunfish, flathead minnows, Eastern mud minnows, and several species of killifish. The CT DEEP Fisheries Division should be consulted regarding species selection. Other natural predators of mosquitoes such as dragonfly nymphs can also be used.
- Pumping of groundwater to maintain the permanent pool should not be allowed.
- The volume below the surface elevation of the permanent pool should not be included in storage calculations for peak flow management.

Side Slopes

- 3(H):1(V) slopes or flatter are preferred.
- The perimeter of permanent pool areas four feet or greater in depth should provide two benches:
    - Provide a flat safety bench that extends 10 feet outward from the normal water edge to the toe of the pond side slope.
    - Provide a flat aquatic bench that extends 10 feet inward from the normal water edge at a depth of 12-18 inches below the normal pool water surface elevation.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.
- The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet to minimize the potential for short-circuiting and should be located in a manner that meets or exceeds desired length to width ratios.
- The ideal inlet configuration is above the permanent pool to prevent potential hydraulic constrictions due to freezing.

Outlet & Overflow

- Design the outlet and any overflows in accordance with the Inlet and Outlet Controls section of this Manual.
- Stormwater ponds should have an outlet structure sized to convey up to the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event if the outlet structure is not designed to pass the 100-year storm event. Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm.

Conveyance

- Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.
- Stabilize any portion of the stormwater pond with Turf Reinforcement Matting (TRM) to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.
- TRM should be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Liner

- When a stormwater pond is located such that the bottom of the pond does not intercept groundwater and the pond is located in permeable soils, an impermeable liner is needed to maintain a permanent pool of water. Pond liners are also necessary to avoid impacts to groundwater quality for stormwater ponds that receive runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) or on contaminated sites.
- If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

Non-clogging Low-Flow Orifice

- A low-flow orifice should be provided, with the size of the orifice sufficient to avoid clogging (recommended minimum orifice diameter of 6 inches, although orifice diameters as small as 3 inches are allowed if required to provide the necessary hydraulic control). The low flow orifice should be protected from clogging using an external trash rack.
- A submerged reverse-slope pipe may also be used that extends downward from the riser to an inflow point one foot below the normal pool elevation.

- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round pipe that extends at least 12 inches below the normal pool level.

Riser in Embankment

- The riser should be located within the embankment for maintenance access and safety.
- Lockable manhole covers and manhole steps within easy reach of valves and other controls should provide access to the riser.

Drain

- For stormwater ponds that do not intercept groundwater, the design may include a drainpipe that can completely or partially drain the pond. The drainpipe should have an elbow or protected intake within the pond to prevent sediment deposition in the pipe, and a diameter capable of draining the pond within 24 hours.
- Care should be exercised during draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The review/approving authority should be notified before draining the system.

Adjustable Gate Valve

- Both the WQV extended detention pipe and the drain may be equipped with an adjustable gate valve, typically a handwheel activated knife gate valve.
- Valves should be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner.
- Both the WQV extended detention pipe and the drain should be sized one pipe size greater than the calculated design diameter.
- To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step, or other fixed object.

Vegetation

- Aquatic plantings around the edge of the pond can provide pollutant uptake, stabilize the soil at the edge of the pond, and improve habitat. Maintaining high vegetation along the edge of the pond (not mowing to the edge) can also deter waterfowl access and filter pollutants.
- Select vegetation and develop a planting plan with the guidance provided in Appendix F of this Manual.

- Wetland plantings should be included in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes, or within shallow areas of the pool.
- The best depth for establishing wetland plants, either through transplantation or volunteer colonization, is within approximately six inches of the normal pool elevation.
- Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.
- Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage.
- Woody vegetation may not be planted or allowed to grow within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure.
- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help discourage resident geese populations, the buffer can be planted with trees, shrubs, and native ground covers.
- Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.
- Plant the pond with salt-tolerant vegetation if the stormwater pond receives road runoff.

Safety Features

- The principal spillway opening must not permit access by small children, and end walls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

- Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.

- Fencing around the perimeter of the pond is generally not encouraged but may be required by some municipalities. The preferred method is to grade the pond to eliminate drop-offs or other safety hazards.

Maintenance Reduction Features

- Ponds should be designed with non-clogging outlets, such as a weir, or by incorporating trash racks for culverts and orifice openings.

- To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.

- Orifices should be less than 6 inches in diameter with a trash rack to prevent clogging. Smaller orifice diameters (3 inches or larger) are allowed if required to provide the necessary hydraulic control.
- Ponds should have a manually operated drain to draw down the pond for infrequent maintenance or dredging of the main cell of the pond.
- Metal components of outlet structures should be corrosion resistant, but not galvanized due to the contribution of zinc to water.
- Outlet structures should be resistant to frost heave and ice action in the pond.

Cold Climate Design Considerations

The following design elements should be considered to minimize potential performance impacts caused by cold weather:

- Inlet pipes should not be submerged since this can result in freezing and upstream damage or flooding.
- Bury pipes below the frost line to prevent frost heave and pipe freezing. Bury pipes at the point furthest from the pond deeper than the frost line to minimize the length of pipe exposed.
- Increase the slope of inlet pipes to a minimum of 1 percent, if site conditions allow, to prevent standing water in the pipe and reduce the potential for ice formation.
- If perforated riser pipes are used, the minimum orifice diameter should be 0.5 inches. In addition, the pipe should have a diameter of at least 6 inches.
- When a standard weir is used, the minimum slot width should be 3 inches, especially when the slot is tall.
- Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system.
- Riser hoods and reverse slope pipes should draw from at least 6 inches below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line ponds.
- Trash racks should be installed at a shallow angle to prevent ice formation.
- Additional storage should be provided to account for storage lost to ice buildup. Ice thickness may be estimated by consulting with local authorities (e.g., the fire department) with knowledge of the typical ice thickness in the area.

Winter Operations

- Stormwater ponds should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the pond
  - After internal grading of microtopography, berms, safety benches, etc.
  - After installation of bypass, outlet/overflow, and inlet controls
  - After vegetation and wetland plants/seed mix has been installed

- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.

- Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.

- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system to promote growth of vegetation.

- The system should be fenced off during the construction period to prevent disturbance of the soils.

- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the pond. A hydraulic excavator or backhoe loader, operating outside the limits of the system, should

be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.

- Install vegetation in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.

- Stormwater ponds classified as dams under the CT DEEP dam safety program (generally those with embankments greater than 4 feet above existing grade) should be constructed, inspected, and maintained in accordance with applicable CT DEEP dam safety regulations and guidance.

Maintenance Needs

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.

- Maintenance should be detailed in a legally binding maintenance agreement.

- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid soil compaction and damage to vegetation. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

Maintenance Access

- Stormwater ponds should be designed with easy access to all components of the system for maintenance purposes. In addition to the maintenance reduction design factors described in this section, also refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.

- A maintenance right-of-way or easement should extend to the pond from a public road.

- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15 percent, and be appropriately stabilized to withstand maintenance equipment and vehicles.

- The maintenance access should extend to the forebay, safety bench, riser, and outlet and be designed to allow vehicles to turn around.

- The principal spillway should be equipped with a removable trash rack, and generally accessible from dry land.

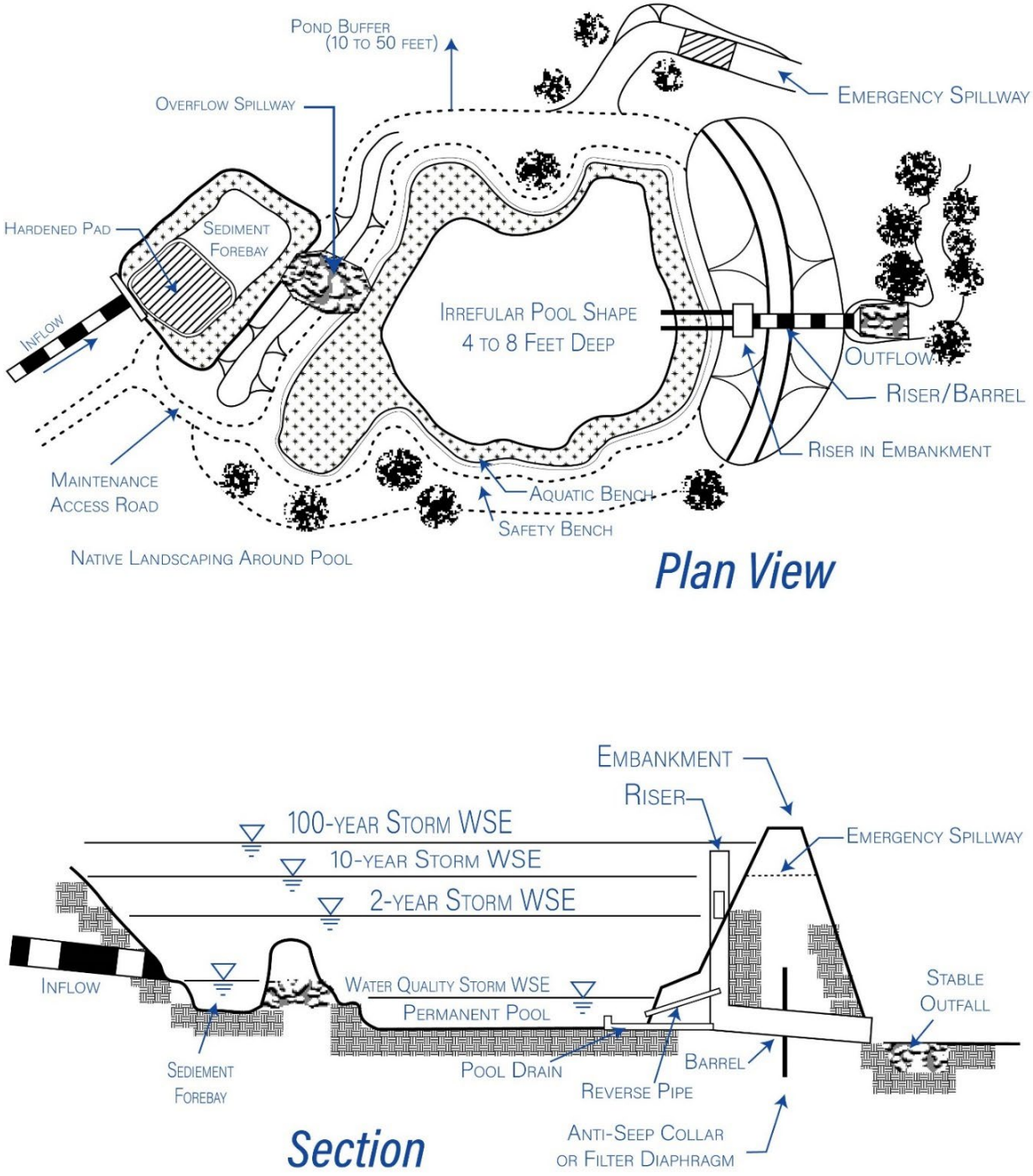
Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect sediment forebay twice per year and the rest of the system annually, including inlet and outlet control structures and the pond embankment.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 24 inches or 50% of the design depth.
- Remove sediment from the permanent pool when the pool volume has become reduced significantly, or when significant algal growth is observed.
- The vegetative cover should be maintained at 85%. If vegetation has damage, the area should be reestablished in accordance with the original specifications.
- Periodically mow the pond side slopes during the growing season. Maintain side slope vegetation at 6 inches or higher. High grass along the pond edge will discourage waterfowl from taking up residence and serve to filter pollutants.
- Inspect and remove invasive vegetation as necessary.
- Inspect wetland plants and manage/harvest dead or dying plants as necessary.
- Remove trees and woody vegetation within 25 feet of all risers, pipe outlet structures, spillways, and downstream embankments that hold back water.
- Prune other woody vegetation where dead or dying branches are observed. Plant reinforcement plantings as necessary.

Other References

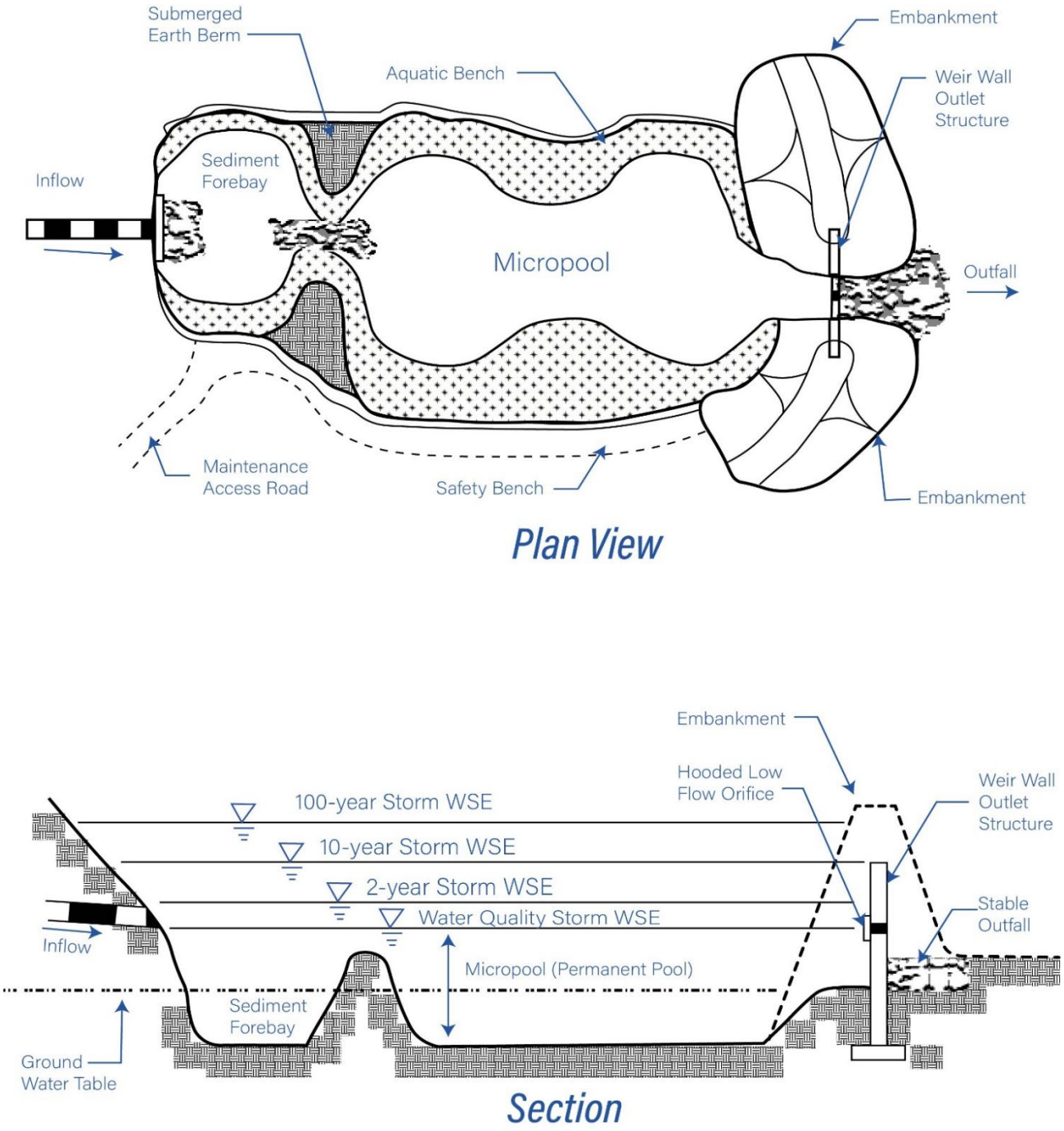
New York State Department of Environmental Conservation (NYDEC). 2001. *New York State Stormwater Management Design Manual.* Prepared by Center for Watershed Protection. Albany, New York.

Figure 13-22. Wet Pond Schematic



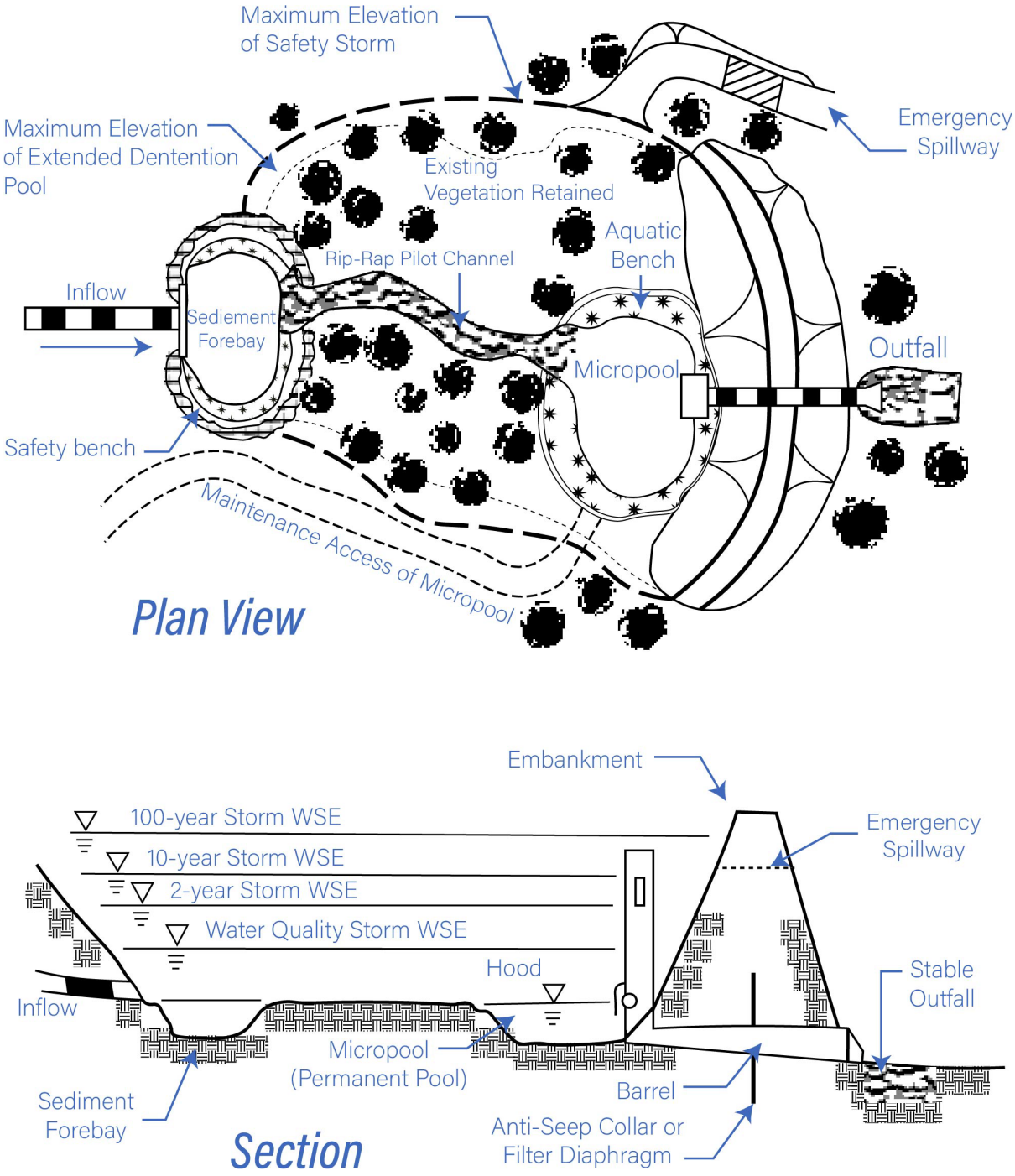
Source: Adapted from NYDEC, 2001.

Figure 13-23. Pocket Pond Schematic



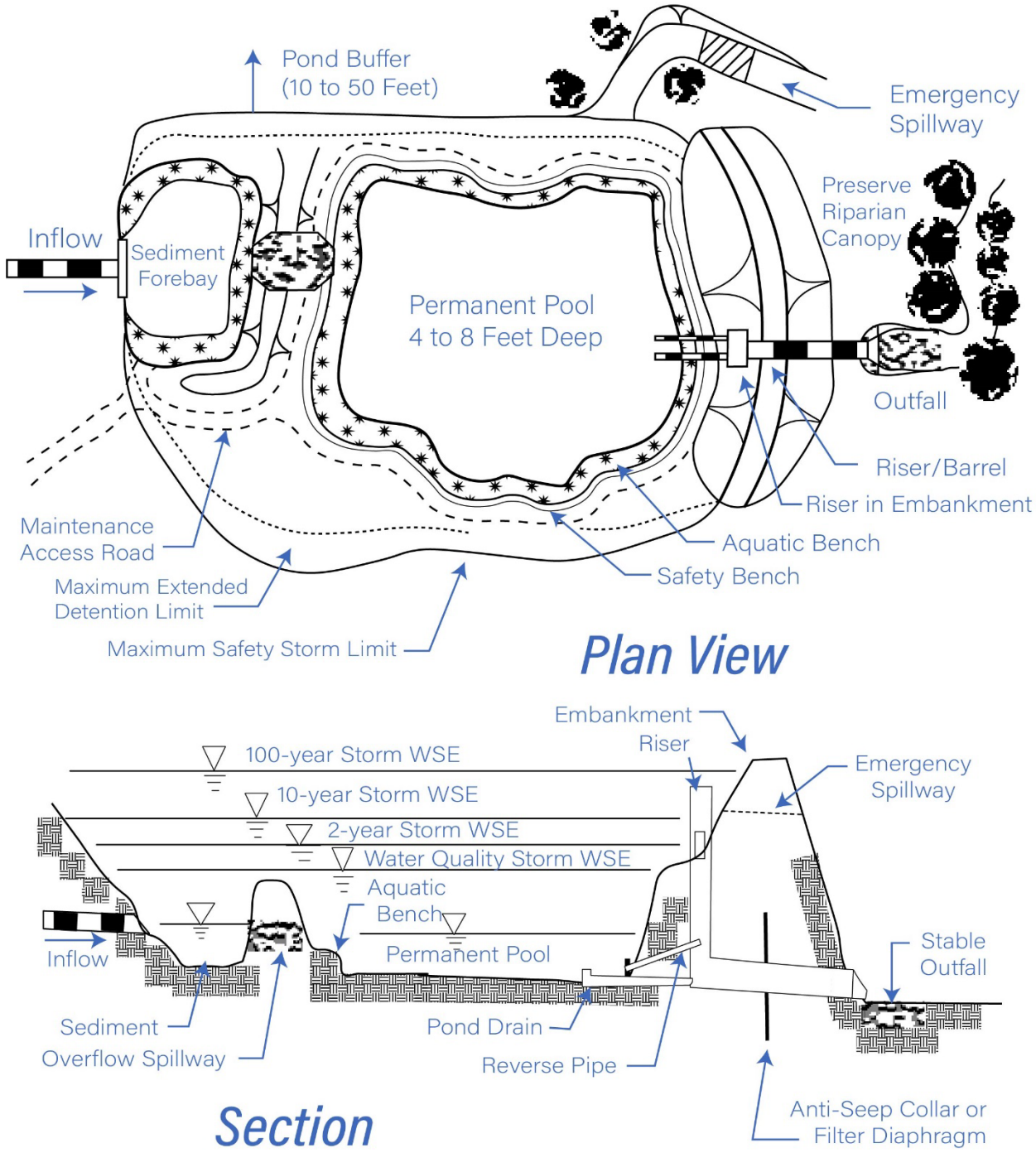
Source: Adapted from NYDEC, 2001.

Figure 13-24. Micropool Extended Detention Pond Schematic



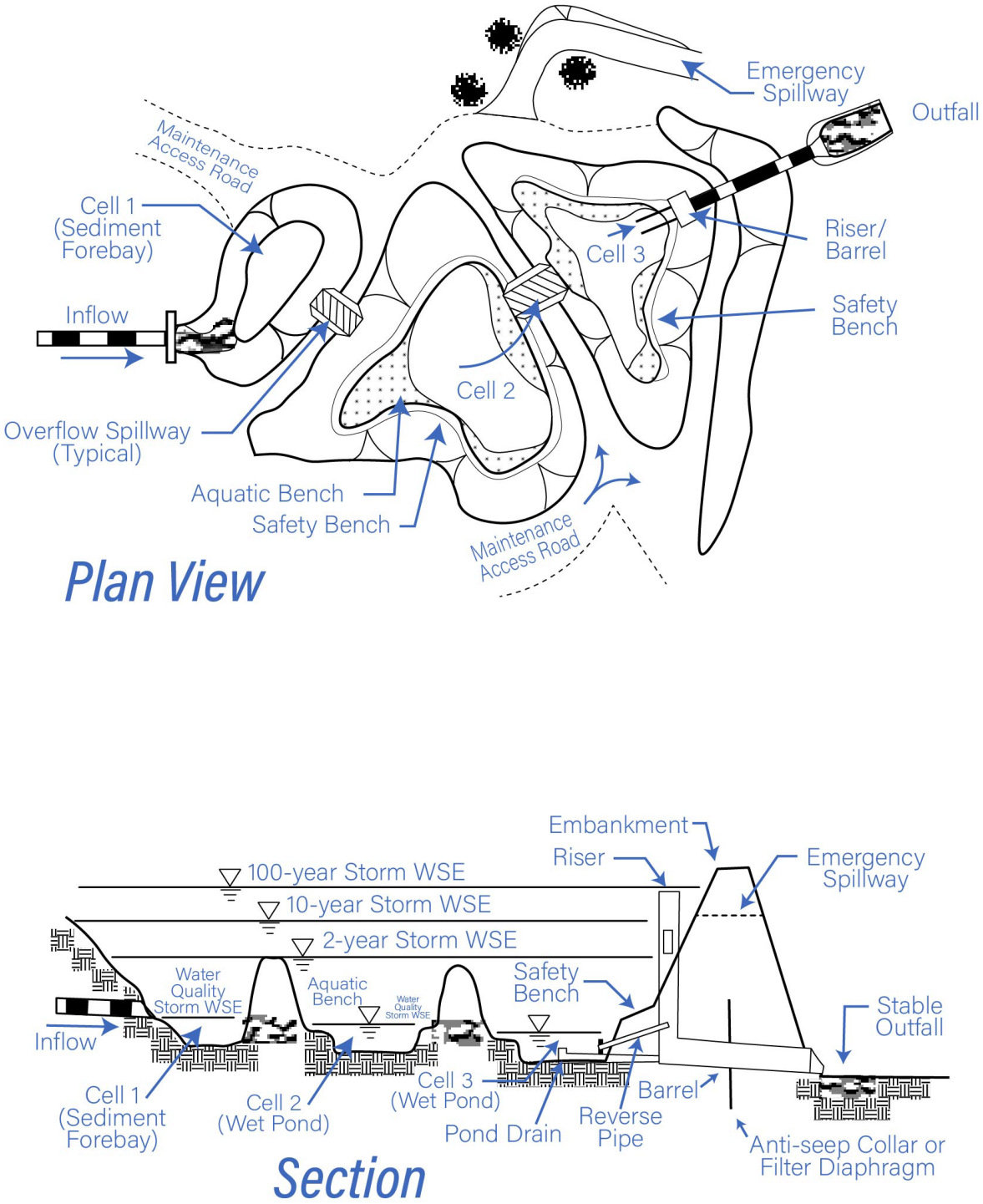
Source: Adapted from NYDEC, 2001.

Figure 13-25. Wet Extended Detention Pond Schematic



Source: Adapted from NYDEC, 2001.

Figure 13-26. Multiple Pond System Schematic



Source: Adapted from NYDEC, 2001.

Stormwater Wetland

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	■
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	■
Pretreatment	□
Peak Runoff Attenuation*	■

*On-line systems only

Pollutant Removal

Sediment**	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Moderate**

**Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**High**

Description

Stormwater wetlands are man-made wetland systems that incorporate marsh areas and permanent pools to provide treatment and attenuation of stormwater flows. Stormwater wetlands differ from stormwater ponds in that wetland vegetation is a major element of the overall treatment mechanism as opposed to a supplementary component. This section addresses four types of stormwater wetlands:

- Subsurface Gravel Wetland
- Shallow Wetland
- Extended Detention Shallow Wetland
- Pond/Wetland System

While stormwater wetlands can provide some of the ecological benefits associated with natural wetlands, these benefits are secondary to the function of the system to treat stormwater. Particulate and soluble pollutants are removed as stormwater runoff flows through the open marsh system. The primary pollutant removal mechanisms include sedimentation and filtration/uptake by wetland vegetation.

Subsurface gravel wetlands are a more recent stormwater wetland design variant that combines a surface marsh and subsurface gravel bed. Pollutants are removed through settling and filtration/uptake by wetland vegetation and by the process of denitrification in the subsurface gravel bed. Subsurface gravel wetlands are particularly effective for nitrogen removal.

The key to maximizing pollutant removal effectiveness in stormwater wetlands is maintaining wet conditions adequate to support wetland vegetation and saturated conditions in the

subsurface gravel bed of subsurface gravel wetlands. Stormwater wetlands should either intercept the groundwater table or should be lined with an impermeable liner if located in permeable soils and should have a watershed large enough to supply storm flows that will maintain wetness even during dry periods.

Stormwater wetland systems are designed to operate on the plug flow principle where the "new" polluted incoming runoff displaces the "old" treated water held in the system from the previous storm event. This is accomplished by maximizing length versus width ratios and/or by creating distinct cells along the treatment path. Stormwater wetlands are designed to treat the Water Quality Volume (WQV). When designed in an on-line configuration, stormwater wetlands can also be sized to treat and provide peak runoff attenuation for storms larger than the water quality storm event.

Stormwater wetlands do not provide sufficient retention or runoff volume reduction through infiltration or other processes and therefore cannot be used to meet the Standard 1 retention performance criterion of this Manual.

Advantages

- Effective for removal of particulate and soluble pollutants. Subsurface gravel wetlands are particularly effective at removing nitrogen.
- Can provide aesthetic benefits.
- Can provide wildlife habitat with appropriate design elements.
- Can provide peak runoff attenuation.
- Subsurface gravel wetlands are well-suited for retrofitting existing stormwater detention and retention ponds to enhance pollutant removal.

Limitations

- Do not provide infiltration or sufficient runoff volume reduction, and therefore cannot be used to meet the Standard 1 retention performance criterion.
- Require a relatively large land area.
- Very sensitive to the ability to maintain wet conditions especially during extended dry weather when there may be significant evaporative losses.
- May cause thermal impacts to receiving waters and therefore should not discharge directly to coldwater streams or other receiving water environments that are sensitive to thermal loads.
- Stormwater wetlands with steep side slopes and/or deep wet pools may present a safety risk in residential areas and areas with public access.
- Stormwater wetlands can serve as decoy wetlands, intercepting breeding amphibians moving toward vernal pools. If amphibians deposit their eggs in these artificial wetlands,

they rarely survive due to the sediment and pollutant loads, as well as fluctuations in water quality, quantity, and temperature.

Siting Considerations

- **Drainage Area:** Stormwater wetlands that utilize a liner system should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, the minimum contributing drainage area for lined wetlands is 10 acres (5 acres for subsurface gravel wetlands). Smaller drainage areas may be suitable if intercepting groundwater or with sufficient surface runoff to support wetlands and a submerged gravel bed for subsurface gravel wetlands. A water budget analysis should be performed to demonstrate that sufficient groundwater flow and/or surface runoff is available to maintain the required water elevations in the various zones of the stormwater wetland.

- **Groundwater:** Stormwater wetlands should intercept groundwater or have an impermeable liner to maintain a permanent pool if located in permeable soils. The elevations of unlined wetlands should be established such that the groundwater elevation is equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered.

- **Land Uses:** Land uses will dictate potential pollutants-of-concern and potential safety risks. A liner is required for stormwater wetlands that receive runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10) or on contaminated sites. The wetland's standing water may pose a safety risk in residential areas and areas with public access, sometimes requiring fencing to limit access to the wetland.

- **Baseflow:** A small amount of baseflow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer. This baseflow can be provided by groundwater discharge to the wetland or the drainage system that feeds the wetland.

- **Site Slopes:** Site slopes greater than 6% may result in the need for an embankment greater than 4 feet above existing grade to provide the desired storage volume, which would be subject to CT DEEP dam safety regulatory requirements. Steep slopes may also present design and construction challenges, and significantly increase the cost of earthwork.

- **Receiving Waters:** Stormwater wetlands should not be used for sites that discharge within 200 feet of coldwater streams, 200 feet from a public water supply reservoir, or 100 feet from streams tributary to a public water supply reservoir.

- **Natural Wetlands/Vernal Pools:** Natural wetlands and vernal pool depressions should not be used, either temporarily or permanently, as a stormwater wetland. Stormwater wetlands should be located at least 750 feet from a vernal pool. They should not be sited between vernal pools, or in areas that are known primary amphibian overland migration routes.

Soil Evaluation and Water Budget Analysis

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, and depth to bedrock. Perform test pits or soil borings in accordance with the soil evaluation guidance in Chapter 10.

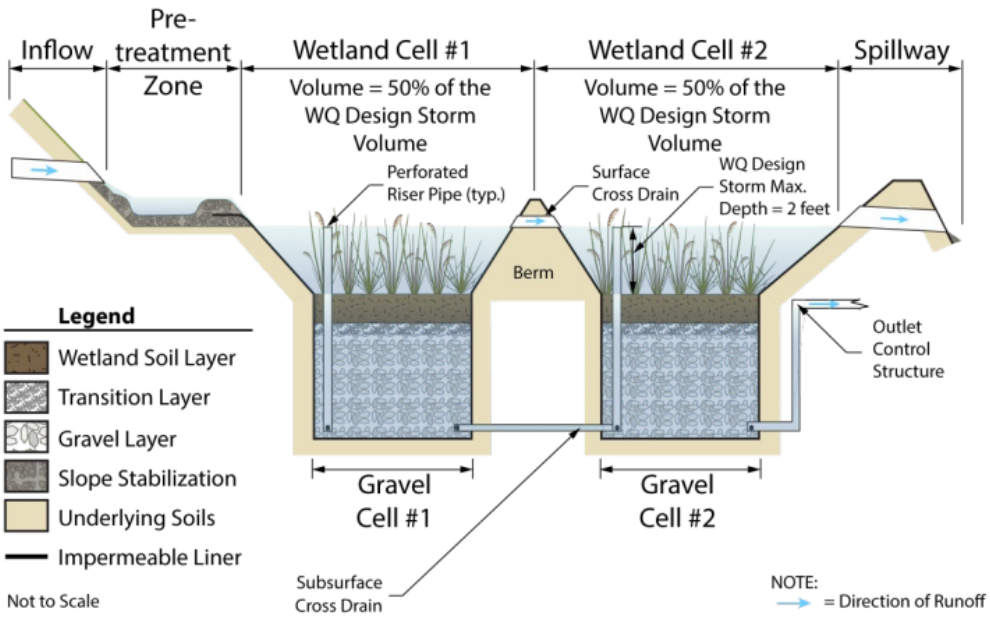
- A water budget analysis should be performed for stormwater wetland designs. The water budget consists of calculations, on a daily basis, of the inflows to and outflows from the wetland to show that the required depth of water in the wetland is maintained throughout the year. The analysis should be performed for a wet year, a dry year, and an average year. The analysis should demonstrate that the depths of water in the various zones of the stormwater wetland meet the minimum requirements of this section for all of the days in each of the three analyses. All of the inputs to and outputs from the wetland should be considered, including direct precipitation, runoff, flooding, groundwater inflow, evapotranspiration, groundwater outflow.

Design Recommendations – Subsurface Gravel Wetland

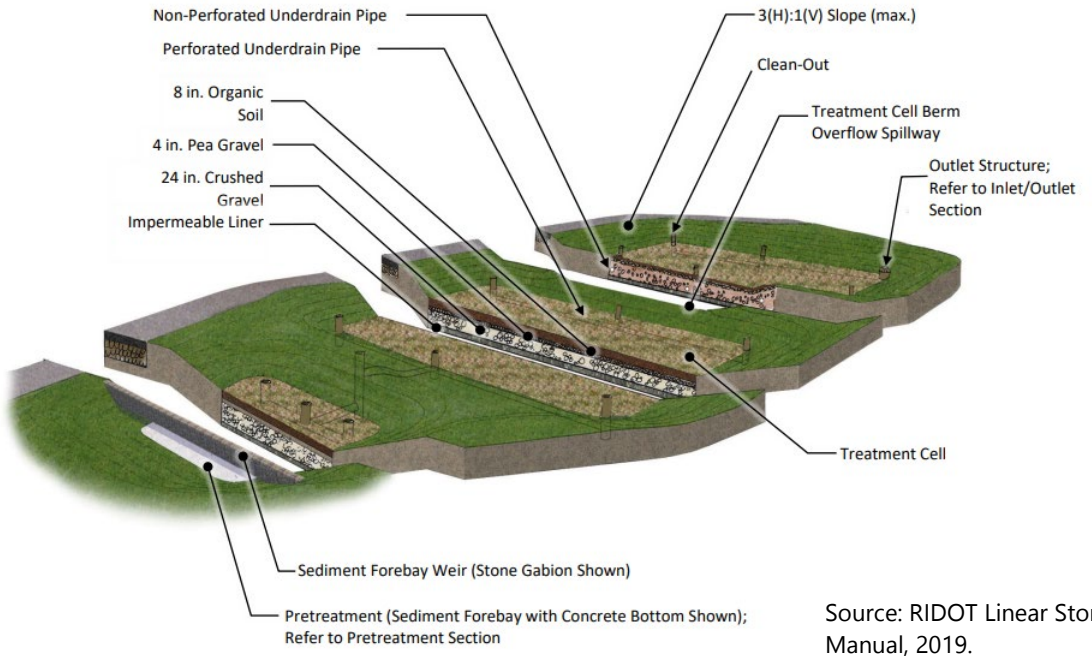
Subsurface gravel wetlands combine a surface marsh and a subsurface gravel bed. In the surface marsh, pollutants are treated through filtration and biological uptake by the marsh vegetation and through sedimentation. Stormwater runoff flows vertically from the surface marsh through perforated pipe into the saturated gravel bed, located directly below the surface marsh. Runoff then flows horizontally through the gravel where additional treatment occurs via denitrification, which is a microbially-facilitated process whereby nitrogen compounds in stormwater runoff are transformed to nitrogen gas. The nitrogen gas is then permanently removed from the system via the soil into the atmosphere. The subsurface gravel bed must always be completely filled with stormwater runoff in order to provide the anoxic environment necessary for denitrification to occur.

A subsurface gravel wetland consists of the following basic components:

- Pretreatment
- Two surface wetland treatment cells connected by a cross drain
- Transition layer located below each surface wetland cell
- Two subsurface gravel cells connected by a subsurface cross drain
- Two perforated riser pipes connecting each of the wetland treatment cells to the gravel cells below them
- Outlet structure.



Source: Adapted from NJDEP, 2021.



Source: RIDOT Linear Stormwater Manual, 2019.

Pretreatment – Sediment Forebay

- A sediment forebay is recommended for subsurface gravel wetlands, although other forms of pretreatment may be used at locations where runoff enters the system.
- The sediment forebay and other pretreatment measures should be designed in accordance with the Pretreatment BMPs section of this Manual.

- The sediment forebay should be a minimum of 3 feet deep and sized to contain at least 10% of the WQV. The forebay storage volume may be used to fulfill the WQV requirement of the overall stormwater wetland. The forebay should also include additional sediment storage volume that may not be used for WQV calculations.

Sizing and Dimensions

- Volume
  - Size the entire facility (including pretreatment, surface ponding in wetland treatment cells, and volume of voids in subsurface gravel beds) to hold 100% of the WQV and to drain the WQV over a 24 to 30 hour period after the end of a storm event.
  - Assume 40% void space when computing the amount of available storage within the gravel substrate.
  - WQV treatment should be equally distributed in each wetland treatment cell.
  - When used as an on-line treatment practice, the subsurface gravel wetland can be designed for extended detention for peak runoff control. In this case, the extended detention volume shall drain over a 24 to 48 hour period.

- Treatment Cell Ponding Depth and Freeboard
  - The maximum ponding depth in the surface wetland cells is 2 feet.
  - Provide at least 1 foot of freeboard above the WQV elevation (if designed to handle the WQV only).
  - Provide a maximum freeboard of 4 feet above the WQV elevation or 6 inches of freeboard above the 100-year storm elevation, whichever is less (if extended detention is provided).

- Treatment Cell Length, Width, and Slope
  - Minimum length: 15 feet (in the direction of flow) to provide sufficient travel time in the anoxic environment for denitrification to occur.
  - Maximum length: None; the length of the flow path in the gravel cell should be maximized to maximize treatment.
  - Minimum width: 1:1 length to width ratio
  - Bottom slope: the top and bottom of the treatment cell should be level.
  - Maximum side slope: 3(H):1(V) slopes or flatter

Berms

- The top of the berms separating treatment cells shall be set at or above the height of the WQV elevation.

- Construct berms of low permeability soils (hydraulic conductivity less than 0.03 feet per day), to prevent water seepage between cells and to maintain the structural integrity of the berm.

- Use solid (non-perforated) pipe sections and watertight joints to connect pipes through the base of the berm to promote flow of the WQV between treatment cells.

- Extended detention (optional) when designed as an on-line system:
    - If provided, extended detention occurs above the treatment cells. An overflow spillway or bypass pipe should be provided in the berm at the height of the WQV elevation.
    - The surface of the berm should be designed with materials to resist erosive velocities.
    - Provide stable and non-erosive energy dissipating devices between berms where overflow velocities are considered erosive.

Conveyance

- Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet to minimize the potential for short-circuiting and should be located in a manner that meets or exceeds desired length to width ratios.

Outlet & Overflow

- Design the outlet and any overflows in accordance with the Inlet and Outlet Controls section of this Manual.

- The primary outlet control structure should be a riser with an orifice/outlet pipe for low flow. The WQV is conveyed into the outlet control structure through the underdrain.

- The WQV orifice/outlet should be located 4-8 inches below the elevation of the organic soil surface.

- The top of the structure should remain open with a grate for overflow. This configuration reduces the potential for creating siphoning.

- Extended detention (optional) when designed as an on-line system:
    - A weir should be provided in the center of the structure with a WQV orifice located in the weir. The elevation of the top of the weir should be set to provide control of lower frequency storm events, such as the 2-year or 10-year, 24-hour storm event.

- If the outlet controls multiple storm events, additional orifices may be added to the structure.
- The top of the structure should be set to allow the bypass of the 100-year event.

Underdrain and Risers

- Underdrains and risers are critical in subsurface gravel wetlands as they convey and distribute stormwater through the treatment cells as driven by the hydraulic head.

- Risers
  - Minimum central riser pipe diameter: 12 inches
  - Minimum end riser pipe diameter: 6 inches
  - Space perforated riser pipes across the width of the treatment cell with a maximum spacing of 15 feet.
  - Place inlet grates atop risers for an overflow when water levels exceed the WQV.

- Underdrains
  - Minimum diameter: 6 inches
  - Use solid (non-perforated) pipe sections and watertight joints wherever the underdrain system passes below berms, connects to a drainage structure and/or daylights.
  - Place the subsurface perforated distribution line at the upstream end of each treatment cell and the subsurface perforated collection drain at the downstream end. At a minimum, there should be 15 feet between both.
  - Provide a marking stake and an animal guard for underdrains that daylight at grade.

- Include an observation well/cleanout at each end of the underdrains. The cleanout should be highly visible.
  - Cleanouts should be at least 6 inches in diameter, should be perforated only within the gravel layer and solid within the organic soil and storage area.
  - Cap cleanouts with a watertight removable cap.

Liner

- Proper functioning of the system requires stormwater runoff to enter the subsurface gravel cells only from the surface wetland cells and only through the perforated riser pipes. It is also essential that discharges from the gravel cells occur only through the outlet structure and not into the underlying soil.

- An impermeable liner is required to prevent groundwater exchange with runoff in the subsurface gravel bed unless the underlying soils are sufficiently impermeable (soils with a field-verified infiltration rate of 0.05 in/hr or less), in which case the liner may be omitted provided that the system is above the seasonal high groundwater table (SHGT).

- A liner is also necessary to avoid impacts to groundwater quality for systems that receive runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) or on contaminated sites.

- Where SHGT is located at or above the bottom of the liner, complete a buoyancy analysis to verify buoyancy will not be an issue.

Materials

- Vegetation
  - Select vegetation and develop a planting plan in with guidance provided in Appendix F of this Manual.
  - Establish a dense vegetative cover or adequately stabilized landscaped surface across any upgradient areas disturbed by construction before runoff can be accepted into the facility.
  - The bottom of the subsurface gravel wetland should be planted to achieve a rigorous root mat with grasses, forbs, and shrubs with obligate and facultative wetland species, such as New England Wetland Plants Wet Mix.

- Gravel Substrate
  - Do not use geotextiles between subsurface layers as they will clog and prevent root growth.
  - Organic Soil
    - Similar to a low permeability wetland soil made up of compost, sand and fine soils blended to have an organic matter content > 15%. Avoid using clay contents in excess of 15%, as the fines could migrate into the subsurface crushed stone (gravel) layer.
  - Pea Gravel
    - Provide a 4-inch layer of pea gravel to provide separation between the organic soil layer and the crushed gravel layer.
    - Should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.
  - Crushed Gravel
    - Minimum Thickness: 24 inches
    - Should consist of 3/4" AASHTO No. 5 stone. Gravel should be clean (washed and free from dirt and debris), crushed, and angular.

- Underdrain/Riser (perforated and non-perforated sections)
  - Polyethylene or polyvinyl pipe.

- Liner
  - should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 with the approval of the review authority.

- Turf Reinforcement Matting (TRM)
  - Stabilize the side slopes with a TRM to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.
  - If used, shall be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Winter Operations

- Subsurface gravel wetlands should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 for general design considerations related to winter operations.

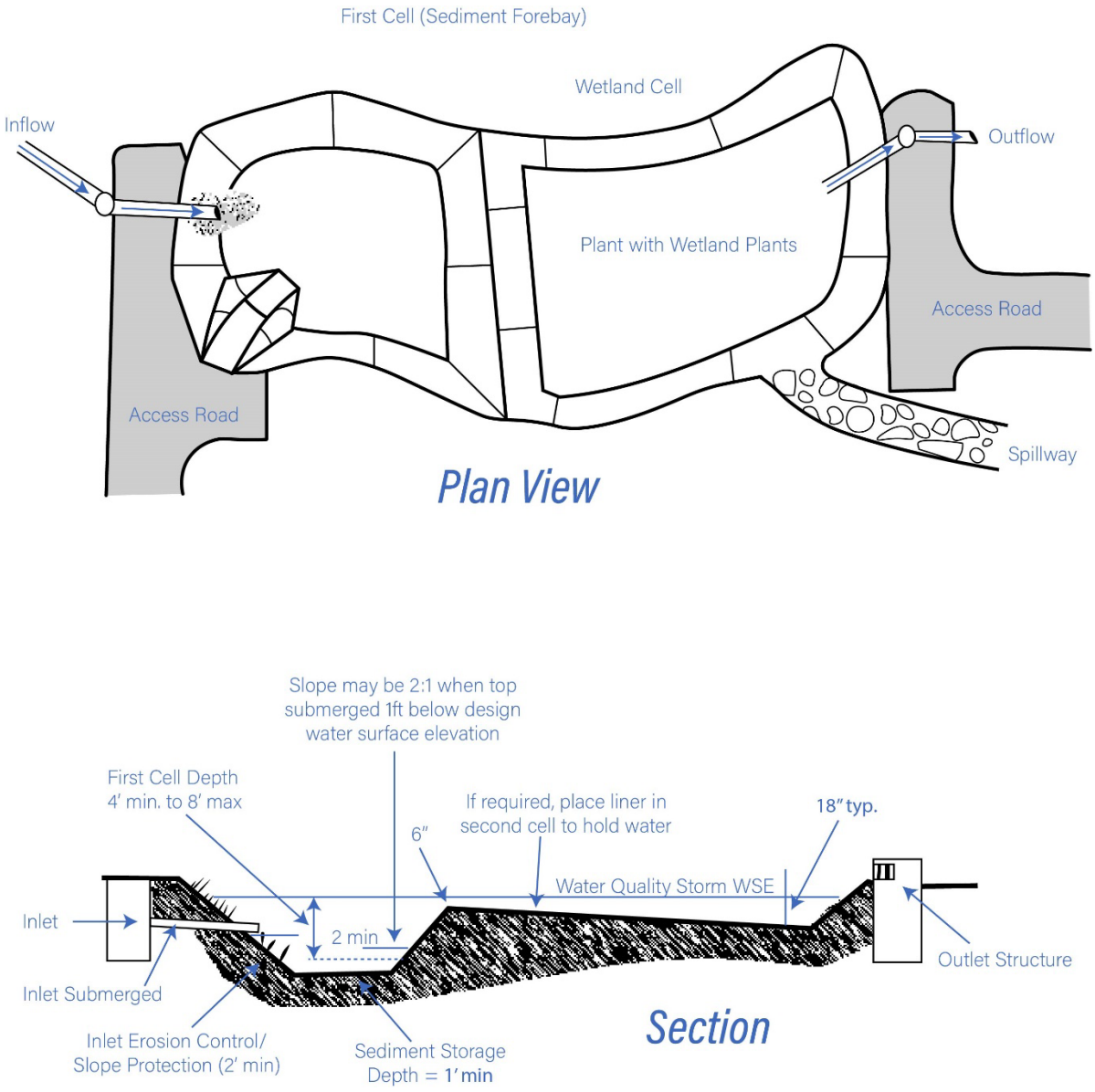
Design Recommendations – Conventional Stormwater Wetlands

The following conventional stormwater wetland design variants are characterized by the volume of the wetland in the deep pool, high marsh, and low marsh zones, and whether the design allows for detention of larger storms above the permanent pool (extended detention).

- **Shallow Wetland:** Shallow wetland systems, also referred to as shallow marsh wetlands, consist of aquatic vegetation with a permanent pool ranging from 6 to 18 inches during normal conditions. Shallow wetlands are designed such that flow through the wetlands is conveyed uniformly across the treatment area. While pathways, channels, or other varied water depths could enhance the aesthetic or ecosystem value of the wetland, they could also cause short-circuiting through the wetland thereby reducing the overall treatment effectiveness. A uniformly sloped system is recommended to maximize treatment performance. Individual wetland cells can be separated by weirs to enhance plug flow conditions across the wetland. Figure 13-27 is a typical schematic design of a shallow wetland.

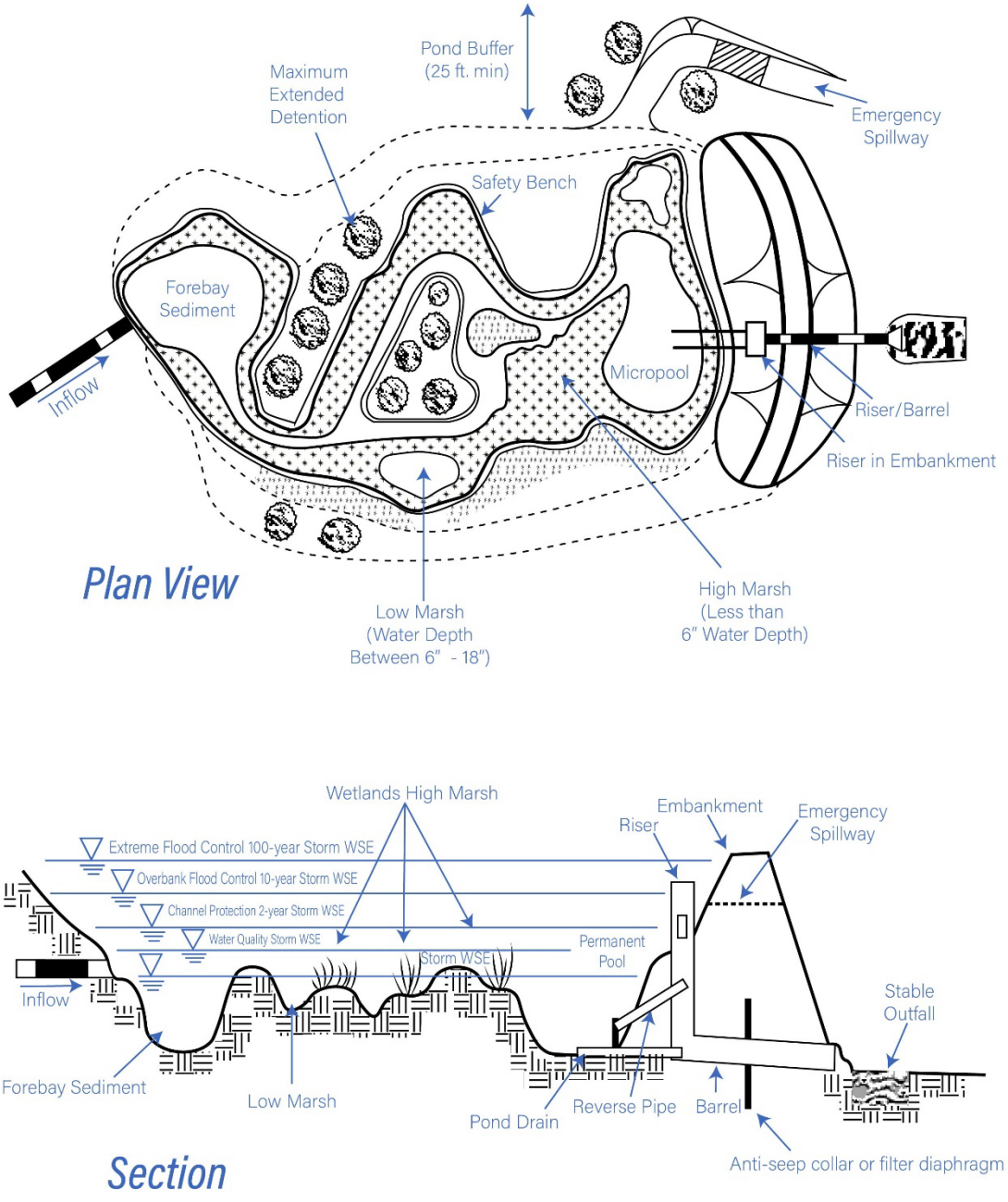
  Shallow wetlands are typically designed as off-line systems to provide treatment of the Water Quality Volume (WQV) but not to provide stormwater quantity control for larger storms.

Figure 13-27. Shallow Wetland Schematic



- **Extended Detention Shallow Wetland:** Extended detention shallow wetlands provide a greater degree of stormwater quantity control as they are designed with more vertical storage capacity. The additional vertical storage volume also provides extra runoff detention above the normal pool elevation. Water levels in the extended detention shallow wetland may increase by as much as 3 feet after a storm event and return gradually to pre-storm elevations within 24 hours of the storm event. The extended detention zone is the inundation area above the normal pool elevation up to the water quality storm elevation. Wetland plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above normal pool elevation. Figure 13-28 is a typical schematic design of an extended detention shallow wetland.

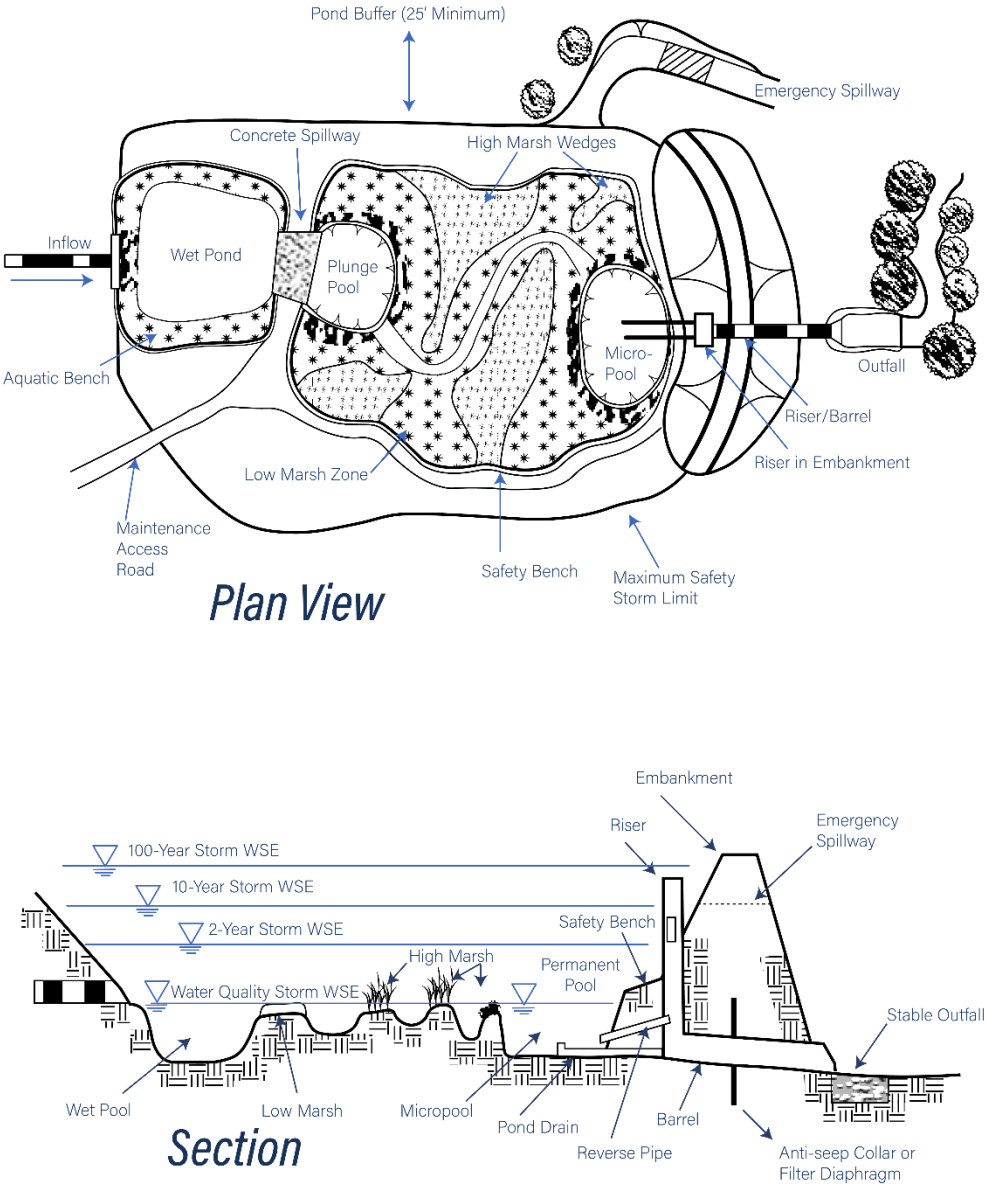
Figure 13-28. Extended Detention Shallow Wetland Schematic



- **Pond/Wetland System:** Multiple cell systems, such as pond/wetland systems, utilize at least one pond component in conjunction with a shallow marsh component. The first cell is typically a wet pond, which provides pretreatment of the runoff by removing particulate pollutants and reduce the velocity of the runoff entering the system. The shallow marsh

then polishes the runoff, particularly for soluble pollutants, prior to discharge. These systems require less space than the shallow marsh systems since more of the water volume is stored in the deep pool which can be designed to reduce peak flows. Because of this system's ability to significantly reduce the velocity and volume of incoming peak flows (i.e., flow equalization or dampening), it can often achieve higher pollutant removal rates than other similarly sized stormwater wetland systems. Figure 13-29 is a typical schematic design of a pond/wetland system.

Figure 13-29. Pond/Wetland System Schematic



Source: Adapted from NYDEC, 2001.

Pretreatment – Sediment Forebay

- A sediment forebay is recommended for conventional stormwater wetlands, although other forms of pretreatment may be used at locations where runoff enters the system.
- The sediment forebay and other pretreatment measures should be designed in accordance with the Pretreatment BMPs section of this Manual.
- The sediment forebay should be a minimum of 3 feet deep and sized to contain at least 10% of the WQV. The forebay storage volume may be used to fulfill the WQV requirement of the overall stormwater wetland. The forebay should also include additional sediment storage volume that may not be used for WQV calculations.

Sizing and Dimensions

- The wetland volume, including the volume of the sediment forebay, the permanent pool volume (high marsh zone, low marsh zone, and pool zone), and the volume of the extended detention area (if any), should be equal to or exceed the WQV. Table 13-11 provides the recommended division of storage between these zones for each stormwater wetland design variant.

Table 13-8. Water Quality Volume Distribution in Stormwater Wetland Designs

Design Variant	Percent of Water Quality Volume (WQV)				
	Sediment Forebay	High Marsh Zone	Low Marsh Zone	Pool Zone	Extended Detention Zone
Water Depth	3 feet min (below permanent pool)	6 inches max (below permanent pool)	6-18 inches (below permanent pool)	4-6 feet (below permanent pool)	Varies (above permanent pool)
Shallow Wetland	10%	0%	90%	0%	0%
Extended Detention Shallow Wetland	10%	10%	20%	10%	50%
Pond/Wetland System	10%	10%	20%	60%	0%

Adapted from NYDEC, 2001 and NJDEP, 2021.

- Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, extended detention, and marsh).
- For extended detention shallow wetlands, the extended detention storage volume (storage volume above the permanent pool provided for additional water quality and stormwater

quantity control) should drain out of the wetland over a minimum of 24 hours, after which the water surface elevation in the wetland will return to the permanent pool elevation.

- Thermal impacts of stormwater wetlands may be mitigated by implementing one or more of the following design measures:
  - Use of a smaller permanent pool with more extended detention storage and an extended detention time of 24 hours or less
  - Planting of shade trees around the perimeter of the wetland (but at least 25 feet away from inlet/outlet structures and the wetland embankment) to reduce solar warming of the pool
  - Designing the wetland with a series of pools, as opposed to a single pool, to allow cooling prior to discharge
  - Use of an outlet structure designed to draw water from near the bottom of the outlet pool where water temperatures may be cooler
  - Use of an underdrained gravel trench outlet.

- The wetland should have a curvilinear shape and a minimum length:width ratio of 3:1 from the wetland inlet to outlet.

- For extended detention shallow wetland and pond/wetland systems, the upper stages of the wetland should provide temporary storage of larger storms (2-year, 10-year, and 100-year, 24-hour events) to control peak discharge rates.

- Wetland Water Depths:
  - High Marsh Zone: 6 inches maximum (below permanent pool)
  - Low Marsh Zone: 6-18 inches (below permanent pool)
  - Pool Zone: 4-6 feet (below permanent pool), includes deeper pool at outlet structure (i.e., micropool)
  - Extended Detention Zone: varies (above permanent pool)

- Pumping of groundwater to maintain the permanent pool should not be allowed.

- The volume below the surface elevation of the permanent pool should not be included in storage calculations for peak flow management.

Side Slopes

- 3(H):1(V) slopes or flatter are preferred.

- The perimeter of permanent pool areas (sediment forebay and outlet pool) four feet or greater in depth should provide two benches:
  - Provide a flat safety bench that extends 10 feet outward from the normal water edge to the toe of the wetland side slope.
  - Provide a flat aquatic bench that extends 10 feet inward from the normal water edge at a depth of 12-18 inches below the normal pool water surface elevation.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.
- The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet to minimize the potential for short-circuiting and should be located in a manner that meets or exceeds desired length to width ratios.
- The ideal inlet configuration is above the permanent pool to prevent potential hydraulic constrictions due to freezing.

Outlet & Overflow

- Design the outlet and any overflows in accordance with the Inlet and Outlet Controls section of this Manual.
- Shallow wetlands should be designed as off-line systems and have an outlet structure sized to convey the water quality storm to the storm drainage system or stabilized channel. An emergency spillway is required to convey flows up to the 100-year, 24-hour storm event in the event that the primary outlet structure gets clogged.
- Extended detention shallow wetlands and pond/wetland systems should have an outlet structure sized to convey flows up to the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event if the outlet structure is not designed to pass the 100-year storm event.

Conveyance

- Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.
- Stabilize any portion of the stormwater wetland with Turf Reinforcement Matting (TRM) to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.
- TRM should be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Liner

- When a stormwater wetland is located such that the bottom of the wetland does not intercept groundwater and the wetland is located in permeable soils, an impermeable liner is needed to maintain a permanent pool of water. A liner is also necessary to avoid impacts

to groundwater quality for stormwater wetlands that receive runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) or on contaminated sites.

- If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 with the approval of the review authority.

Non-clogging Low-Flow Orifice

- A low-flow orifice should be provided, with the size of the orifice sufficient to avoid clogging (recommended minimum orifice diameter of 6 inches, although orifice diameters as small as 3 inches are allowed if required to provide the necessary hydraulic control). The low flow orifice should be protected from clogging using an external trash rack.

- A submerged reverse-slope pipe may also be used that extends downward from the riser to an inflow point one foot below the normal pool elevation.

- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round pipe that extends at least 12 inches below the normal pool level.

Riser in Embankment

- The riser should be located within the embankment for maintenance access and safety.

- Lockable manhole covers and manhole steps within easy reach of valves and other controls should provide access to the riser.

Drain

- For stormwater wetlands that do not intercept groundwater, the design may include a drain pipe that can completely or partially drain the permanent pool. The drain pipe should have an elbow or protected intake within the outlet pool to prevent sediment deposition in the pipe, and a diameter capable of draining the pool within 24 hours.

- Care should be exercised during draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The review/approving authority should be notified before draining the system.

Adjustable Gate Valve

- Both the WQV extended detention pipe and the drain may be equipped with an adjustable gate valve, typically a handwheel activated knife gate valve.

- Valves should be located inside of the riser at a point where they will not normally be inundated and can be operated in a safe manner.

- Both the WQV extended detention pipe and the drain should be sized one pipe size greater than the calculated design diameter.

- To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step, or other fixed object.

Vegetation

- Establishing and maintaining wetland vegetation is critical to the success of stormwater wetlands. Use plants that have high colonization and growth rates, can establish large surface areas that continue through the winter dormant season, have high potential for treating pollutants, and are very robust in flooded environments. Selected species must be able to adapt to a broad range of conditions, including large variations in water depth and inundation. Select vegetation and develop a planting plan in with guidance provided in Appendix F of this Manual.
    - The best depth for establishing emergent wetland plants, either through transplantation or volunteer colonization, is within approximately six inches of the normal pool elevation.
    - Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.
    - Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage.
    - Woody vegetation may not be planted or allowed to grow within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure.
    - Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to wetlands. To help discourage resident geese populations, the buffer can be planted with trees, shrubs, and native ground covers.
    - Annual mowing of the wetland buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.
    - Plant the wetland with salt-tolerant vegetation if the stormwater wetland receives road runoff.

Safety Features

- The principal spillway opening must not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

- Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.

- Fencing around the perimeter of the wetland is generally not encouraged but may be required by some municipalities. The preferred method is to grade the wetland to eliminate dropoffs or other safety hazards.

Maintenance Reduction Features

- Wetlands should be designed with non-clogging outlets, such as a weir, or by incorporating trash racks for culverts and orifice openings.
- To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.
- Orifices should be less than 6 inches in diameter with a trash rack to prevent clogging. Smaller orifice diameters (3 inches or larger) are allowed if required to provide the necessary hydraulic control.
- Metal components of outlet structures should be corrosion resistant, but not galvanized due to the contribution of zinc to water.
- Outlet structures should be resistant to frost heave and ice action in the wetland.

Cold Climate Design Considerations

The following design elements should be considered to minimize potential performance impacts caused by cold weather:

- Inlet pipes should not be submerged since this can result in freezing and upstream damage or flooding.
- Bury pipes below the frost line to prevent frost heave and pipe freezing. Bury pipes at the point furthest from the pond deeper than the frost line to minimize the length of pipe exposed.
- Increase the slope of inlet pipes to a minimum of 1 percent, if site conditions allow, to prevent standing water in the pipe and reduce the potential for ice formation.
- If perforated riser pipes are used, the minimum orifice diameter should be 0.5 inches. In addition, the pipe should have a diameter of at least 6 inches.
- When a standard weir is used, the minimum slot width should be 3 inches, especially when the slot is tall.
- Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system.

- Riser hoods and reverse slope pipes should draw from at least 6 inches below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line systems.
- Trash racks should be installed at a shallow angle to prevent ice formation.
- Additional storage should be provided to account for storage lost to ice buildup. Ice thickness may be estimated by consulting with local authorities (e.g., the fire department) with knowledge of the typical ice thickness in the area.

Winter Operations

- Stormwater wetlands should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 for general design considerations related to winter operations.

Construction Recommendations

- The design engineer should develop a detailed, site-specific construction sequence.
- The design engineer should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the wetland
  - After internal grading of microtopography, berms, safety benches, etc.
  - After installation of bypass, outlet/overflow, and inlet controls
  - After vegetation and wetland plants/seed mix has been installed
- The design engineer should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system to promote growth of vegetation.

- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the wetland. A hydraulic excavator or backhoe loader, operating outside the limits of the system, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.
- Install vegetation in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.
- Stormwater wetlands classified as dams under the CT DEEP dam safety program (generally those with embankments greater than 4 feet above existing grade) should be constructed, inspected, and maintained in accordance with applicable CT DEEP dam safety regulations and guidance.

Maintenance Needs

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid soil compaction and damage to vegetation. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

Maintenance Access

- Stormwater wetlands should be designed with easy access to all components of the system for maintenance purposes. In addition to the maintenance reduction design factors described in this section, also refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- A maintenance right-of-way or easement should extend to the wetland from a public road.
- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15 percent, and be appropriately stabilized to withstand maintenance equipment and vehicles.

- The maintenance access should extend to the forebay, safety bench, outlet pool, riser, and outlet and be designed to allow vehicles to turn around.
- The principal spillway should be equipped with a removable trash rack, and generally accessible from dry land.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect sediment forebay twice per year and the rest of the system annually, including inlet and outlet control structures and the pond embankment.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 24 inches or 50% of the design depth.
- Remove sediment from the permanent pool when the pool volume has become reduced significantly, or when significant algal growth is observed.
- The vegetative cover should be maintained at 85%. If vegetation has damage, the area should be reestablished in accordance with the original specifications.
- Prune wetland vegetation on a regular schedule. Inspect wetland plants and manage/harvest dead or dying plants as necessary. Plant reinforcement plantings as necessary.
- Periodically mow perimeter grass during the growing season. Maintain perimeter grass at 6 inches or higher. High grass along the wetland edge will discourage waterfowl from taking up residence and serve to filter pollutants.
- Inspect and remove invasive vegetation as necessary.
- Remove trees and woody vegetation within 25 feet of all risers, pipe outlet structures, spillways, and downstream embankments that hold back water.
- Prune other woody vegetation where dead or dying branches are observed.

Other References

King County Department of Natural Resources. 1998. *King County Surface Water Design Manual*. Seattle, WA. https://kingcounty.gov/services/environment/water-and-land/stormwater/documents/surface-water-design-manual.aspx

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New Jersey Department of Environmental Protection (NJDEP). 2021. *New Jersey Stormwater Best Management Practices Manual.* https://nj.gov/dep/stormwater/bmp_manual2.htm

Rhode Island Department of Environmental Management (RIDEM) and Coastal Resources Management Council (CRMC). 2015. *Rhode Island Stormwater Design and Installation Standards Manual*. Amended March 2015. https://dem.ri.gov/sites/g/files/xkgbur861/files/pubs/regs/regs/water/swmanual15.pdf

Rhode Island Department of Transportation (RIDOT). 2019. Rhode Island Department of Transportation Linear Stormwater Manual. http://www.dot.ri.gov/documents/about/protecting/stormwater/RIDOT_Linear_SW_Manual.pdf

Dry Water Quality Swale

Source: Southwest Conservation District

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	■
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	■
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Moderate**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**Medium**

Description

Water quality swales are shallow vegetated open channels designed to treat and convey stormwater runoff. Water quality swales provide higher pollutant removal than traditional grass drainage channels, which are designed strictly for conveyance.

Dry water quality swales (also referred to as "dry swales") have a bioretention soil media below the surface of the swale that facilitates stormwater filtration and vegetative growth. Dry swales are frequently designed to infiltrate but can be designed with an underdrain to capture filtered water and assist with drainage from the system. In certain situations, bioretention swales can also be designed with impermeable liners to prevent infiltration into the underlying soil. Dry swales are planted with dense, native grasses or plants that function to slow the flow of runoff and encourage filtration. The use of check dams is recommended to enhance water quality performance by promoting ponding, filtration, and infiltration of stormwater into the underlying soil. Pollutants are removed through sedimentation, filtration, adsorption, pollutant uptake, and infiltration.

If not designed with an impermeable liner, dry water quality swales can provide retention of stormwater and reduce runoff volumes through infiltration and groundwater recharge. Dry swales may also be used to provide stormwater quantity control when designed as on-line facilities.

Dry water quality swales are valuable systems for linear projects as well. However, linear projects have alternative standards and may take an alternative approach to address constraints that are different than those that affect traditional parcel development projects. These alternative linear project standards can be found in the CTDOT drainage manual, the CTDOT MS4 General Permit and in the supporting materials that CTDOT has developed.

Advantages

- Dry water quality swales are an alternative to bioretention systems where the site requires a sloped base or must convey runoff between points.
- Can provide stormwater retention, runoff volume reduction, and groundwater recharge if designed for infiltration.
- Provide runoff conveyance and can provide some peak runoff attenuation by reducing runoff velocity and providing temporary storage.
- High pollutant removal efficiency and water quality benefits, like bioretention.

Limitations

- Individual dry swales treat a relatively small area.
- May be impractical in areas with steep topography or poorly drained soils.
- Large area requirements for highly impervious sites.
- May not be practical in areas with many driveway culverts or extensive sidewalk systems.
- Higher relative construction costs than other stormwater infiltration systems due to cost of bioretention soil media.

Siting Considerations

- **Potential Locations:** Linear nature makes swales ideal for use within roadway right-of-way areas, along shared-use paths, and within or around parking lots. Dry swales are suitable in urban and rural settings.
- **Drainage Area:** The maximum contributing drainage area is 5 acres to any single inlet, unless the flow enters the dry swale via sheet flow along a linear feature such as a road.
- **Soils:** Dry swales that return filtered runoff to the conveyance system and do not infiltrate into the ground can be used in almost any soil type. Dry swale designs that rely on infiltration should be used only when the soil infiltration characteristics are appropriate (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for design guidance for stormwater infiltration systems).
- **Land Use:** Dry swales can be used in most land use settings where space is available.

- **Water Table and Bedrock:** For dry swales designed for infiltration (unlined systems), at least 3 feet of separation is recommended between the bottom of the system and the seasonal high groundwater table (SHGT) and bedrock. The vertical separation distance to the SHGT or bedrock may be reduced to 2 feet as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- Horizontal Setbacks: For dry swales designed for infiltration (unlined systems), meet the minimum horizontal setback distances in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, depth to bedrock, and soil infiltration rate. Refer to Chapter 10 - General Design Guidance for Stormwater Infiltration Systems for soil evaluation guidance.

Design Recommendations

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the swale in accordance with the Pretreatment BMPs section of this Manual.

- Acceptable pretreatment measures include vegetative filter strips, sediment forebays, pretreatment swales, deep sump catch basins, oil grit separators, and proprietary pretreatment devices.

- Sediment forebays should have a minimum storage volume of 10% of the Water Quality Volume (WQV), while flow-through Pretreatment BMPs should treat at least the equivalent Water Quality Flow (WQF).

Sizing and Dimensions

- Dry Swale Filter Bed (Bottom) Area
    - Dry swale should be designed by either the Static or Dynamic Methods as described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems
    - System should completely drain in 48 hours or less after the end of the design storm as described in Chapter 10.
    - For underdrained systems, use the coefficient of permeability of the bioretention soil media (1.0 feet per day or 0.52 inches per hour) in the drain time analysis. If the system is designed with a loam surface, also use a coefficient of permeability value of 1.0 feet per day or 0.52 inches per hour.
    - Install check dams to retain the applicable Water Quality Volume and to accommodate slopes greater than 2%. The volume of water retained behind check dams should be included in the system storage volume calculation.

- Bioretention Soil Depth
  - Engineered bioretention soil media should have a depth of 24 to 48 inches as necessary to accommodate the required sizing, vegetation species and root establishment, and subsurface conditions.
  - Soil depth may be limited by the requirement to maintain adequate separation to groundwater and bedrock as specified in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

- Ponding Depth
  - Maximum ponding depth for water quality storm: 12 inches at longitudinal mid-point of swale; 18 inches at downstream end of swale
  - Maximum ponding depth for overflow events: 36 inches
  - Minimum freeboard for overflow events: 6 inches above the 10-year, 24-hour storm water surface elevation to top of swale

- Bottom Width
  - Minimum: 2 feet
  - Maximum: 8 feet

- Bottom Slope
  - Dry swales should have a maximum longitudinal slope of 2%, provided flow velocities are non-erosive (e.g., flow velocities should not exceed 3 feet per second for grassed surfaces).
  - Dry swales can have slightly steeper slopes (up to 6%) if designed with check dams.
  - Check dams should be designed to reduce the effective slope of the bottom of the dry swale to 2.0% or less for optimum water quality performance. Consider designing as a terraced system with check dams and relatively flat bottoms in each cell.

- Side Slopes
  - 3(H):1(V) slopes or flatter are preferred especially on grassed slopes where mowing is required.
  - In ultra-urban locations or space constrained areas, side slopes of 2(H):1(V) may be utilized if properly designed to account for erosion and slope stability. Stabilize the slope with turf reinforcement matting or equivalent if the slope could potentially erode.

- Water Velocity
  - For water quality storm: 1.5 feet per second (maximum)
  - Peak flow design storm: 5.0 feet per second (maximum)

Check Dams

- Check dams should be evenly spaced and designed with a maximum height of 18 inches. Check dams should be designed to pass the design flow over the top of the check dam without exceeding maximum ponding depths.

- Spacing of check dams should be a function of both the longitudinal slope of the swale and the design volume that must be retained behind the dams. Space such that the upstream limit of ponding from one check dam is just below the downstream edge of the adjacent check dam.

- Check dams that are designed to infiltrate (with no underdrain system) should not be constructed of permeable materials like gabions, as water must sufficiently pond behind each check dam and be forced to infiltrate.
- Utilize weirs constructed from concrete or granite curbing.
- Anchor check dams into swale side slopes to prevent washout. Each side of the dam should extend 2-3 feet into the swale side slopes.
- Protect downstream side of check dams from scour with stabilized surface protection measures.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.
- Runoff can be introduced to the dry swale through overland flow, curb cuts, inlet structures, swales/channels, and/or pipes.
- Design the system in an off-line configuration to the extent feasible if runoff is delivered by a storm drainpipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.
- Outlets are typically a stabilized spillway, gabion berm, concrete weir, curb cut opening, precast concrete structure, or polyethylene/polyvinyl chloride riser structure.
- Dry water quality swales should have an outlet sized to convey the 10-year, 24-hour storm event, at a minimum. Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm.

Underdrain System

- Install an underdrain system when a proposed dry swale meets one or more of the following conditions:
    - Is in native soil that has an infiltration rate less than 0.3 inch per hour (HSG C and D soils)
    - Does not meet vertical separation distance to SHGT or bedrock (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) and should be lined
    - Does not meet minimum horizontal setback distances (Chapter 10) and should be lined
    - Is within a Land Use with Higher Potential Pollutant Loads (LUHPPL) (Chapter 10) or area of contaminated soils and should be lined.

- An underdrain is also recommended, but not required, for all other dry swales to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall.
- Minimum underdrain pipe diameter: 4 inches
- Minimum underdrain pipe slope: 0.5%
- Use two layers of gravel with the underdrain system. Both layers of gravel should be located below and extend across the entire bottom of the system. The upper gravel layer should consist of 3 inches of pea gravel, and the lower layer should consist of a 12-inch-thick gravel sump.
- For unlined systems, install the perforated underdrain pipe 2 inches below the top of the gravel sump to promote infiltration. For systems that are lined with an impermeable liner to prevent infiltration, install the underdrain pipe 2 inches above the bottom of the gravel sump so the system can drain between storm events.
- If the system is designed without an underdrain, pea gravel and gravel sump are optional.
- Lay underdrain such that perforations are on the bottom of the pipe.
- Use solid (non-perforated) pipe sections and watertight joints wherever the underdrain system passes below berms, extends down steep slopes, connects to a drainage structure, and/or daylights.
- Place filter fabric along sidewalls of excavation and above the pea gravel (below the bioretention soil layer) for 1 to 2 feet on both sides of the underdrain. Filter fabric shall not be placed across the entire width of the swale.
- Other considerations when designing/installing underdrains:
    - Provide a marking stake and an animal guard for underdrains that daylight at grade.
    - If designed with laterals, space collection laterals every 25 feet or less.
- Include a minimum of two observation wells/cleanouts for each underdrain, one at the upstream end and one at the downstream end.
    - Cleanouts should be at least 4 inches in diameter, be nonperforated, and extend to the surface. Cap cleanouts with a watertight removable cap. The cleanout should be highly visible.
    - Provide one cleanout for every 1,000 square feet of surface area (at a minimum) or for every 250 linear feet of total pipe length in larger systems.

Liner

- An impermeable liner is required for use of dry swales when receiving runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (Chapter 10 - General Design Guidance for Stormwater Infiltration Systems), in locations with subsurface contamination, where the required vertical separation to SHGT cannot be met, and in locations with unacceptable horizontal setbacks for infiltration.

- If designing a lined system in a location where 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.

- For lined swales within LUHPPLs, a shutoff valve can be installed on the underdrain outlet to capture and contain accidental spills or releases that reach the swale.

Materials

- Surface Cover
    - Native grasses or plants is the preferred surface cover type for dry water quality swales. 3 to 4 inches of washed river stone or smooth crushed stone sized to resist the 10-year, 24-hour storm may also be used as an alternative surface cover type. Mulch should NOT be used on the bottom of the swale.

- Vegetation
    - Vegetation should be designed for regular mowing, like a typical lawn, or less frequently.
    - Select vegetation and provide a planting plan with the guidance provided in Appendix F of this Manual.
    - Native grasses are preferred for enhanced biodiversity, wildlife habitat, and drought tolerance.
    - Grass species should be sod-forming to resist scouring; have a high stem density to help slow water and facilitate sedimentation; be tolerant to frequent inundation; and be able to survive and continue to grow after the inundation period.
    - If to be used near a road that is subject to winter salt operations, the vegetation must also be salt tolerant.
    - Establish a dense vegetative cover or adequately stabilized landscaped surface throughout swale and any upgradient areas disturbed by construction before runoff can be accepted into the facility.
    - Trees should only be planted along the perimeter of the facility and with 15 feet of separation from underdrain piping.
    - Trees should not be planted in dry swales.
    - Do not use vegetation with a mature vegetation height exceeding 24 inches above the surrounding sidewalk or pavement surface in dry swales within

medians, near intersections, or near pedestrian crossings to avoid obstruction of sight lines.

- Engineered Bioretention Soil Media
  - The engineered soil media in bioretention systems is designed to filter/treat runoff and to provide sufficient organic material to support plan establishment and growth.
  - The engineered bioretention soil media should be a homogeneous soil mix of (by volume):
    - 60–85% Sand
    - 15–25% Topsoil
    - 3–8% Organic Matter
  - **Sand** should be washed concrete sand (ASTM C33 or AASHTO M-6) or coarse washed sand that meets the gradation schedule as shown in State of Connecticut Department of Transportation Standard Specifications, Section M.01 (Aggregates), Table M.01.04-1 for Fine Aggregate Gradations.
  - **Topsoil** should contain 5–20% organic material, have a pH range of 5.5 to 7.0, and be a sandy loam, loamy sand, or loam per USDA soil texture with less than 5% clay content. Topsoil that meets the State of Connecticut Department of Transportation Standard Specifications, Section M.13.01 (Roadside Development) for Topsoil may also be used, except it should contain less than 5% clay.
  - **Organic matter** should consist of one of the following materials
    - Sphagnum Peat: Partially decomposed sphagnum peat moss, finely divided or of granular texture with 100 percent passing through a 1/2-inch (13-mm) sieve, a pH of 3.4 to 4.8.
    - Wood Derivatives: Shredded wood, wood chips, ground bark, or wood waste; of uniform texture and free of stones, sticks, soil, or toxic materials.
  - Compost shall NOT be used as organic matter since the use of compost in bioretention soil media can result in nutrient export from the system.
  - Soil amendments such as zerovalent iron and/or drinking water treatment residuals (alum) may be used to further enhance phosphorus sorption.
  - Bioretention soil mix should have a pH of 5.2 to 7.0 and meet the particle size distribution in Table 13-12.

Table 13-9. Acceptable Particle Size Distribution of Final Bioretention Soil Mix

Media Type	Sieve #	Size (inches)	Size (mm)	% Passing
Coarse Sand	4	0.187	4.76	100
Medium Sand	10	0.079	2.00	95
Fine Sand	40	0.017	0.42	40-15
Silt	200	0.003	0.075	10-20
Clay	<200	Pan	Pan	0-5

- Bioretention soil mix should NOT contain any of the following materials: stones, clods, roots, clay lumps, and pockets of coarse sand exceeding 0.187 inches (4.76 mm) in any dimension; plants, sod, concrete slurry, concrete layers or chunks, cement, plaster, building debris, asphalt, bricks, oils, gasoline, diesel fuel, paint thinner, turpentine, tar, roofing compound, acid, solid waste, and any other extraneous materials that are harmful to plant growth.

- Pea Gravel
  - Should consist of 3/8" AASHTO No. 8 stone. Pea gravel should be clean (washed and free from dirt and debris) and rounded in shape.

- Gravel Sump
  - Should consist of 3/4" AASHTO No. 5 stone. Gravel should be clean (washed and free from dirt and debris), crushed, and angular.

- Filter Fabric
  - Use non-woven filter fabric that complies with State of Connecticut Department of Transportation Standard Specifications, Section M.08.01.19 (Drainage – Geotextiles).

- Underdrain (perforated and non-perforated pipe sections)
  - Polyethylene or polyvinyl pipe

- Liner
  - If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

- Check Dams
  - Construct of gabions, granite or concrete curbing, or precast/poured-in-place concrete. If constructed of granite or concrete curbing, curbing should conform

to State of Connecticut Department of Transportation Standard Specifications, Section M.12.06 (Stone Curbing) and Section 8.11 (Concrete Curbing).

- Poured-in-place Concrete
  - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section 6.01 (Concrete for Structures).

- Turf Reinforcement Matting (TRM)
  - Stabilize the side slopes of the swale with TRM to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.
  - If used, shall be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Other Considerations

- Roadway stability can be a design issue when installing swales along roadways. It may be necessary to provide a vertical impermeable barrier to keep water from saturating the road's sub-base. The barrier should be capable of supporting H-20 loads.

- Non-woven filter fabric should be placed along the sidewalls of the system to help direct the water flow downward, reduce lateral flows, and to reduce lateral soil migration. This is critical when installing swales in a median strip or adjacent to a roadway or parking lot.

- Non-woven filter fabric should also be placed above the pea gravel layer (below the bioretention soil layer) for 1 to 2 feet on both sides of the underdrain pipe. Filter fabric should NOT be placed across the entire width of the bioretention system because filter fabric installed in this manner can result in clogging and system failure.

Winter Operations

- Swales should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the swale and scarification of bottom and sidewalls of excavation

- After placement of gravel layer
- After placement of underdrain before covering by the pea gravel layer
- After placement of bioretention soil media
- After installation of bypass, outlet/overflow, and inlet controls
- After grass or other vegetation has been installed

- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- The bioretention soil mix should be tested prior to placement according to the specifications in this section (at least one test per bioretention system). The designing qualified professional should certify that the bioretention soil mix meets the specifications in the previous section based on soil testing results.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.

- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.

- The system should be fenced off during the construction period to prevent disturbance of the soils.

- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the bioretention system. A hydraulic excavator or backhoe loader, operating outside the limits of the system, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.

- The gravel, pea gravel, and bioretention soil media should be placed in the excavation by a hydraulic excavator or backhoe loader located outside the limits of the system and then hand-raked to the desired elevation.

- Place the bioretention soil in 6 to 12-inch lifts. The bioretention soil needs to settle before planting. Lightly tamp or spray the surface of the bioretention soil with water until saturated. The elevation of the bioretention soil can be a couple of inches higher at installation than the design elevation in anticipation of settling. Bring bioretention soil levels back to the design elevation if necessary.

- Install vegetation in the swale in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established. The bioretention soil mix provides enough organic material to adequately supply nutrients from natural cycling.

Maintenance Needs

- Swales should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.

- Maintenance should be detailed in a legally binding maintenance agreement.

- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid compaction of the bioretention soil media and underlying soils. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.

- Inspect swale annually.

- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.

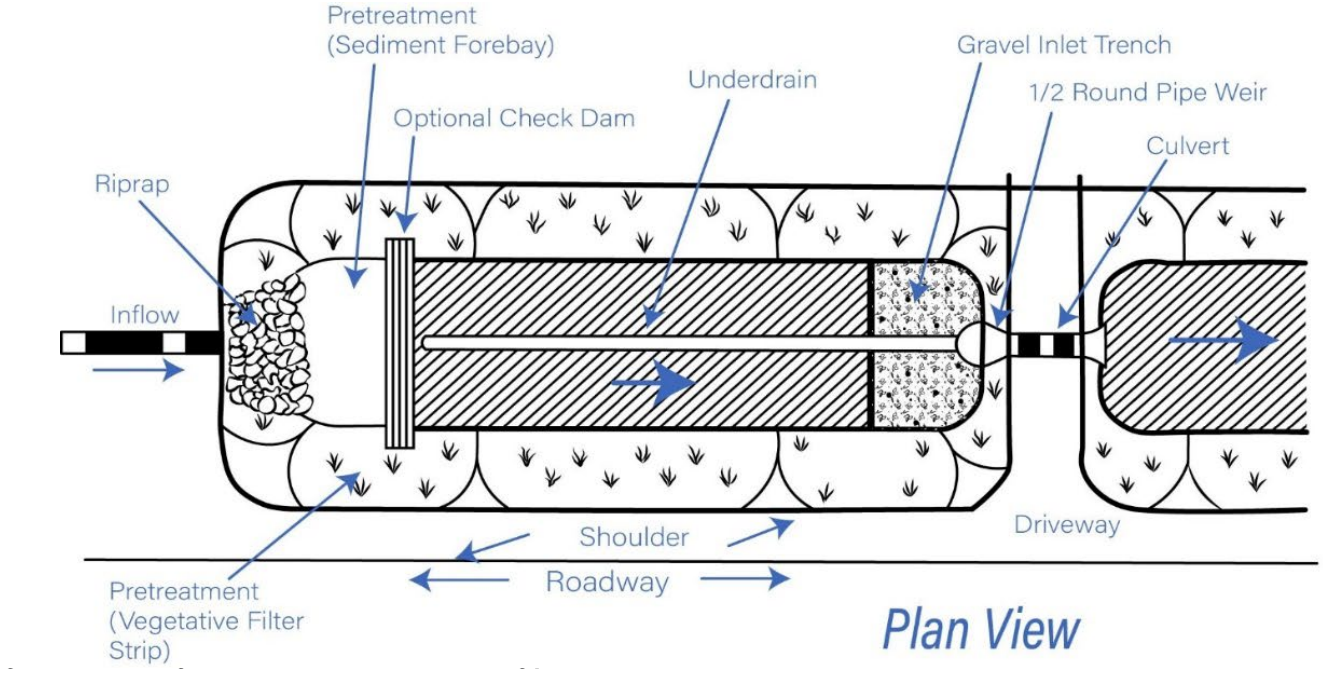
- Remove trash and organic debris (leaves) in the Spring and Fall.

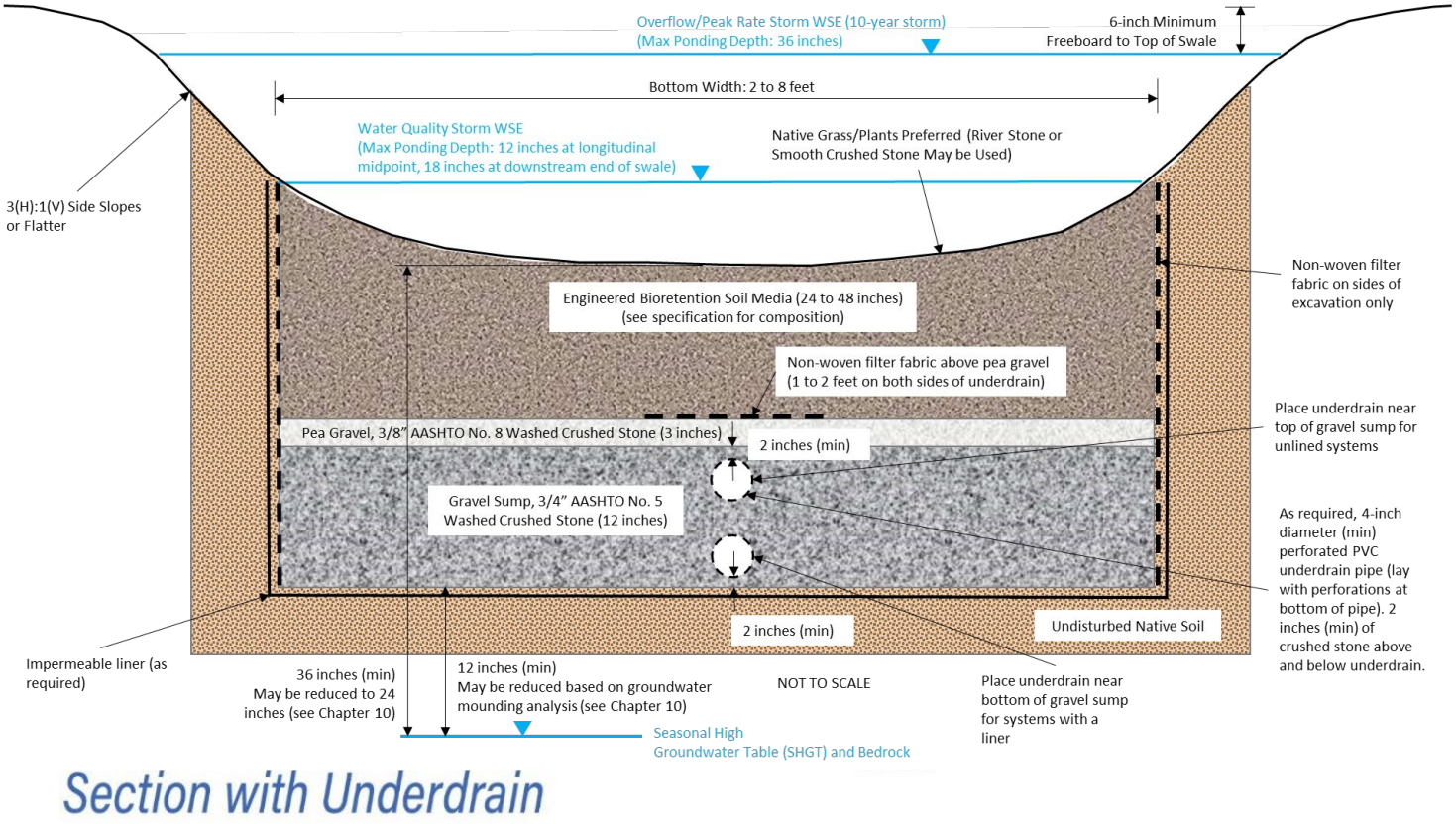
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.

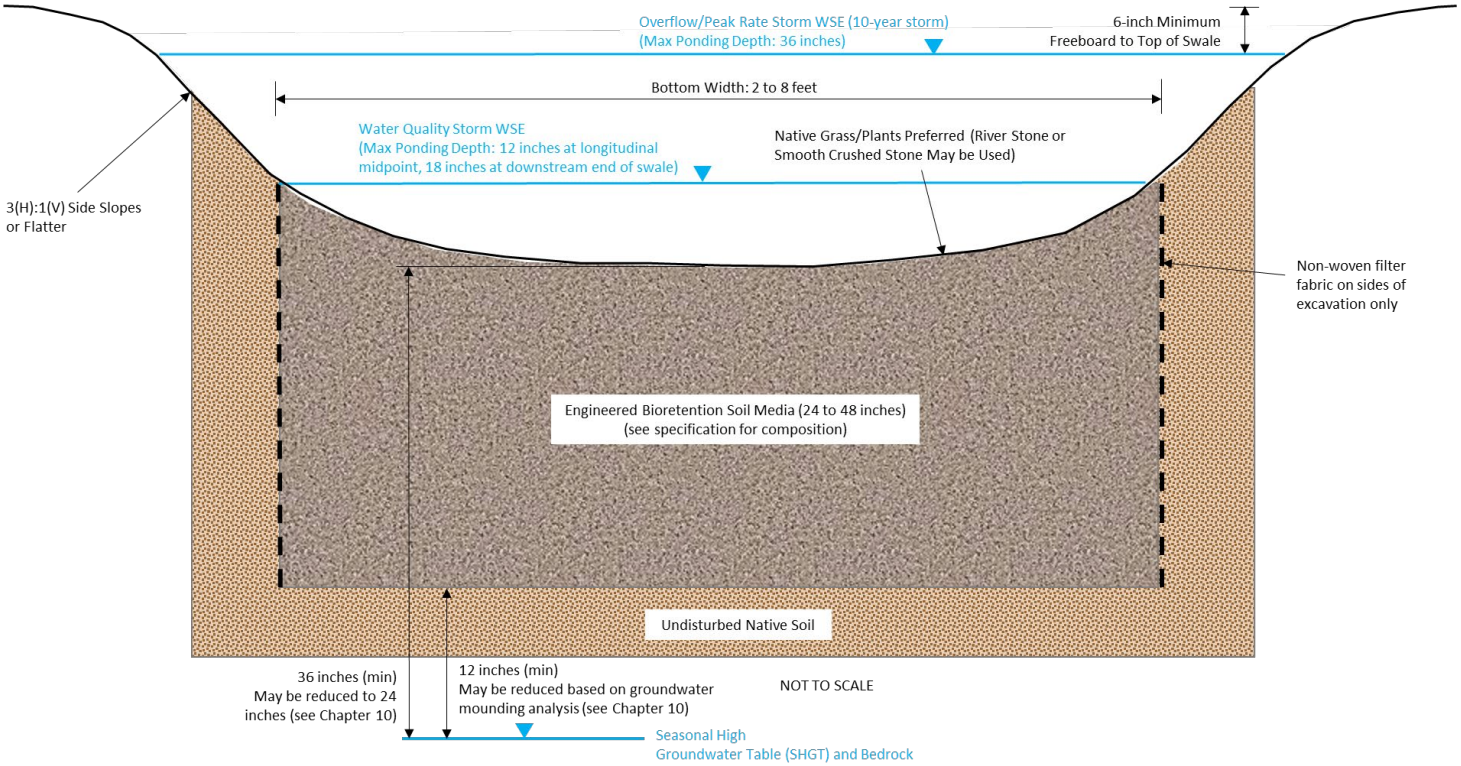
- Remove sediment from the swale surface when the sediment accumulation exceeds 2 inches or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the system is clogged.

- Weed as necessary. Mow grass within swale to a height of 4 to 6 inches. Maintain a healthy, vigorous stand of grass cover, re-seed as necessary.
- Maintain vegetated filter strips or grassed side slopes of swale in accordance with maintenance recommendations in the Pretreatment BMPs section of this Manual.
- Periodically remove grass clippings to prevent clogging of the surface of the swale.
- Mowing should not be performed when the ground is soft to avoid the creation of ruts and compaction, which can reduce infiltration.

Figure 13-30. Dry Water Quality Swale with and without Underdrain Schematics







Section without Underdrain

Wet Water Quality Swale

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	■
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	□
Treatment	■
Pretreatment	□
Peak Runoff Attenuation*	■

*On-line systems only

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**Medium**

Description

Water quality swales are shallow vegetated open channels designed to treat and convey stormwater runoff. Water quality swales provide higher pollutant removal than traditional grass drainage channels, which are designed strictly for conveyance.

Wet water quality swales (also referred to as "wet swales") temporarily store and treat stormwater runoff from the water quality storm. However, unlike Dry Water Quality Swales, wet swales are constructed directly within existing soils and are not underlain by a bioretention soil media or underdrain system. Wet swales store stormwater runoff within a series of cells within the channel, which may be formed by berms or check dams. Wet swales are designed to remain saturated, maintaining wetland plants and conditions. The pollutant removal mechanisms in wet swales are similar to those of Stormwater Wetland BMPs, which rely on sedimentation, adsorption, and microbial breakdown.

Wet water quality swales are primarily used for treatment and conveyance of stormwater runoff. They do not provide stormwater retention, runoff volume reduction, or groundwater recharge because they are constructed in groundwater and are not designed for infiltration. Wet swales may also be used to provide stormwater quantity control when designed as on-line facilities.

Advantages

- Wet water quality swales are an alternative to stormwater pond and wetlands where the site requires a sloped base or must convey runoff between points.
- Provide runoff conveyance and can provide some peak runoff attenuation by reducing runoff velocity and providing temporary storage.
- Can be used on sites with high groundwater or poorly drained soils.

Limitations

- Do not provide stormwater retention, runoff volume reduction, or groundwater recharge.
- May be impractical in areas with steep topography.
- Large area requirements for highly impervious sites unless used with another stormwater BMP solely to provide additional treatment along with stormwater conveyance.
- May not be practical in areas with many driveway culverts or extensive sidewalk systems.

Siting Considerations

- **Potential Locations:** Linear nature makes swales ideal for use within roadway right-of-way areas, along shared-use paths, and around the perimeter of parking lots.

- **Drainage Area:** The maximum contributing drainage area is 5 acres to any single inlet, unless the flow enters the wet swale via sheet flow along a linear feature such as a road.

- **Soils:** Wet swales are best suited to sites with poorly drained soils (HSG C and D soils). Although feasible if constructed with an impermeable liner similar to those used with stormwater ponds and wetlands, wet swales are generally impractical for use in HSG A and B soils.

- **Land Use:** Wet swales can be used in most land use settings where stormwater can be conveyed in surface channels. Wet swales are not recommended in residential areas or within commercial parking lots with significant foot traffic because of the potential for stagnant water and other nuisance ponding.

- **Water Table and Bedrock:** Wet swales should only be used where the water table is at or near the soil surface. The bottom of a wet swale should be constructed at or below the seasonal high groundwater table (SHGT). At least 1 foot of separation is recommended between the bottom of the swale and bedrock. Test pits or soil borings are required at the location of the proposed system to verify soil types, depth to SHGT, and depth to bedrock in accordance with the soil evaluation guidance provided in Chapter 10.

- **Horizontal Setbacks:** Wet swales should be located at least 50 feet downgradient of on-site subsurface sewage disposal systems for single family residential use, and at least 75 feet downgradient from on-site subsurface sewage disposal systems for all other uses.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, and depth to bedrock. Perform test pits or soil borings in accordance with the soil evaluation guidance in Chapter 10.

Design Recommendations

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the swale in accordance with the Pretreatment BMPs section of this Manual.

- Acceptable pretreatment measures include vegetative filter strips, sediment forebays, pretreatment swales, oil grit separators, and proprietary pretreatment devices.

- Sediment forebays should have a minimum storage volume of 10% of the Water Quality Volume (WQV), while flow-through Pretreatment BMPs should treat at least the equivalent Water Quality Flow (WQF).

Sizing and Dimensions

- Wet Swale Dimensions
    - Wet swale length, width, depth, and slope should be designed to temporarily store the Water Quality Volume through surface ponding. The permanent pool may be included in the static storage volume calculation and system sizing.
    - Install check dams as necessary to store the Water Quality Volume and to accommodate slopes greater than 2%. The volume of water retained behind check dams should be included in the design storage volume calculation.
    - The soil bed below wet swales should consist of undisturbed soils. The underlying soil should be inundated as the bottom of the swale should be at or below the SHGT.
    - Wet swales should not be constructed in highly permeable soils that cannot easily support dense vegetation.

- Ponding Depth
    - Maximum ponding depth for water quality storm: 12 inches at longitudinal mid-point of swale; 18 inches at downstream end of swale
    - Maximum ponding depth for overflow events: 36 inches
    - Minimum freeboard for overflow events: 6 inches above the 10-year, 24-hour storm water surface elevation to top of swale

- Bottom Width
    - Minimum: 2 feet
    - Maximum: 8 feet

- Bottom Slope
  - Wet swales should have a maximum longitudinal slope of 2% without check dams, provided flow velocities are non-erosive (e.g., flow velocities should not exceed 3 feet per second for grassed surfaces).
  - Wet swales can have slightly steeper slopes (up to 6%) if designed with check dams.
  - Check dams should be designed to reduce the effective slope of the bottom of the wet swale to 2.0% or less for optimum water quality performance. Consider designing as a terraced system with check dams and relatively flat bottoms in each cell.

- Side Slopes
  - 3(H):1(V) slopes or flatter are preferred especially on vegetated slopes where mowing is required.
  - In ultra-urban locations or space constrained areas, side slopes of 2(H):1(V) may be utilized if properly designed to account for erosion and slope stability. Stabilize the slope with turf reinforcement matting or equivalent if the slope could potentially erode.

- Water Velocity
  - For water quality storm: 1.5 feet per second (maximum)
  - Peak flow design storm: 5.0 feet per second (maximum)

Check Dams

- Check dams should be evenly spaced and designed with a maximum height of 18 inches. Check dams should be designed to pass the design flow over the top of the check dam without exceeding maximum ponding depths.

- Spacing of check dams should be a function of both the longitudinal slope of the swale and the design volume that must be retained behind the dams. Space such that the upstream limit of ponding from one check dam is just below the downstream edge of the adjacent check dam.

- Check dams should be constructed of washed crushed stone, gabions, granite or concrete curbing, or precast/poured-in-place concrete.

- Anchor check dams into swale side slopes to prevent washout. Each side of the dam should extend 2-3 feet into the swale side slopes.

- Protect downstream side of check dams from scour with stabilized surface protection measures.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.

- Runoff can be introduced to the wet swale through overland flow, curb cuts, inlet structures, swales/channels, and/or pipes.
- Design the system in an off-line configuration to the extent feasible if runoff is delivered by a storm drain pipe or is along the main storm conveyance system.

Outlet & Overflow

- Design the outlet in accordance with the Inlet and Outlet Controls section of this Manual.
- Outlets are typically a stabilized spillway, gabion berm, concrete weir, curb cut opening, precast concrete structure, or polyethylene/polyvinyl chloride riser structure.
- Wet water quality swales should have an outlet sized to convey the 10-year, 24-hour storm event, at a minimum. Off-line systems should be designed with a bypass or overflow for flows in excess of the water quality storm.

Materials

- Vegetation
    - Emergent wetland plants are the preferred type of vegetation for wet water quality swales.
    - Select vegetation and provide a planting plan with the guidance provided in Appendix F of this Manual.
        - Native vegetation is preferred for enhanced biodiversity and wildlife habitat.
        - Vegetation should be suitable for sustained inundation and/or a high water table.
        - If to be used near a road that is subject to winter salt operations, the vegetation must also be salt tolerant.
    - Establish a dense vegetative cover throughout swale and any upgradient areas disturbed by construction before runoff can be accepted into the facility.
    - Trees should be planted only along the perimeter of the facility.
    - Trees should not be planted in wet swales.
- Check Dams
    - Construct of washed crushed stone, gabions, granite or concrete curbing, or precast/poured-in-place concrete. If constructed of granite or concrete curbing, curbing shall conform to State of Connecticut Department of Transportation Standard Specifications, Section M.12.06 (Stone Curbing) and Section 8.11 (Concrete Curbing).
- Poured-in-place Concrete
    - If used, should be an appropriate class of concrete based on the application and conform to State of Connecticut Department of Transportation Standard Specifications, Section 6.01 (Concrete for Structures).

- Turf Reinforcement Matting (TRM)
  - Stabilize the side slopes of the swale with TRM to limit erosion in locations where flow velocities exceed 3 to 5 feet per second (depending on soil and vegetation types) for the 1-year, 24-hour storm event.
  - If used, shall be a woven material included on the CTDOT Qualified Products List that exceeds the design velocity of the design storm and allows for the growth of the proposed vegetative species.

Other Considerations

- Roadway stability can be a design issue when installing swales along roadways. It may be necessary to provide a vertical impermeable barrier to keep water from saturating the road's sub-base. The barrier should be capable of supporting H-20 loads.

Winter Operations

- Swales should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.

- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the swale and scarification of bottom and sidewalls of excavation
  - After installation of bypass, outlet/overflow, and inlet controls
  - After vegetation and wetland plants/seed mix has been installed

- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.

- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.

- Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system.
- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans. The method of excavation should avoid compaction of the bottom of the swale. A hydraulic excavator or backhoe loader, operating outside the limits of the system, should be used to excavate the system. Excavation equipment should not be allowed within the limits of the system.
- Install vegetation in the swale in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.

Maintenance Needs

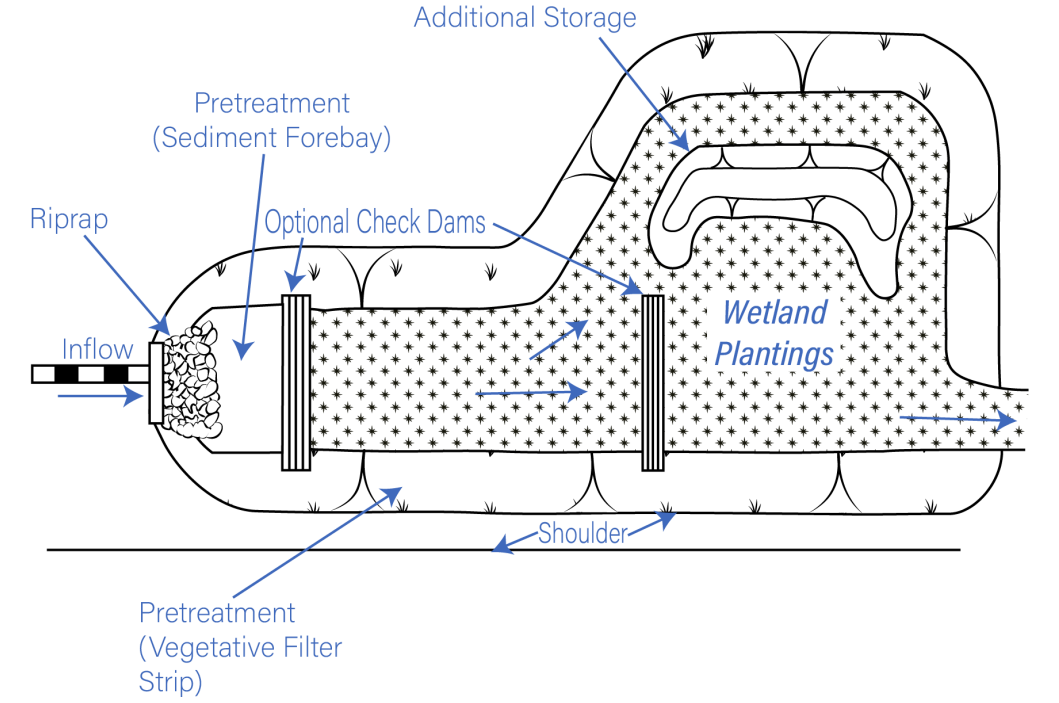
- Swales should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid soil compaction and damage to vegetation. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

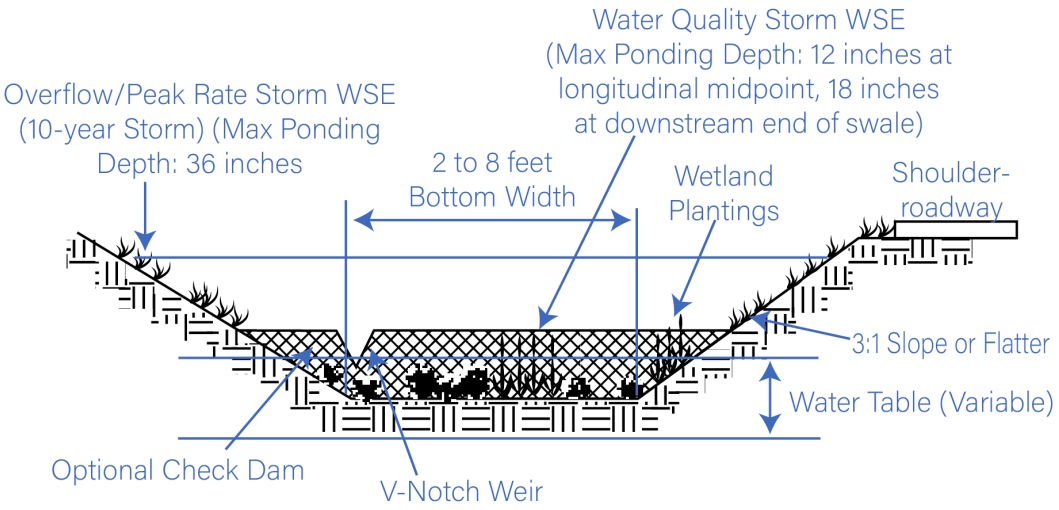
Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect swale annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.

- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 12 inches or 50% of the design depth. Clean outlet of sediment forebay or other pretreatment measures when drawdown time exceeds 36 hours after the end of a storm event.
- Remove sediment from the swale surface when the sediment accumulation exceeds 2 inches or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the system is clogged.
- Periodically mow vegetation within swale. Maintain a healthy, vigorous stand of vegetation; re-seed as necessary.
- Prune woody vegetation in wet swales where dead or dying branches are observed. Plant reinforcement plantings as necessary.
- Maintain vegetated filter strips or grassed side slopes of swale in accordance with maintenance recommendations in the Pretreatment BMPs section of this Manual.
- Periodically remove grass clippings to prevent clogging of the surface of the swale.
- Mowing should not be performed when the ground is soft to avoid the creation of ruts, soil compaction, and damage to vegetation.

Figure 13-31. Wet Water Quality Swale Schematic





Rain Barrel and Cistern

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	■
Proprietary BMP	□
Other BMPs and Accessories	□

Stormwater Management Suitability

Retention	■
Treatment	□
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**Low**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Varies**
Maintenance Burden	**Low**
Land Requirement	**Low**

Description

Rainwater harvesting involves the collection of rainwater from rooftops and other impervious surfaces and storage of the rainwater in a rain barrel or cistern for non-potable use. Rainwater harvesting practices are extremely versatile and scalable from small-scale residential applications to large-scale commercial or industrial sites. Collection systems can be located outside, inside, above or below the ground and can be designed in a variety of shapes and sizes to fit the site conditions.

Rainwater harvesting systems generally consist of five main components: catchment, conveyance, pretreatment, storage, and distribution. Catchment areas include clean roofs (rain barrels and cisterns) and other impervious surfaces (cisterns only). Pretreatment is required for larger harvesting systems (cisterns) to remove stormwater pollutants from paved surfaces and to remove leaves, debris, and other coarse solids from roof runoff. Storage can be in a prefabricated or custom-built above or below ground system, and either detached or structurally integrated with a building. Finally, distribution systems can range from garden hoses on a rain barrel, to plumbing or underground irrigation systems associated with a cistern.

Rain barrels are storage containers that are connected to a downspout and capture runoff from a roof. Rain barrels are typically sized to retain 50-100 gallons of irrigation water for gardening and landscaping. Many different types of rain barrels are commercially available. Although they primarily function as storage for stormwater reuse, rain barrels can help to control localized drainage issues and reduce the effects of small-scale point discharge, such as scour at the outlet of a roof drain system.

Cisterns have a greater storage capacity than rain barrels and may be located above or below ground. Cisterns typically collect runoff from areas larger than residential rooftops such as roof areas of larger buildings or parking lots. Stored water is fed by gravity or pumped via a distribution system to the point of use. Unlike rain barrels, cisterns can provide some peak runoff attenuation depending on the size of the system and the volume of water in the cistern at the start of a storm event.

Table 13-10. Summary Comparison of Rain Barrels and Cisterns

Feature	Rain Barrel	Cistern
Uses (non-potable)	Outdoor uses: gardening, landscape irrigation, rinsing.	Indoor and outdoor uses: landscape and turf irrigation, washing, flushing, cooling.
Size	Small; usually serve an individual roof. Typically, sufficient for 100-200 square feet of roof area.	Large; usually collect runoff from a larger area and often multiple sources.
Location	Above ground	Above ground tanks or underground storage system.
Cost	Inexpensive (Sometimes barrels can be obtained at little or no charge)	More expensive (Cost depends on materials, size, and construction method)
Requires Pretreatment or Treatment?	No	Yes
Suitable for Treatment?	No	No
Suitable for Retention?	Yes	Yes
Suitable for Peak Runoff Attenuation?	Too small to attenuate peak runoff; can have localized drainage benefits. Multiple barrels can be installed on a site to increase their effectiveness.	Can be large enough to attenuate peak flows depending on the size of the system and the amount of water stored when the storm event occurs.

Rain barrels and cisterns can provide retention credit for the volume of water captured and reused. However, they are limited in their capacity to achieve other goals such as pretreatment and infiltration. For example, neither system recharges groundwater. As stand-alone strategies, they do not provide stormwater treatment but are nonetheless ideal for capturing, collecting, and reusing stormwater for non-potable uses such as irrigation, vehicle washing, or toilet flushing. Providing an alternate source of water for those activities can lower demand on public and private water supplies, which is especially beneficial during dry spells in summer months.

Additionally, rain barrels and cisterns can be an important component of a more complex stormwater management system. For example, the overflow from rain barrels and cisterns can be directed to a dry well or other infiltration BMP to provide groundwater recharge and additional retention. Including a cistern in a stormwater treatment train can also increase the overall capacity of the system.

Advantages

- Conserve potable water for essential uses.
- Provide alternative to potable water during time of peak demand.
- Reduce or limit withdrawals from ground or surface water supply.
- Effective method for capturing runoff for a variety of uses, especially in areas where public water supply is limited.
- Efficient use of space in urban areas and for retrofits.
- Cisterns can be sized to fit small to large scale needs.
- Quick installation using prefabricated modular systems.
- Systems are durable with a long life with effective pretreatment and routine maintenance.
- Suitable for use as part of a stormwater treatment train, particularly in combination with off-line retention and treatment stormwater BMPs.
- Rainwater is typically soft compared to other sources of water and contains low levels of dissolved salts and minerals which makes it preferable for irrigation, gardening, and landscaping uses. Soft water can also be less taxing on plumbing if the water is harvested to supply flushing, car washing, or other non-potable uses.

Limitations

- Strictly for stormwater reuse and limited quantity control. Not suitable for treatment.
- Rain barrels and smaller cisterns have minimal impact on runoff volume and peak flows.
- Capture and reuse of stormwater from paved surfaces and some roof surfaces requires appropriate pretreatment, as well as additional post-storage treatment for certain uses, which can add cost and complexity to the system.
- Deteriorated and/or clogged gutters and downspouts can cause a system to fail.
- Underground cisterns can require extensive, costly excavation.

Siting Considerations

- **Drainage Area:** A single 55-gallon rain barrel can generally serve a roof area of 100 to 200 square feet depending on how frequently the stored water is used for irrigation. Cisterns

can be used to store runoff from larger drainage areas, including rooftops and other impervious surfaces, generally up to 1 acre or more depending on the water demand.

- **Groundwater and Bedrock:** No restrictions. Anti-buoyancy measures may be needed for underground cisterns at or below the water table.

- **Land Uses:** Rain barrels are applicable to a wide range of land uses (i.e., residential, commercial, industrial, municipal, institutional) where reuse for gardening or landscape irrigation is desired. Cisterns are typically used in land use settings with larger water demand such as commercial, institutional, and industrial facilities.

- **General:** Both rain barrels and cisterns should be located as close as possible to the source and/or point of use. This minimizes the infrastructure required to convey the water to the system and distribute it where it is needed. To function effectively, rain barrels and cisterns should be sized according to the on-site water needs. An over-sized system will not be drained sufficiently to accommodate input during rain events and an under-sized system will not meet the water needs for the site.

Soil Evaluation

- A soil evaluation is not required for rain barrels.

- A soil evaluation is required for all subsurface rainwater harvesting storage systems and may be required for large aboveground storage tanks to evaluate the need for a foundation (i.e., crushed stone and/or concrete or concrete block) to support the weight of the tank when full and to prevent the cistern from settling, overturning, or incurring other damage.

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed cistern including soil type, depth to the seasonal high groundwater table, depth to bedrock, and other geotechnical testing as necessary. Perform test pits or soil borings in accordance with the soil evaluation guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

Design Recommendations – Rain Barrel

- Rain barrels are typically located at the downspout of a roof gutter system.

- Place the rain barrel on a sturdy, level surface 1-3 feet above the ground. The surface or platform should be capable of supporting the barrel when it is full, which for a standard 55-gallon rain barrel can be between 400 and 500 pounds. Elevating the barrel increases the water pressure and facilitates drainage.

- Install an overflow pipe from the top of the barrel to an Infiltration BMP, Filtering BMP designed for infiltration, or onto a vegetated surface consistent with the requirements for

simple disconnection as described in Chapter 5 - Low Impact Development Site Planning and Design Strategies of this Manual.

- A single 55-gallon rain barrel can typically serve 100 to 200 square feet of roof area depending on the water needs for gardening or landscape irrigation. Use multiple rain barrels if larger volumes are desired. Calculate the volume of stormwater runoff generated for a given storm and roof area using the following equation:

$$V = \frac{A * P * 0.9 * 7.5}{12}$$

where:

V = required volume of rain barrel (gallons)
A = surface area of roof (square feet)
P = rainfall (inches)
0.9 = losses to system (no units)
12 = conversion factor (inches per foot)
7.5 = conversion factor (gallons per cubic foot)

Example: One 60-gallon rain barrel would provide sufficient storage from a rooftop area of approximately 100 square feet for a 1.0-inch storm, assuming that the rain barrel is empty prior to the storm.

$$V = \frac{100\ ft^2 * 1.0\ in * 0.9 * 7.5\ gal/ft^3}{12\ in/ft} = 56.25\ gallons$$

- Pretreatment of stored rainwater is typically not required for gardening or landscape uses.
- If there is a downspout from the roof and it extends to the ground, use a downspout diverter to divert water to the top of a "closed-top" rain barrel.
- If the downspout is cut a few feet above the ground use a plastic, flexible gutter extension or elbow to connect to top of an "open-top" rain barrel.
- If there isn't a downspout, a rain chain can be used to connect the roof to the top of an "open-top" rain barrel.
- A filter system, such as a screen, can be installed as a part of the connection to prevent sediment and debris from entering the barrel.
- Cover the top of the barrel with a tight-fitting, light-blocking, locking lid that will keep the lid from blowing off in a storm, keep children and animals out of the water, limit the development of algae, and limit access to the standing water for mosquitos.

- Cover all openings into the barrel with window screening that is tightly affixed, or even caulked, at all edges. A screen can be added under the lid as an extra precaution.
- Provide a spigot, with garden hose threading, a few inches (minimum) above the bottom of the rain barrel to create a sump for sediment and debris on the bottom of the barrel. A regular garden hose can be connected to the spigot. Use a garden hose that is at least 8-10 feet long to discourage mosquitos from flying up the hose. The end of the hose can be fitted with screen to further prevent intrusions.
- Disconnect and drain rain barrels in the winter to prevent freezing and deformation of the rainwater harvesting system.

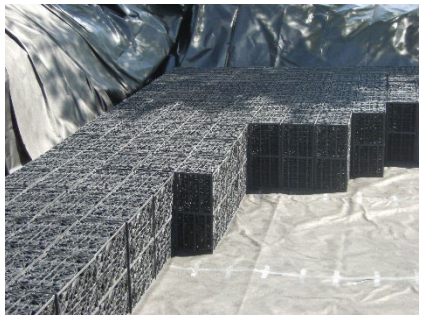
Design Recommendations - Cistern

The selection and design of stormwater cisterns and larger rainwater harvesting systems depends on many factors including the size and characteristics of the contributing drainage area; the volume, timing and location of water use on the site; physical and operational site constraints; system costs versus anticipated water savings; operation and maintenance considerations; and other factors. Cisterns come in many configurations and sizes, and the design of stormwater cisterns is highly site-specific. Table 13-14 provides a summary comparison of various types of cisterns. System design should be consistent with design guidance of the product manufacturer as well as local and state building and public health codes regarding beneficial reuse of rainwater or stormwater.

Table 13-11. Comparison of Types of Rainwater Harvesting Storage Systems (Cisterns)

Type/Material	Advantages	Disadvantages
Fiberglass and Fiber Reinforced Polymer rainharvest.com	➢ Economical storage solution for larger volumes of water ➢ Protection from UV sunlight degradation ➢ Available in a variety of sizes and capacities ➢ Provides strength and durability for reliable performance ➢ Material is inert to soil compounds which can degrade tanks manufactured with other materials ➢ Accessible for maintenance, minimal maintenance	➢ Expensive in smaller sizes ➢ Excavation for cistern can be difficult ➢ Can be expensive to ship
Polyethylene, Polypropylene, & HDPE Pipe ads-pipe.com	➢ Commercially available ➢ Alterable and movable ➢ Affordable ➢ Available in a variety of sizes ➢ Easy to install ➢ Accessible for maintenance, minimal maintenance	➢ Can be degraded by UV sunlight if aboveground ➢ Can detract visually if not well-sited

Type/Material	Advantages	Disadvantages
Plastic (Aboveground) Cistern Watercache.com	➢ Commercially available ➢ Alterable and movable ➢ Available in a variety of sizes, shaped, configurations, colors ➢ Easy to access for maintenance	➢ Possible UV deterioration ➢ Aboveground use only ➢ Must be insulated and heat traced for year-round use ➢ Can detract visually if not well-sited ➢ Can be expensive to ship
Galvanized Metal rainwatermanagement.com	➢ Commercially available ➢ Alterable and movable ➢ Available in a variety of sizes, shapes, configurations ➢ Easy to access for maintenance	➢ Possible corrosion and rust ➢ Aboveground use only ➢ Must be insulated and heat traced for year-round use ➢ Can detract visually if not well-sited ➢ Can be expensive to ship

Type/Material	Advantages	Disadvantages
Concrete Hillandgriffith.com	○ Can be economical storage solution for larger volumes of water ○ Long life ○ Load bearing capabilities for use under parking lots and driveways ○ Can be configured in custom shape and layout ○ Can neutralize slightly acidic rainwater ○ Can be made accessible for maintenance	○ Expensive in smaller sizes ○ Excavation for cistern can be difficult ○ Precast concrete cisterns are not readily available and may involve expensive shipping costs ○ Susceptible to cracks and leaks over time (install liner inside tank)
Modular (Plastic Lattice) Storage Systems  watercache.com	○ Can be economical storage solution for larger volumes of water ○ Low shipping cost compared to other system types ○ Flexible in shape, layout, and depth ○ Available in a variety of sizes and capacities ○ Units can be specified for traffic loading for use under parking lots and driveways ○ Provides strength and durability for reliable performance	○ Requires specific excavation and burial preparation to ensure longevity of system ○ Internal cleaning is not possible; pretreatment system is extremely important for system longevity

Water Budget Analysis

- Perform a water budget analysis to determine if the desired capture volumes can be achieved and to properly size the system. A water balance consists of estimating the amount of water that can be captured and the amount of water that is used. Key considerations include balancing the amount of storage unit overflow with the size of the storage unit and limiting or eliminating the need for a secondary water supply.
- Estimate the water budget using a daily time step, mass balance approach. Daily changes in storage volume are equal to watershed runoff inputs minus evaporation, overflow, and indoor/outdoor use outputs.
- Water budget calculations can be performed using a water balance calculator specifically designed for rainwater harvesting systems, other models, or a spreadsheet.
- Water demand for irrigation is determined based on irrigation rates and water needs of the landscaped or turf area

Siting

- Located the cistern as close as possible to the water collection and/or point of use.
- Locate the cistern upslope from the point of use, if possible, to maximize gravity flow to the point of use.
- Locate the cistern below ground, if possible, to avoid freezing in the winter.
- Co-locate the cistern with building foundations, where possible.
- Grade away from the cistern; avoid low points where a cistern can become flooded.
- Direct cistern overflow away from an adjacent structure's foundation.
- Locate the cistern upslope from any sewage disposal facilities, septic tanks, or other source of potential contamination.
- Where possible, do not locate cisterns under areas with high vehicle loading. If unavoidable, design the structure to support the vehicle load.

Pretreatment

- Pretreatment is required to extend the functional life of a cistern. Incorporate pretreatment measures at locations where runoff enters the cistern in accordance with the Pretreatment BMPs section of this Manual.
- Pretreatment measure(s) should treat at least the Water Quality Flow (WQF).

- Acceptable pretreatment measures depend on the characteristics of the drainage area.
    - **Runoff from Paved Areas:** Pretreatment of runoff from paved areas includes pretreatment measures that are suitable for piped drainage systems – deep sump hooded catch basins,[88] oil grit separators, and proprietary pretreatment devices.
    - **Roof Runoff:** For runoff from roofs with low potential for accumulation of leaves or other solids, pretreatment may be waived by the reviewing authority. For roofs with moderate or high potential to collect leaves or other solids (e.g., roofs that are lower than the surrounding trees), pretreatment is required to remove coarse solids from the runoff prior to entering the cistern. Pretreatment options for roof runoff include leaf screens, first flush diverters, or roof washers.
- Additional treatment of the stored water may be necessary prior to use depending on the water quality requirements of the proposed use.

General Design Considerations

- The cistern should have sufficient storage volume to contain the Water Quality Volume (WQV) without overflow.
- The demand for stormwater reuse on site should be sufficient to empty the cistern within 72 hours after a rain event in order to allow for sufficient storage for the next rain event. Additionally, storage in excess of 72 hours may result in anaerobic conditions, odor, and both water quality and mosquito breeding issues.
- If the lowest 3-day water demand is insufficient to empty a cistern sized for the water quality storm, but the demand is greater on other days, a secondary storage tank should be used, sized with sufficient capacity to hold water from each storm event until it is reused.
- Cisterns can be constructed as off-line or on-line systems. In an off-line configuration, runoff from storms larger than the water quality storm bypasses the cistern through an upgradient diversion. On-line systems receive runoff from all storm events, which can be used or pumped to a secondary storage tank for later use. Runoff from larger storm events is conveyed through an overflow. On-line systems can also provide some stormwater runoff quantity control.
- Aboveground cisterns should be insulated to prevent the contents from freezing in the winter, or the cistern and rainwater harvesting system should be drained in the winter and only used seasonally. Aboveground cisterns should be covered to avoid becoming a breeding ground for insects.

[88] Only recommended for space constrained sites where no other Pretreatment BMPs are feasible.

- Underground cisterns should be located 3 feet below grade (or below the frost line) to prevent the harvested rainwater from freezing. For underground installations, the cistern should be at or above the seasonal high groundwater table (SHGT) and bedrock. Anti-buoyancy measures may be needed if cisterns are designed at or below the water table.

- When installing a cistern on a rooftop, consider the weight of the cistern at full capacity to be certain the roof structure is designed to accommodate the full load.

- To find the minimum required elevation of a cistern, calculate the hydraulic head required to distribute the water to the point of use. If the cistern cannot be located at that elevation, then pumps are required to distribute the water.

- All cisterns should include a vent pipe. The vent is necessary to allow fresh air to circulate in the cistern and it should be installed so that the opening faces the prevailing wind. Provide a water-tight seal where the vent pipe penetrates the cistern.

- All cisterns should include an overflow pipe. The diameter of the overflow pipe should be at least as large as the diameter of the inflow pipe. Install a fine-mesh screen on the end of the vent and overflow pipes to prevent the incursion of animals and insects. The overflow should discharge to an Infiltration BMP, Filtering BMP designed for infiltration, or onto a vegetated surface consistent with the requirements for simple disconnection as described in Chapter 5 - Low Impact Development Site Planning and Design Strategies of this Manual. The cistern may be designed to continuously discharge water at a very slow rate so that there is capacity in the cistern to retain stormwater in subsequent rain events.

- The water line from the cistern to the point of use should be buried below the frost line, be located at least one foot above the floor of the cistern and be positioned on the opposite side of the cistern from the input pipe to allow for sediment to settle.

- A separate input pipe can be included if water needs to be added to the cistern from a source other than captured stormwater.

- Provide a backflow prevention system to prevent contamination of public water supplies when public water is used as a backup source of water.

- Include sufficient freeboard above the outlet to allow for large storm events to pass through the cistern without backing up in upstream pipes or spilling out onto nearby surfaces.

- For cistern systems where controls to automate or regulate flow are required to move water from the cistern into the distribution system, include methods for detecting flows, identifying system failure (i.e., high level alarm) as well as an emergency shut-off and emergency backup power.

- All cisterns should include a cleanout drain for system cleaning. Slope the floor of the cistern towards the cleanout drain to facilitate cleaning. The drain cover can be controlled

by a valve that is either controlled from ground level or directly. The drain line and valve to control the drain cover will both need to be buried below the frost line to avoid freezing. The drain line should be sized adequately to move sediment that builds up in the cistern. A 4-inch diameter pipe is typically sufficient.

- Provide access manholes for system maintenance. Manholes should be placed, at a minimum, near the inlet and outlet of the system and in intermediate locations. The number of manholes depends on maintenance methods and design guidance of the product manufacturer.
- Custom concrete cisterns should be a minimum of 6 inches thick and reinforced with steel rods.
- When using prefabricated units follow the product manufacturer guidelines for installation requirements, minimum cover, and bedding/foundation design below the structure to support the design load associated with the structure, water storage, and adjacent backfill weight.
- If a liner is used for underground modular storage systems, the liner should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

Construction Recommendations

Rain Barrel

- Commercially available rain barrels can be installed quickly by placing the rain barrel on a sturdy, level, elevated platform and connecting it to a downspout.
- Use a food-grade container for the barrel, if possible, to prevent harmful chemicals from leaching into the stored rainwater.
- When drilling holes into the rain barrel, make the orifice fit the attachments as close as possible. Ragged edges can create openings for mosquitos and other insects to enter the rain barrel.
- Teflon tape can be used to fill spaces between the threads of any fittings and the barrel to create a water-tight seal. Wrap the tap clockwise to prevent it from coming undone when the adapter is screwed into place.
- Use washers on the inside and outside of each fitting attachment to ensure a snug fit.
- Caulk or plumbing adhesive can be used to seal the fittings.

Cistern

- The designing qualified professional should develop a detailed, site-specific construction sequence.
- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the system (underground systems)
  - After placement and leveling of any necessary bedding or foundation below the cistern
  - After placement of the cistern(s) and any pretreatment devices and secondary storage tanks
  - After the installation of bypass, outlet/overflow, and inlet controls
  - After connection of the cistern and harvesting system to secondary water sources
  - After the system has been backfilled (underground systems)
- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- The system should be fenced off during the construction period.
- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans.

Maintenance Needs

Rain Barrel

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Sediment and debris should be cleaned out on a regular basis.

- Use a screw-on lid, whether it is a solid or screened lid to facilitate easy access for maintenance.
- Gutters on the roof should be kept clear of debris to limit the amount of stormwater that reaches the rain barrel or could contribute to a build-up of debris in the rain barrel that limits its performance.
- Winterization is required to limit damage to the barrel from freeze-thaw cycles. Drain the barrel and store it upside down for the winter.
- Before reconnecting it to the downspout in the spring, clean the barrel with a nontoxic cleaning solution, check all of the connections, and make any necessary repairs.
- Inspect the roof catchment area for leaves or particulate matter that may be entering the gutter and downspout to the rain barrel.
- Inspect the gutters, downspouts, and entrance to the rain barrel for leaks or obstructions.
- Inspect the rain barrel for potential leaks, including barrel top and seal.
- Inspect the overflow pipe for erosion at the outlet.
- Inspect the spigot to ensure that it is functioning correctly.
- Drain and disconnect the system before winter to prevent freezing and cracking.
- Mosquito larvae can form in rain barrels when water is retained over 72 hours. The larvae need to be at the surface to breathe so controlling the growth of mosquitos at this stage is manageable. Adding a tablespoon of non-toxic liquid dish soap after a storm or even on a weekly basis will add a film on the top of the water that will break the surface tension of the water and make it impossible for adults to lay eggs. Another strategy is to add ¼ cup of vegetable oil can be added weekly or after storm events. The oil forms a film on top of the water that prevents the larvae from breathing.
- Cleaning with a diluted bleach solution periodically can help remove any available food for the mosquito larvae and it makes the barrel less attractive to adults looking to lay eggs.

Cistern

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintain underground structures in accordance with the manufacturer's guidelines.

- Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment from the pretreatment structure using a vacuum truck and removal of accumulated sediment from the cistern using a high-pressure water nozzle (i.e., JetVac process) and vacuum truck.
- Confined space safety procedures as required by OSHA regulations must be followed by workers entering an underground cistern.
- Inspect the pretreatment structure and cistern twice a year.
- Inspect the remainder of the system annually including an inspection for material failure (such as cracking, spalling, deterioration, subsidence, etc.).
- Pumps, valves, alarms, and other controls should be kept in good working order in compliance with the manufacturer's guidelines.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove sediment from the pretreatment structure when it accumulates to more than 50% of the design depth.
- Remove sediment from the cistern when the sediment accumulation exceeds 2 inches throughout the length of the structure.
- Because rainwater is acidic and therefore corrosive, measures should be taken to neutralize rainwater in cisterns. Using plastic pipe can reduce corrosion or a neutralizing agent, such as limestone, quick lime, hydrated lime, soda ash, or caustic soda, can be added directly to the cistern.
- During winter months, downspouts, pretreatment mechanisms, and outflows should be periodically checked for ice buildup and all ice removed to keep the system functioning. It is sometimes economical to add heat trace to the piping in larger stormwater harvesting installations.

Other References

Connecticut Department of Energy and Environmental Protection. 2009. *Rainfall as a Resource: A Resident's Guide to Rain Barrels in Connecticut*. June 2009. https://portal.ct.gov/-/media/DEEP/water/watershed_management/wm_plans/LID/whatisarainbarrelpdf.pdf?la=en

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Massachusetts Department of Environmental Protection. *Rain Barrels & Cisterns. Massachusetts Clean Water Toolkit*. https://megamanual.geosyntec.com/npsmanual/rainbarrelsandcisterns.aspx

New Jersey Department of Environmental Protection (NJDEP). 2021. *New Jersey Stormwater Best Management Practices Manual*. https://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.1-cisterns.pdf

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Green Roof

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	■

Stormwater Management Suitability

Retention	■
Treatment	□
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**High**
Phosphorus	**Moderate**
Nitrogen	**Moderate**
Bacteria	**Moderate**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**Varies**

Description

Green roofs, also known as eco-roofs or vegetated roofs, consist of layers of soil and vegetation installed on building rooftops. Green roofs are typically multilayered systems that consist of a waterproof membrane, a synthetic drainage layer, a root barrier topped with a lightweight soil media, and a selection of plants suited to harsh rooftop conditions. Green roofs reduce runoff volumes and peak discharge rates by retaining runoff and creating longer flow paths. Rainwater is either intercepted by vegetation and evaporated to the atmosphere or retained in the substrate before being returned to the atmosphere through evapotranspiration.

The ability of a green roof to absorb and/or retain stormwater depends primarily on the type of plant material and soil medium but also depends on the drainage layer, the roof slope, the size of the roof and the season and climate. Green roofs may be used on newly constructed buildings or as retrofits of existing buildings. The structural integrity of the building is an important consideration for evaluating the feasibility of a green roof for a given application.

A green roof's ability to influence the water quality of runoff depends on the chemical composition of the rain falling on it, the materials used to promote plant growth such as fertilizer, and the type of plants. While the soil media and vegetation of green roofs can reduce pollutants in stormwater, green roofs are generally not used for stormwater treatment because

they capture rainwater, which is typically relatively clean. Green roofs primarily slow the flow of stormwater or intercept rainwater and supply it for non-potable uses like flushing toilets and irrigation. In addition to reducing the amount of stormwater runoff leaving a site, green roofs can mitigate heat island effects, reduce local air pollution, and lower building energy costs by providing additional insulation, among other benefits.

Advantages

- Can reduce the peak rate of runoff by 50-90% as well as delay the peak rate by up to three hours as compared to runoff from a conventional impermeable roof.
- Can reduce stormwater runoff volumes by retaining a portion if not all the rainfall in a storm event by releasing it back into the atmosphere via evaporation and evapotranspiration. (Unplanted "Blue Roofs" are designed specifically to retain water and slowly release it back via managed release of runoff and/or evaporation.)
- Can moderate the temperature of runoff.
- Can be used in densely developed areas where the use of other stormwater management practices is limited due to space constraints.
- Can improve runoff water quality if planted with material that naturally takes up contaminants from the soil.
- Can buffer the effects of acid rain by filtering it through a growth medium with a basic pH.
- Can contribute to air quality improvements by reducing carbon dioxides levels, binding airborne particulates and sequestering greenhouse gases.
- Can provide habitat for birds and pollinators and thus promote biodiversity.
- Can reduce the "urban heat island" effect by helping to regulate air temperature.
- Can extend the life of the conventional roof below.
- Can contribute to building's energy efficiency by providing additional insulation and reducing heat loss in the winter and cooling the roof in the hot summer months.
- Can provide sites for recreational amenities or even urban agriculture.
- Can increase the property's marketability or that of surrounding properties by improving views from neighbors into the site.

Limitations

- Can be expensive to design and construct.
- Construction can be challenging and require gardening and roofing experts to work together.
- Roof system must be designed to support the green roof under fully saturated conditions.
- Inadequate or improperly maintained drainage can cause the system to underperform or in extreme cases exceed the capacity of the load-bearing structure supporting it.
- Sloped-roof applications require additional erosion control measures.
- Historic buildings and building codes/standards can increase regulatory requirements and cost.
- More frequent maintenance required than for a conventional roof.
- Can contribute nutrient pollutant loads if fertilizer is used.
- Leaks can damage the building it is sited on.

- Damage to materials under the plantings such as the root barrier or waterproofing materials can be difficult to repair or replace.
- Plants can be difficult to establish and even once they are established, they can expire from the harsh conditions and need replacement.
- Soils can erode if soil levels are not maintained as organic matter deteriorates or if soils are washed out by a rain event.

Siting Considerations

- **Potential Locations:** Green roofs are appropriate for all types of structures and uses from commercial, institutional to residential. Wide, relatively flat roof areas are preferred but not necessary as green roofs can be installed in narrow areas and on slopes. Green roof technology makes it possible to install a green roof in a wide variety of locations where stormwater flow reduction is desired. Green roofs can be incorporated into new construction and can often be added to existing structures.

- **Drainage Area:** A green roof has no maximum contributing drainage area limitation because it only manages the precipitation that falls on the vegetated roof surface. Runoff from other surfaces and structures should not be directed onto the green roof.

- **Roof Slope:** Roof slope can affect the overall cost and performance. The flatter the roof the easier it is to retain water and stabilize planted areas. When roofs are sloped it is necessary to consider the different requirements for upslope and downslope conditions, which will tend to collect more water and will require plant, depth of soil media, and structural considerations to accommodate those conditions. Green roofs are difficult to install on structures with a pitch in excess of 45 degrees and it is recommended that green wall technology be implemented in those situations. Sloped roofs do not necessarily result in increased peak flows in comparison to flat roofs as long as the green roof system is designed to accommodate the flow of water down the slope of the conventional roof. Gravel ballast, wrapped in filter fabric, can be used along the perimeter of the roof to promote drainage and prevent soil medium migration. [89]

- **Roof Size:** Roof size is a factor that contributes to the overall performance. Larger green roof installations tend to have a higher capacity to reduce runoff volumes, peak flow rates, and time of runoff concentration than smaller roof areas.

- **Seasons and Climate:** Season and climate should be considered in Connecticut where conditions differ dramatically throughout the year. Green roofs tend to retain more stormwater during the growing months and less when plants are dormant. Additionally, evaporation rates are higher during the warmer months. Green roofs also typically work more effectively during low-impact short-term rain events in comparison to high-intensity

[89] Landscape Development and Landscaping Research Society e.V., Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL). 2018 Edition. Guidelines for the Planning, Construction and Maintenance of Green Roofs.

events or storms that have a long duration. Micro-climatic conditions such as seasonal shade, seasonal wind shifts, etc. can affect the performance of a green roof. Height of the rooftop and orientation can create stronger winds requiring tree staking and special mulching

- **Use with Other BMPs:** Green roofs can be sited so that runoff from them feeds into other BMPs, which can provide additional retention, treatment, peak runoff attenuation, or stormwater reuse. Pairing a green roof with cisterns and other structural stormwater BMPs can improve the overall system's ability to achieve stormwater quality and quantity objectives for the range of storm conditions that can be expected in Connecticut.

Types of Green Roofs

A variety of green roof designs exist, which fall into two major categories based on the type of construction, the program, and related specifically to the depth of the growing medium (Table 13-15):

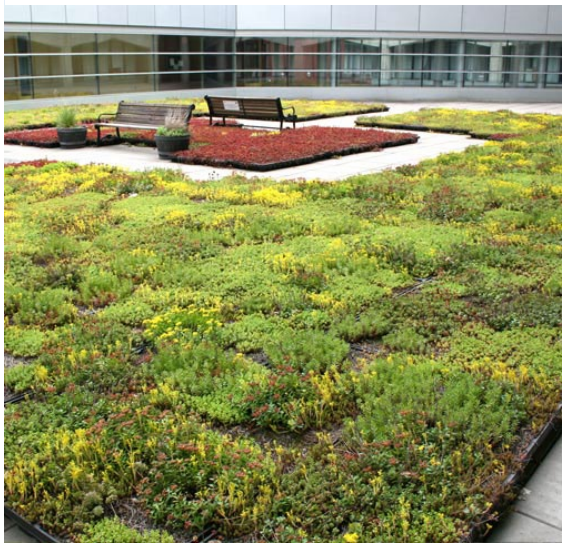
- **Extensive:** Typically less complex and less expensive than an intensive system, these installations usually include a planted area sometimes accessible only to maintenance personnel and do not typically require irrigation after the initial establishment of plant material. Extensive green roofs can be used on flat or sloped roofs.

- **Intensive:** or, roof gardens, are typically designed to provide amenity spaces and accommodate varied planting designs, and thus deeper planting media is typically necessary to accommodate larger plant material, like trees. Intensive green roofs can be designed to provide more environmental services than extensive roofs, but tend to cost more than extensive green roofs. Intensive green roofs are typically used on flat roofs. In addition to garden spaces, intensive green roofs can be used for urban agriculture or even turf sports fields.

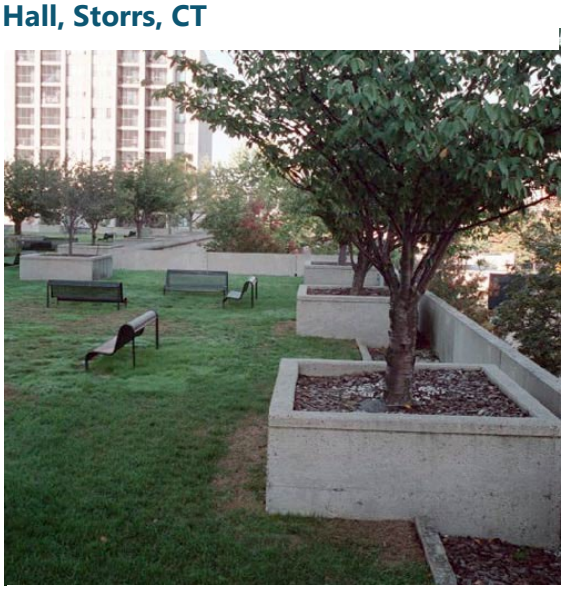
The following photographs are examples of extensive and intensive green roofs in Connecticut. Figure 13-32 provides schematics of common types of extensive and intensive green roofs showing the differences in the various layers that comprise each type.

Extensive Green Roof, Laurel Hall, Storrs, CT

Simple Intensive Green Roof, Storrs Hall, Storrs, CT



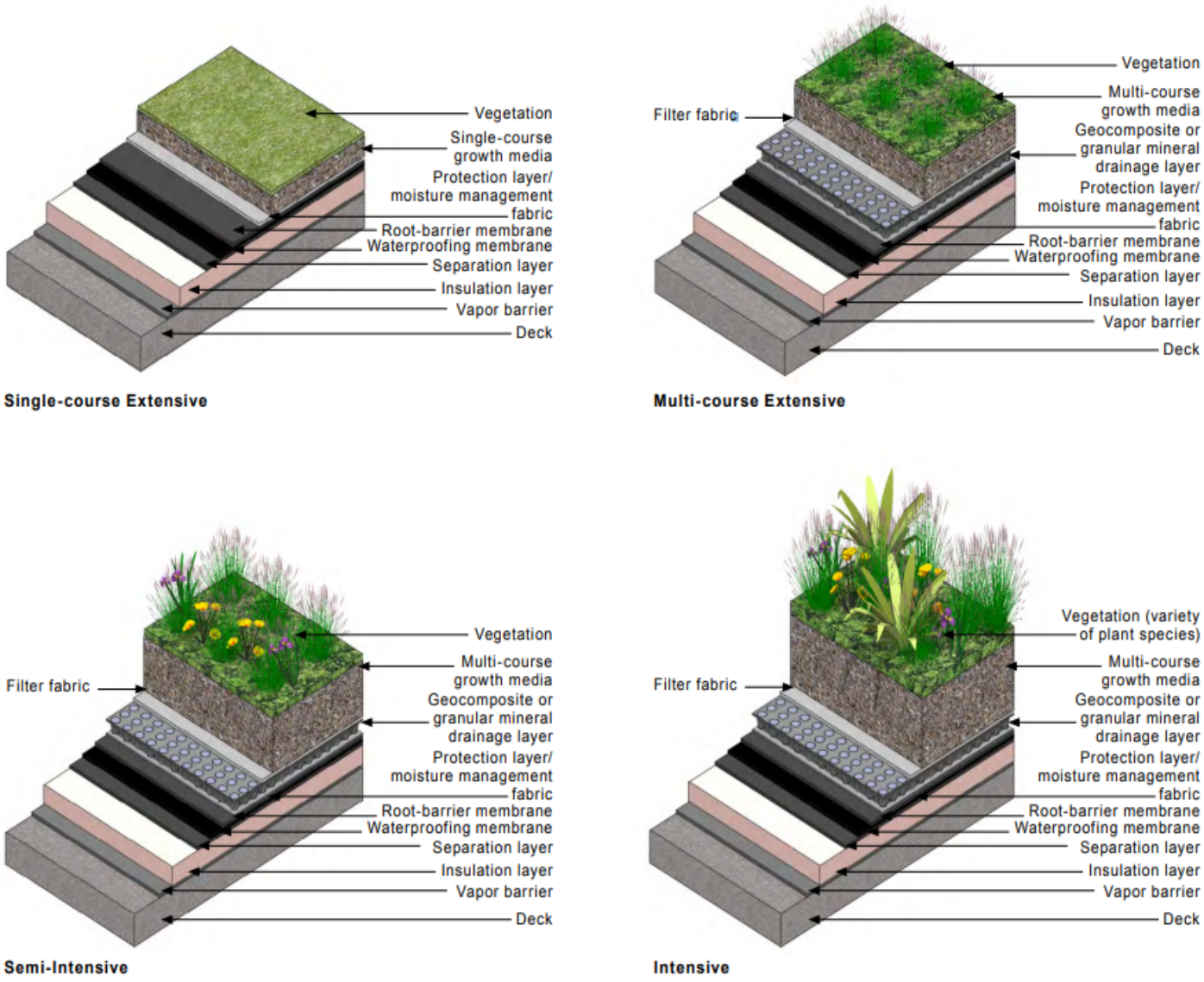
Modular Green Roof, Gant Plaza, Storrs, CT



Intensive Green Roof, Stamford Government Center, Stamford, CT

Source: UConn NEMO Program

Figure 13-32. Typical Green Roof Types



Source: GSA, 2011[90]

[90] U.S. General Services Administration (GSA). 2011. The Benefits and Challenges of Green Roofs on Public and Commercial Buildings: A Report of the United States General Services Administration. May 2011, p.18. https://www.gsa.gov/cdnstatic/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.pdf

Table 13-12. Comparison of Extensive and Intensive Green Roof Systems

	Extensive		Intensive	
Typical Feature	**Single Course**	**Multi Course**	**Simple**	**Full**
Relative Cost	$ Least Expensive			Most Expensive $ $
Thickness	3-4"	4-6"	6-12"	>12"
Establishment	As short as one growing season	1-3 growing seasons	Depends on plant selection	Intensive care throughout
Vegetation	Self-sustaining, adapted to extreme site conditions with a high regeneration rate such as succulents, sedums, moss, or a native meadow seed mix appropriate to the site's USDA hardiness zone and local biotope.	Self-sustaining, adapted to extreme site conditions with a high regeneration rate such as succulents, sedums, moss, or native herbaceous material; other plants as possible, such as grasses, depending on the USDA hardiness zone and the availability of supplemental irrigation when required.	A variety of species can be supported with the right blend of soil medium and moisture. Species include herbaceous and smaller woody meadow perennials, turf grasses, and other ornamentals. Plants that can withstand extreme site conditions should be given preference.	Depending on the roof garden's micro-climate, plantings can be implemented similar to ground-level installations. Due to micro-climates on rooftops, plants that can withstand heat, wind and fluctuations in moisture are more likely to thrive and will require less maintenance.
Growth media	Light-weight coarse growing media integrated with a drainage media	Light-weight, typically finer-grained media over a discrete drainage layer	Multi-course growth media overlaid on a discrete drainage layer	Growth media must be compiled at sufficient depths and composition to support the plant's needs. Higher levels of organics might be necessary and their effects on the water storage and density of the media must be considered when designing the structural support system. For trees a minimum planting depth 30 inches is required. The use of structural soil or soil cell system will be required for larger trees integrated with pavement areas

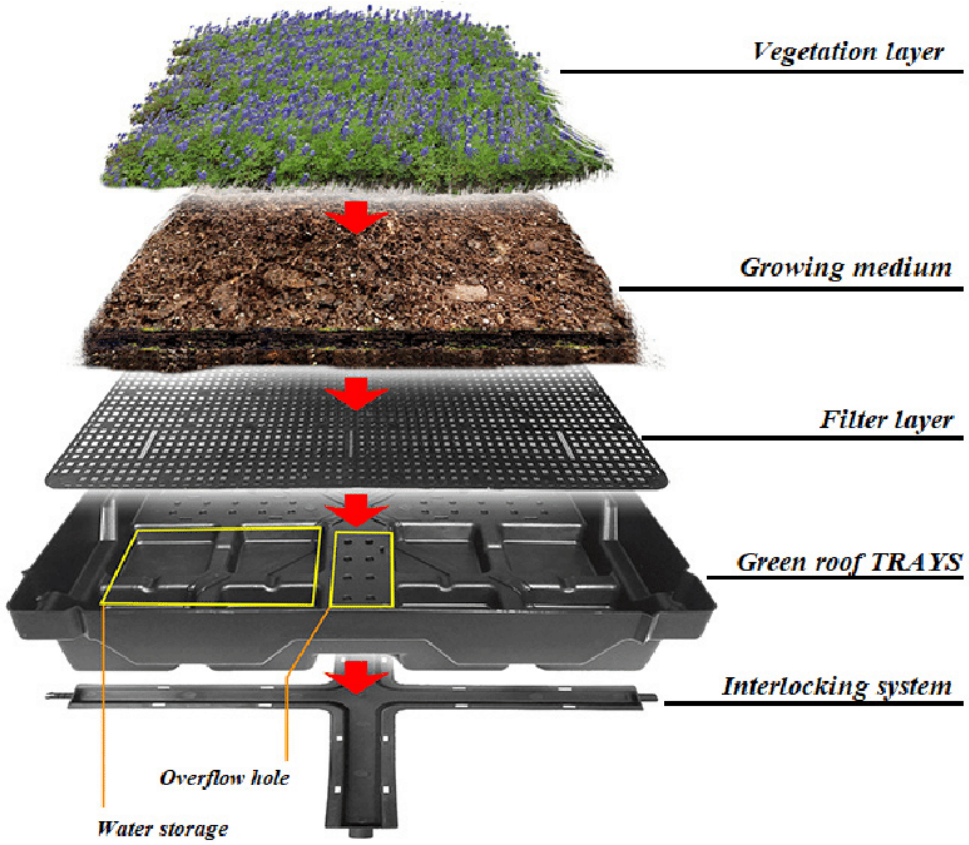
	Extensive		Intensive	
Typical Feature	**Single Course**	**Multi Course**	**Simple**	**Full**
Relative Cost	$ Least Expensive			Most Expensive $ $
Thickness	3-4"	4-6"	6-12"	>12"
Establishment	As short as one growing season	1-3 growing seasons	Depends on plant selection	Intensive care throughout
Drainage & Other Layers	Least complex layer structure. Drainage is integrated into soil media.	Potential for a less-complex layer structure. Typically a geocomposite is used but specific selection is related to the composition of the soil media, the types of plants selected, and regional climate and micro-climate conditions	Complex layer structure. Discrete drainage layer: either geocomposite or drainage media such as sand or gravel wrapped in a filter fabric or underlain with drainage board	Most complex layer structure. Discrete drainage layer is essential: either geocomposite or drainage media such as sand or gravel wrapped in a filter fabric or underlain with drainage board
Irrigation	None	Usually provided to establish vegetation; used to supplement as needed afterwards	Usually provided to establish vegetation; used to supplement as needed afterwards; required to maintain a turf grass installation	Typically required to supplement rainfall. Must be regulated to maintain the roof's ability to attenuate stormwater during a rain events

Typical Feature	Extensive		Intensive	
	Single Course	Multi Course	Simple	Full
Relative Cost	$ Least Expensive			Most Expensive $ $
Thickness	3-4"	4-6"	6-12"	>12"
Establishment	As short as one growing season	1-3 growing seasons	Depends on plant selection	Intensive care throughout
Maintanence	Minimal: regular weeding, plant replacement as necessary, regular material inspection to insure functionality. If the material is planted in a certain pattern or design additional maintenance to retain the desired pattern will be required.	Minimal: regular weeding, plant replacement as necessary, seasonal removal of spent plant material (such as cutting back meadow grasses); regular material inspection of hardscape layers to insure functionality	Intensive: regular weeding, plant care, mulching, pruning and typical garden maintenance; irrigation as necessary; regular material inspections, care, and maintenance	Intensive: regular weeding, plant care, mulching, pruning and typical garden maintenance; irrigation as necessary; regular material inspections, care, and maintenance

Created with Canva.com

- **Modular Green Roofs:** Modular green roof systems are either extensive or semi- intensive and can be used with new installations and building retrofits. These prefabricated systems consist of interlocking modules (trays or units) containing plants and soil medium. The modules typically have established vegetation prior to installation and can be easily installed and removed/replaced, thereby facilitating roof maintenance and repair. These systems can be more expensive than the built-in-place systems, and aspects of modular construction can interfere with the optimal performance of the green roof to achieve stormwater benefits. Figure 13-33 is a schematic cross-section of a modular green roof.

Figure 13-33. Typical Modular Green Roof Assembly



Source: www.sedumgreenroof.co.uk

Design Recommendations

Pretreatment

No pretreatment is required for direct rainfall onto the green roof surface.

Sizing and Dimensions

- Green roofs should be designed to retain without bypass or overflow the Required Retention Volume (100% or 50% of the roof's Water Quality Volume or WQV).
- Maximum roof slope: 20%

Green Roof Elements

The elements of a green roof are all interdependent and must be carefully selected and detailed to work together to achieve the desired goal of the green roof installation. For example, a green roof designed to maximize the interception of stormwater might rely on large-leafed plants to maximize evapotranspiration. Those types of plants will require a deeper growth medium than plants with lower evapotranspiration rates, which will present a larger load that the structure will need to support. Alternatively, a roof garden that uses a water-retention system such as hydrogel will require a structure that will bear the load of the material when it is fully saturated.

Vegetation

Plant choices must be appropriate to the USDA growing zone as well as the rooftop microclimate, balanced with the roof's capacity to support their needs for growth medium and moisture as well as with the project's overall budget for installation and ongoing maintenance. Evaluating the rooftop for site-specific conditions such as reflections, thermal loading and/ or shade from adjacent structures, specific air quality resultant from co-located utilities, as well as wind tunnel effects due to adjacent structures, is critical when identifying species that will succeed.

Plants that succeed are typically:

- Hardy in a harsh rooftop microclimate:
    - Able to survive intense temperature fluctuation
    - Able to endure freeze-thaw cycles
    - Capable of withstanding the impact and desiccation from high winds
    - Tolerant of droughts as well as deluges
    - Adapted to urban air quality
- Self-sustaining with a high rate of regeneration
- Low growing for extensive, but can be all different sizes in an intensive application
- Fire-resistant
- Low maintenance

Plants that take up water through roots more readily can help maximize the performance of the green roof, but those species are often not low-maintenance or suited for rooftop conditions and thus require more care. Sedums and other succulents, like Delosperma (ice plant) or Sempervirums, as well as creeping thyme, Allium, Anntenaria, Ameria and Abretia along with urban-tolerant meadow grasses, such as Ammophilia brevigulata are typically selected for rooftop installations because they are highly tolerant of droughts and desiccating winds and have a high capacity for absorbing stormwater.

Evapotranspiration rates for all plants vary depending on the species, climate, and localized environmental conditions. Plants with higher evapotranspiration rates increase the stormwater absorption rates but they tend to require deeper growth medium and potentially could require a supplemental irrigation system. Adding an irrigation system requires monitoring so that the roof is not already saturated, and thus unable to retain and reduce runoff when a rain event occurs.

Vegetation should be kept back from roof edges so that drainage is not inadvertently conveyed over the edge of a building.

Growth Medium

- Particle sizes, type of material and depth of medium must be balanced as together they affect the overall performance of a green roof. The soil medium must support the vegetation and retain stormwater without overburdening the structural system. The shallower the growth medium, the more diminished the water retention capacity and the less nutrients necessary to support plants.

- Smaller particles, with more surface area, have a higher capacity for retaining stormwater, but smaller particles can retain too much water or get washed out during heavy storm events and end up clogging the drainage system. It is recommended that no grain diameter be smaller than 0.063 mm as smaller material will clog typical filter fabrics.

- The organic content must be balanced to promote plant growth without causing negative effects. As organic material decomposes it can contribute phosphorus and nitrogen to the runoff and it can also lose volume which would need to be replaced to sustain root masses. Deeper soil medium can retain more water, but the bearing capacity of the roof must be designed to accommodate a higher load, which can greatly increase project costs. A typical planting medium for a green roof will consist of 80-90% lightweight aggregate and 10-20% stable organic matter.

- For extensive green roofs, use 2 to 6 inches of lightweight growth substrate consisting of inorganic absorbent material such as perlite, clay shale, pumice, or crushed terracotta, with no more than 5% organic content.

- The pH of the planting medium should be between 6 and 8.5.

- Tested permeability (hydraulic conductivity) of the growing medium to be at least 1 inch per hour. The permeability can be determined by following the test method outlined in ASTM E2399.

- The following growth media design criteria apply to extensive green roofs: (NJDEP, 2021)
  - The tested maximum media water retention, when using the ASTM E2399 method, or the or the maximum water capacity, when using the *FLL* method, should be at least 35% by volume but not greater than 65% by volume.
  - The organic content should be less than 4.06 pounds per cubic foot or 65 grams per liter.

- The following growth media design criteria apply to intensive green roofs: (NJDEP, 2021)
  - The tested maximum media water retention, when using the ASTM E2399 method, or the maximum water capacity, when using the *FLL* method, should be at least 45% by volume but not greater than 65% by volume.
  - The organic content should be less than 5.62 pounds per cubic foot or 90 grams per liter.

- Consider adding biochar to the soil medium to (NJDEP, 2021):
  - Increase water absorption
  - Manage the weight of the soil medium
  - Decrease the pollution discharge including decreasing the suspended solids in runoff

Drainage Layer

- Overall, the drainage layer should be dimensioned and implemented with consideration of the roof pitch, unevenness on the roof surface, and to tie into roof drains.

- The hydraulic conductivity of the drainage layer should exceed the planting medium's hydraulic conductivity to promote positive conveyance of runoff.

- Factors to consider include:
  - Structure and layer stability/ compatibility with other materials
  - Compressive performance (i.e., will it still perform under compression)
  - Water permeability
  - Water storage capacity
  - Plant compatibility (phytotoxicity safety)
  - Root penetrability
  - Particle distribution/ mesh width
  - Resistance to freeze-thaw cycles
  - pH value (should match the growing medium or, at a minimum avoid a deleterious effect on it)

- Salt content
- Weatherability/ vulnerability to erosion
- Chemical stability (tendency to leach)
- Resistance to micro-organisms/ rot potential

- Multi-course systems should consist of either a coarse aggregate material like sand or gravel wrapped in a filter fabric or a synthetic geocomposite made from plastic or filaments. Aggregate materials tend to resist the horizontal flow of stormwater and so they delay peak runoff effectively. However, even though they tend to promote root development, they tend to be heavier and store less water than geocomposites. Fabricated from synthetic polymers, geocomposites are typically designed to achieve a specific goal such as stormwater storage, promotion of drainage, or the reduction of hydrostatic pressure on the waterproofing layer.

- Drainage can be addressed with multiple layers. It can be useful to install a geocomposite directly above the waterproofing membrane in addition to a multi-course drainage layer directly under the growth medium.

- Vegetated and non-vegetated areas should be drained and often require different drainage design and separate overflow mechanisms. At least one drain and one emergency overflow are recommended for each drainage field.

- Ideally, the system should be designed so that the pressure of the rainwater flow through the system will self-clean the mechanisms so that maintenance and inspections can be minimized.

- Calcareous materials, such as recycled concrete aggregate, should not be used in drainage layers as they can lead to efflorescence in the drainage system which can damage the system in the long term.

- Drainage such as gravel strips should be installed at the edge of green roofs to convey water at the edges to the designed system and to avoid allowing runoff to flow over the edge of the building.

- While roots can grow in the drainage layer, drainage infrastructure, such as scuppers, drains, and other conveyances for stormwater should be kept clear of vegetation and protected from clogging with debris with a filter screen or mesh coordinated with the particle sizes of the growth medium and/or gravel used in the drainage layer.

- Drainage must be considered at all thresholds to the green roof installation and can require special detailing that includes:
  - A heated channel drain at the threshold
  - Splash protection/ protection from snow accumulation

- Doors with special sealing functions
- Additional waterproofing and drainage in the interior of the threshold

Moisture Management Layer

- Separation fabric can directly affect drainage and should be selected and installed so that it achieves the desired design goal.

Root Barrier/ Protective Layer

- Can consist of:
  - A layer of perforated plastic sheets
  - A thin layer of gravel that prevents root growth from advancing but does not interfere with the drainage or the roots' ability to access water
  - A full surface coating or liquid sealant on the roof material below
- Can be combined with the waterproofing layer
- The required strength of the barrier is directly related to the type of root growth of the specified plant species. For example, bamboos with aggressive rhizome growth may require extra-strength protection.
- Special root protection treatment may be required at transition points, roof penetrations and joints in the roofing material.
- Thinner growth medium can cause an increase in competition among plants which respond with more aggressive root growth and can require additional protection.
- Should arrest the advancement of root growth to prevent damage to the waterproof membrane, the leak detection system below it, and the roof itself.
- Root barriers containing chemical root-growth-blockers and/or herbicide should be avoided as they will contaminate the runoff from the green roof.
- Some installations, such as waterproof concrete roofs, or roofs constructed from welded metal sections, do not require a root barrier because the material is already resistant to root penetration.
- Special care should be taken when installing the root barrier layer as many are UV-sensitive and can deteriorate if left exposed during construction. Also, protection for the material may be necessary when installing it over a rough surface below.
- Root protection layers can be manipulated to establish pockets of water in areas of the garden where they are needed to support plant material but should be installed carefully to prevent unwanted ponding from occurring.

- On sloped roofs, root protection should be installed and pinned as necessary to prevent it from sliding relative to a waterproof membrane below it.

Waterproof Membrane

- Typically made of materials such as bitumen, synthetic rubber (such as EPDM), hypolan (CPSE), or reinforced PVC. Adhesives used to bind panels of the membrane together should be impermeable.
- An impermeable root barrier sometimes doubles as a waterproofing membrane.
- The waterproofing must be extended at all transitions, particularly at the edge of the roof where it should wrap around and overlap with the wall waterproofing.
- The waterproof membrane should be reviewed by both the roof expert and the garden expert to be certain that it meets the physical requirements for the structure below and the green roof installation above.

Leak Detection System

- Many options for electronic leak detection and moisture monitoring systems exist in the market. A leak detection system should be used under the waterproof membrane and above the roof so that leaks can be detected quickly before damage to the underlying roof structure occurs.

Roof Materials

- Transition points
  - Special care is needed to secure root barriers and waterproofing where roof materials or slopes transition. Snow accumulation at these points should also be considered.
- Separation Layer(s)
  - Can be installed as needed between the green roof layers or under the green roof materials and above the traditional roof materials.
  - Should be compatible with other materials in the installation.
  - Should be resistant to mechanical, thermal, and chemical stresses of the green roof installation
  - Should be resistant to rotting from exposure to biological factors present in a living green roof system.
  - Should not off-gas or leach pollutants into the stormwater released from the green roof.
- Insulation Layer
  - Needed if there is an occupied space directly under the green roof.

- Vapor Barrier
- Roof Deck or Membrane
    - If not separated from the stormwater conveyance system:
        - Concrete roofing can leach carbonates
        - Asphalt roofing can leach polycyclic aromatic hydrocarbons (PAHs) and hydrocarbons

Safety Considerations

- All green roofs will require access whether just for maintenance personnel or for recreational users. Safety measures, such as proper tie-off points for fall protection, will need to be installed to enable maintenance of all green spaces.
- All synthetic materials layered in the green roof installation should be chosen to be chemically compatible with one another so as to avoid leaching or off-gassing of pollutants. Additionally, materials should be evaluated to be certain that they are not toxic to the plant species.

Stormwater Quantity Control Design – Adjusted Runoff Curve Number

- Green roofs reduce the volume of runoff from building roofs and therefore result in a reduced NRCS Runoff Curve Number (CN), which should be used for hydrologic and hydraulic routing calculations that are required for stormwater quantity control design.
- Determine adjusted CN values for the green roof by the following method:

    1. Calculate the volume of stormwater retained by the green roof based on the available water capacity of the planting/growing media using the methodology presented in the New Jersey Stormwater Best Management Practices Manual.
    2. Calculate the stormwater runoff volume produced by the water quality storm and the 2-, 10-, and 100-year, 24-hour design storms as described in Chapter 4 of this Manual.
    3. Subtract the volume of stormwater retained by the green roof from the stormwater runoff volume for the various design storm events. The result is the runoff volume that will be discharged from the green roof during each design storm event.
    4. Convert the volume of stormwater retained by the green roof to an equivalent retention depth (in inches) by dividing the volume retained by the area of the green roof.
    5. Convert the volume of stormwater discharged from the green roof to an equivalent discharge depth (in inches) by dividing the volume discharged by the area of the green roof.

6. Determine the adjusted CN values for each design storm using one of the following two approaches:
    - Intensive green roofs should use the runoff CNs for Woods, Brush, or Grass, depending on the specific plant communities used. Extensive green roofs should use the adjusted CN values listed in Table 13-16 based on the calculated retention depth in inches.
    - Using the calculated discharge depth described above and the precipitation for each design storm event, calculate the adjusted CN values using the equation or graphical solution (Figure 2-1 from TR-55) presented in Appendix D of this Manual (i.e., Graphical Peak Discharge Method).

Table 13-13. Adjusted Curve Numbers for Extensive Green Roofs

Retention Depth (inches)	Adjusted Curve Number (CN)
0.6	94
1.0	92
1.2	90
1.4	88
1.6	86
1.8	85
2.0	82
2.2	81
2.4	77

Adapted from Maryland Department of the Environment, Stormwater Design Guidance – Green Roofs, March 2018.

- Once the adjusted CN values are determined, also calculate the time of concentration and either follow the remaining steps in the Graphical Peak Discharge Method in Appendix D or use a stormwater hydrologic/hydraulic routing model based on the NRCS Curve Number method (e.g., HydroCAD or similar software) to calculate peak discharge for each design storm event.

Green Roof Retrofit Assessment

- Where a green roof is proposed as a retrofit, perform a site assessment of the existing building and roof integrity necessary to support the proposed green roof.

- Structural Analysis
  - For the roof to be considered viable for green roof installation, the structural analysis must indicate that the roof structure is capable of supporting the additional load from the proposed green roof(s) when saturated in addition to any other live loads expected as part of the project.
  - Connections to building systems, such as plumbing (for irrigation), drainage, electrical, etc. should be carefully considered so as to not compromise those systems or to create issues.
- Roof Membrane Assessment
  - Evaluate the condition of the existing roof membrane and confirm the remaining years on its warranty, if any.
  - If there are remaining year(s) on the warranty, contact the roof membrane manufacturer and confirm the necessary steps required to protect the membrane before installing the proposed green roof.
  - Confirm if the manufacturer cannot continue to honor the warranty if a green roof is installed.
  - Note major or numerous roof penetrations by pipes, ducts, equipment, or other features.
- Historic Structure Considerations
  - Evaluate historic structure code requirements and any limitations of prohibitions relative to the use of green roofs. Can the historic character of the building be maintained? For example, green roofs on federal buildings cannot be visible from public thoroughfares.

Outlet & Overflow

- Runoff exceeding the retention capacity of the green roof system should be safely conveyed to the drainage system or another structural stormwater BMP. Design the outlet/overflow in accordance with the Inlet and Outlet Controls section of this Manual.

- The green roof system should safely convey runoff from the 100-year, 24-hour storm to a downgradient drainage system to avoid erosion or flooding.

- Roof drains and scuppers should be protected to prevent clogging through the use of a stone/gravel apron surrounding the drain or similar measures.

Other Considerations

- The following ASTM standards should be used for design of a green roof system:
  - ASTM E2396 – Standard Testing Method for Saturated Water Permeability of Granular Drainage Media (Falling-Head Method) for Green Roof Systems
  - ASTM E2397 – Standard Practice for Determination of Dead Loads and Live Loads Associated with Green Roof Systems

- ASTM E2398 – Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems
- ASTM E2399 – Standard Test Method for Maximum Media Density for Dead Load Analysis
- ASTM E2400 – Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems
- ANSI/SPRI VF-1 – External Fire Design Standard for Vegetative Roofs
- ANSI/ SPRI Standard for Wind Design- method for designing wind uplift resistance of green roofs
- ANSI/ SPRI Fire Design Standard- method for designing external fire resistance for green roofs
- ANSI/ SPRI Standard for Preventing Root Penetration- in development

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.
- The designing qualified professional should inspect the installation after placement of each roof layer, plantings, modular units, and outlet/overflow structures.
- The designing qualified professional r should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The green roof planting media should be tested prior to placement according to the specifications in this section. The designing qualified professional should certify that the planting media meets the specifications based on soil testing results and soil weight requirements.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- Temporary erosion protection, such as mats or mesh, should be provided until plant cover is well established.
- Vegetation can be installed as vegetation mats, plugs, sprigs, seeds or as potted plants. Mats tend to be the fastest to establish, but the material is expensive even though it requires lower labor costs to install. In comparison, potted plants can establish coverage quickly but are expensive to purchase and install. Sprigs can be cost effective but often require irrigation, weeding and can be difficult to establish and often require replacement.

Maintenance Needs

- Green roof systems should be designed with easy access to the building roof and all components of the system for maintenance purposes. Refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- A method for detecting leaks should be included in the green roof's maintenance plan.
- Maintenance should be detailed in a legally binding maintenance agreement.

Recommended Maintenance Activities

- Plan for extra maintenance, often labor-intensive work like hand-watering and weeding, while plants establish.
- Perform inspections at least four times annually and after every storm event exceeding 1 inch of rainfall. Check for and clear debris, sediment, dead vegetation, and check whether the planting medium has eroded or been transported to the drainage gutter or outlets.
- Remove organic litter, cutting herbaceous material back and pruning woody material two to three times annually.
- Provide extra maintenance to retain the desired aesthetic of a detailed planting.
- Perform periodic weeding, sometimes every other week during the growing season.
- Replace plants as needed. Maintain a minimum 85% vegetative cover at all times.
- Replace organic matter as it deteriorates.
- Fertilize to maintain plant health only as needed. Avoid use of fertilizer or over-fertilization to minimize nutrient export from the roof.
- Provide seasonal irrigation when necessary.
- Periodically maintain outflows (unclogging if debris enters) and inspect them two times a year at a minimum.
- Inspect roof materials for any problems, particularly the underlying membrane for deterioration.

- Relatively low-cost electronic grids can be installed under the membrane to help pinpoint leaks if they occur.

Other References

Massachusetts Low Impact Development Toolkit. *Fact Sheet #9 Green Roofs*. Metropolitan Area Planning Council. https://www.mapc.org/wp-content/uploads/2017/11/LID_toolkit_factsheets_7-9.pdf

New Jersey Department of Environmental Protection (NJDEP). 2021. *New Jersey Stormwater Best Management Practices Manual.* https://nj.gov/dep/stormwater/bmp_manual2.htm

Save the Sound. Reduce Runoff.org. https://www.reducerunoff.org/green-blue-roofs

U.S. Environmental Protection Agency (EPA). 2018. *Estimating the environmental effects of green roofs: A case study in Kansas City, Missouri.* EPA 430-S-18-001. www.epa.gov/heat-islands/using-greenroofs-reduce-heat-islands

U.S. General Services Administration (GSA). 2011. *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings: A Report of the United States General Services Administration*. May 2011, p.18. https://www.gsa.gov/cdnstatic/The_Benefits_and_Challenges_of_Green_Roofs_on_Public_and_Commercial_Buildings.pdf

Dry Extended Detention Basin

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	■

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**Moderate**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

Capital Cost	**Medium**
Maintenance Burden	**Medium**
Land Requirement	**High**

Description

Dry extended detention basins, also called "dry ponds" or "detention basins", are stormwater basins designed to capture, temporarily hold, and gradually release a volume of stormwater runoff to attenuate and delay stormwater runoff peaks. Dry extended detention basins are typically designed as on-line systems and provide stormwater quantity control but only limited water quality benefit. The primary outlet structure of a dry extended detention basin is located at the bottom of the basin and sized to limit the maximum flow rate from the basin for the water quality storm. The higher stages of the basin attenuate the peak rates of runoff from larger storm events. Dry basins are designed to completely empty between storms, typically in 24 to 48 hours, resulting in limited settling of particulate matter and the potential for re-suspension of sediment by subsequent runoff events.

Dry extended detention basins differ from wet extended detention ponds, which provide a permanent pool and greater pollutant removal (see Stormwater Ponds section of this chapter). Dry extended detention basins are not suitable as infiltration or groundwater recharge measures, and therefore do not reduce runoff volumes and cannot be used to meet the Standard 1 retention or treatment performance criterion of this Manual. Figure 13-34 shows a schematic of a typical dry extended detention basin.

Advantages

- Low-density residential, industrial, and commercial developments with adequate space and low visibility.

- Suitable for use as part of a stormwater treatment train, particularly in combination with off-line retention and treatment stormwater BMPs. The size of dry detention basins can be reduced substantially by placing them at the end of the treatment train to take advantage of reduced runoff volume resulting from upstream practices that employ infiltration.

- Less frequently used portions of larger or regional dry detention basins can offer recreational, aesthetic, and open space opportunities (e.g., athletic fields, jogging and walking trails, picnic areas).

Limitations

- Strictly for water quantity control to attenuate peak flows, limit downstream flooding, and provide some degree of channel protection.

- Not suitable for treatment. Most dry extended detention basins have detention times of less than 24 hours and lack a permanent pool, providing insufficient settling of particles, and minimal stormwater treatment.

- Not suitable for stormwater retention or runoff reduction since dry detention basins drain completely between storms and do not provide significant infiltration.

- Susceptible to re-suspension of settled material by subsequent storms.

Siting Considerations

- **Drainage Area:** Dry extended detention basins generally require a drainage area of 10 acres or greater to avoid an excessively small outlet structure susceptible to clogging. Dry extended detention basins are impractical and less cost-effective for drainage areas smaller than 1 acre.

- **Groundwater and Bedrock:** The lowest point in the bottom of the basin should be at least 1 foot above the seasonal high groundwater table (SHGT) and bedrock. Intercepting groundwater or shallow bedrock mat result in the loss of runoff storage volume. An impermeable liner is recommended when the lowest point in the bottom of the basin is less than 1 foot above SHGT.

- **Land Uses**: Land uses will dictate potential pollutants-of-concern and potential safety risks. A liner is required for dry detention basins that receive runoff from Land Uses with Higher Potential Pollutant Loads (LUHPPLs) (see Chapter 10 - General Design Guidance for Stormwater Infiltration Systems) or on contaminated sites. The basin's temporary pool may pose a safety risk in residential areas and areas with public access, sometimes requiring fencing to limit access to the basin.

- **Soils:** Well-drained soils are preferred (HSG A and B soils). A liner is recommended for use in HSG C and D soils to prevent groundwater inflow and loss of storage volume.

- **Site Slopes:** Site slopes greater than 6% may result in the need for a large embankment to be constructed to provide the desired storage volume, which could be subject to CT DEEP dam safety regulatory requirements. Steep slopes may also present design and construction challenges, and significantly increase the cost of earthwork.

- **Receiving Waters:** Stormwater ponds should not be used for sites that discharge within 200 feet of cold-water streams, 200 feet from a public water supply reservoir, or 100 feet from streams tributary to a public water supply reservoir.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, and depth to bedrock. Perform test pits or soil borings in accordance with the soil evaluation guidance in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems.

Design Recommendations

Pretreatment – Sediment Forebay

- A sediment forebay is recommended for dry extended detention basins, although other forms of pretreatment may be used at locations where runoff enters the basin.

- The sediment forebay and other pretreatment measures should be designed in accordance with the Pretreatment BMPs section of this Manual.

- The sediment forebay should be sized to contain at least 10% of the Water Quality Volume (WQV).

Extended Detention Storage

- Extended detention requires sufficient storage capacity to hold stormwater for at least 24 hours to allow solids to settle out.

- The primary outlet structure of a dry extended detention basin is located at the bottom of the basin and sized to limit the maximum flow rate from the basin for the water quality storm. The higher stages of the basin attenuate the peak rates of runoff from larger storms (2-year, 10-year, 25-year and 100-year, 24-hour events).

- The detention basin should completely drain within 48 hours after the end of a storm.

- Thermal impacts of dry extended detention basins may be mitigated by:
    - Planting of shade trees around the perimeter of the basin (but at least 25 feet away from inlet/outlet structures and the basin embankment) to reduce solar warming of the temporary pool
    - Use of an underdrained gravel trench outlet.

- A minimum length-to-width ratio of 2:1 is recommended, although a 3:1 ratio is preferred for longer flow path lengths and enhanced sedimentation.
- Irregularly shaped basins are desirable due to their more natural and less engineered appearance.
- To enhance safety by minimizing standing water depths, the depth of the temporary pool associated with the water quality design storm should be no greater than 3 feet.
- Maximum ponding depths of 4 feet are recommended to avoid CT DEEP dam safety regulatory requirements, unless the basin is excavated below existing grade and does not require an embankment that may be subject to CT DEEP dam safety provisions.

Conveyance

- Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual.
- The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet to minimize the potential for short-circuiting and should be in a manner that meets or exceeds desired length to width ratios.

Outlet & Overflow

- Design the outlet and any overflows in accordance with the Inlet and Outlet Controls section of this Manual.
- A low flow orifice or weir should be located at the lowest point in the bottom of the detention basin with the size of the orifice sufficient to avoid clogging (recommended minimum orifice diameter of 6 inches, although orifice diameters as small as 3 inches are allowed if required to provide the necessary hydraulic control). The low flow orifice should be protected from clogging using an external trash rack.
- Multiple orifices or weirs in the outlet structure provide stormwater quantity control of larger storm events.
- The outlet structure should be sized to convey up to the 10-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel. An emergency spillway is required to convey the 100-year storm event if the outlet structure is not designed to pass the 100-year storm event.

Low Flow Channel

- A stone-lined low flow channel should be installed in the bottom of the basin to convey low flows from the basin inlet(s) to the outlet structure.

Bottom and Side Slopes

- Bottom of the basin should be sloped from the inlet to the outlet with a minimum slope of 1%.
- 3(H):1(V) slopes or flatter are preferred.

Riser in Embankment

- The riser should be located within the embankment for maintenance access and safety.
- Lockable manhole covers and manhole steps within easy reach of valves and other controls should provide access to the riser.

Liner

- A liner is required for dry detention basins that receive runoff from LUHPPLs or on contaminated sites. A liner is recommended when the lowest point in the bottom of the basin is less than 1 foot above SHGT or for use in HSG C and D soils to prevent groundwater inflow and loss of storage volume.
- If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 - General Design Guidance for Stormwater Infiltration Systems with the approval of the review authority.

Safety Features

- The principal spillway opening must not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.
- Fencing around the perimeter of the basin is generally not encouraged but may be required by some municipalities. The preferred method is to grade the basin to eliminate dropoffs or other safety hazards.

Maintenance Reduction Features

- Dry detention basins should be designed with non-clogging outlets, such as a weir, or by incorporating trash racks for orifice openings.
- Orifices should be less than 6 inches in diameter with a trash rack to prevent clogging. Smaller orifice diameters (3 inches or larger) are allowed if required to provide the necessary hydraulic control.

- Metal components of outlet structures should be corrosion resistant, but not galvanized due to the contribution of zinc to water.
- Outlet structures should be resistant to frost heave and ice action in the basin.

Vegetation

- Select vegetation and develop a planting plan with the guidance provided in Appendix F of this Manual.
- Vegetation in a dry extended detention basin typically consists of grasses that can tolerate temporary inundation by up to 4 feet of water for 24 to 48 hours in duration.
- Woody vegetation may not be planted or allowed to grow within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure.
- Use salt-tolerant vegetation if the basin receives road runoff.

Winter Operations

- Detention basins should not be used as dedicated snow storage areas. To the extent feasible, locate and design the system to avoid snow storage areas and potential damage from snow plowing activities. Refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations related to winter operations.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.
- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the basin
  - After internal grading of basin bottom, low-flow channel, microtopography, berms, etc.
  - After installation of outlet/overflow and inlet controls
  - After seeding and final stabilization of the basin
- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.

- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- During clearing and grading of the site, measures should be taken to avoid soil compaction at the location of the proposed system to promote growth of vegetation.
- The system should be fenced off during the construction period to prevent disturbance of the soils.
- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans.
- Install vegetation in accordance with the planting plan and plant schedule on the plans. Water vegetation thoroughly immediately after planting and as necessary until fully established.
- Dry extended detention basins classified as dams under the CT DEEP dam safety program should be constructed, inspected, and maintained in accordance with applicable CT DEEP dam safety regulations and guidance.

Maintenance Needs

- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintenance activities such as sediment removal, mowing, and repairs should be performed with rakes and light-weight equipment rather than heavy construction equipment to avoid soil compaction and damage to vegetation. Heavy equipment may be used for sediment removal and other maintenance activities if the equipment is positioned outside the limits of the system. Heavy construction equipment should not be allowed within the limits of the system for maintenance purposes.

Maintenance Access

- Dry detention basins should be designed with easy access to all components of the system for maintenance purposes. In addition to the maintenance reduction design factors described in this section, also refer to Chapter 7 - Overview of Structural Stormwater Best Management Practices for general design considerations to reduce and facilitate system maintenance.
- A maintenance right-of-way or easement should extend to the basin from a public road.

- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15 percent, and be appropriately stabilized to withstand maintenance equipment and vehicles.
- The maintenance access should extend to the forebay and outlet structure/spillway and be designed to allow vehicles to turn around.

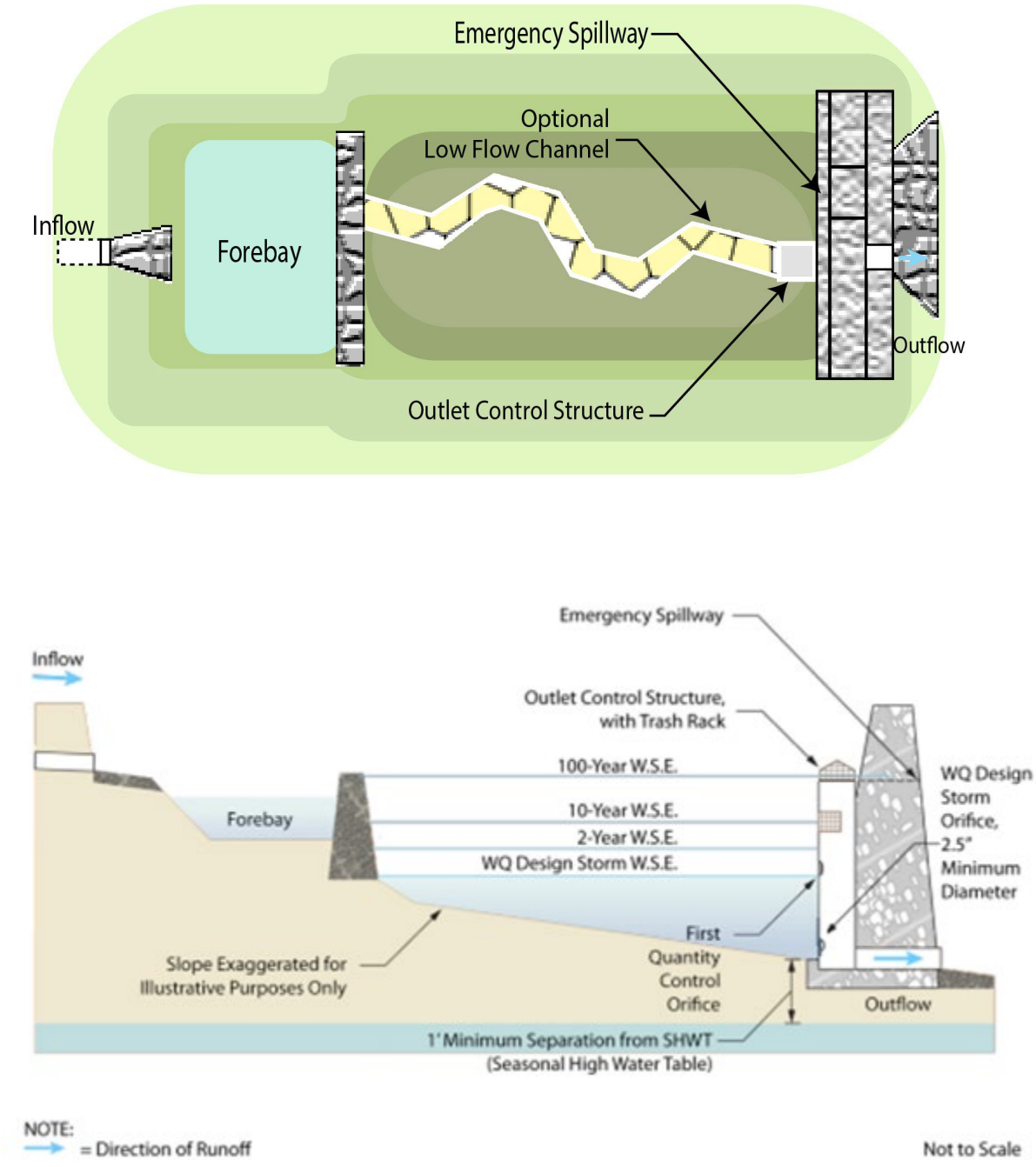
Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect sediment forebay twice per year and the rest of the system annually, including inlet and outlet control structures and the pond embankment.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during the inspections.
- Remove trash and organic debris (leaves) in the Spring and Fall.
- Remove sediment from the sediment forebay or other pretreatment area when it accumulates to a depth of more than 24 inches or 50% of the design depth.
- Remove sediment from the main portion of the basin when the basin volume has become reduced significantly.
- The vegetative cover should be maintained at 85%. If vegetation has damage, the area should be reestablished in accordance with the original specifications.
- Periodically mow the basin during the growing season. Maintain vegetation at 6 inches or higher.
- Inspect and remove invasive vegetation as necessary.
- Remove trees and woody vegetation within the basin and within 25 feet of all risers, pipe outlet structures, spillways, and downstream embankments that hold back water.

Other References

New Jersey Department of Environmental Protection (NJDEP). 2021. *New Jersey Stormwater Best Management Practices Manual.* New Jersey Department of Environmental Protection (NJDEP). 2021. *New Jersey Stormwater Best Management Practices Manual.* https://nj.gov/dep/stormwater/bmp_manual2.htm

Figure 13-34. Dry Extended Detention Basin Schematic



Source: Adapted from New Jersey Stormwater Best Management Practices Manual, 2021.

Underground Detention

Stormwater BMP Type

Pretreatment BMP	□
Infiltration BMP	□
Filtering BMP	□
Stormwater Pond BMP	□
Stormwater Wetland BMP	□
Water Quality Conveyance BMP	□
Stormwater Reuse BMP	□
Proprietary BMP	□
Other BMPs and Accessories	■

Stormwater Management Suitability

Retention	□
Treatment	□
Pretreatment	□
Peak Runoff Attenuation	■

Pollutant Removal

Sediment*	**Low**
Phosphorus	**Low**
Nitrogen	**Low**
Bacteria	**Low**

*Includes sediment-bound pollutants and floatables (with pretreatment)

Implementation

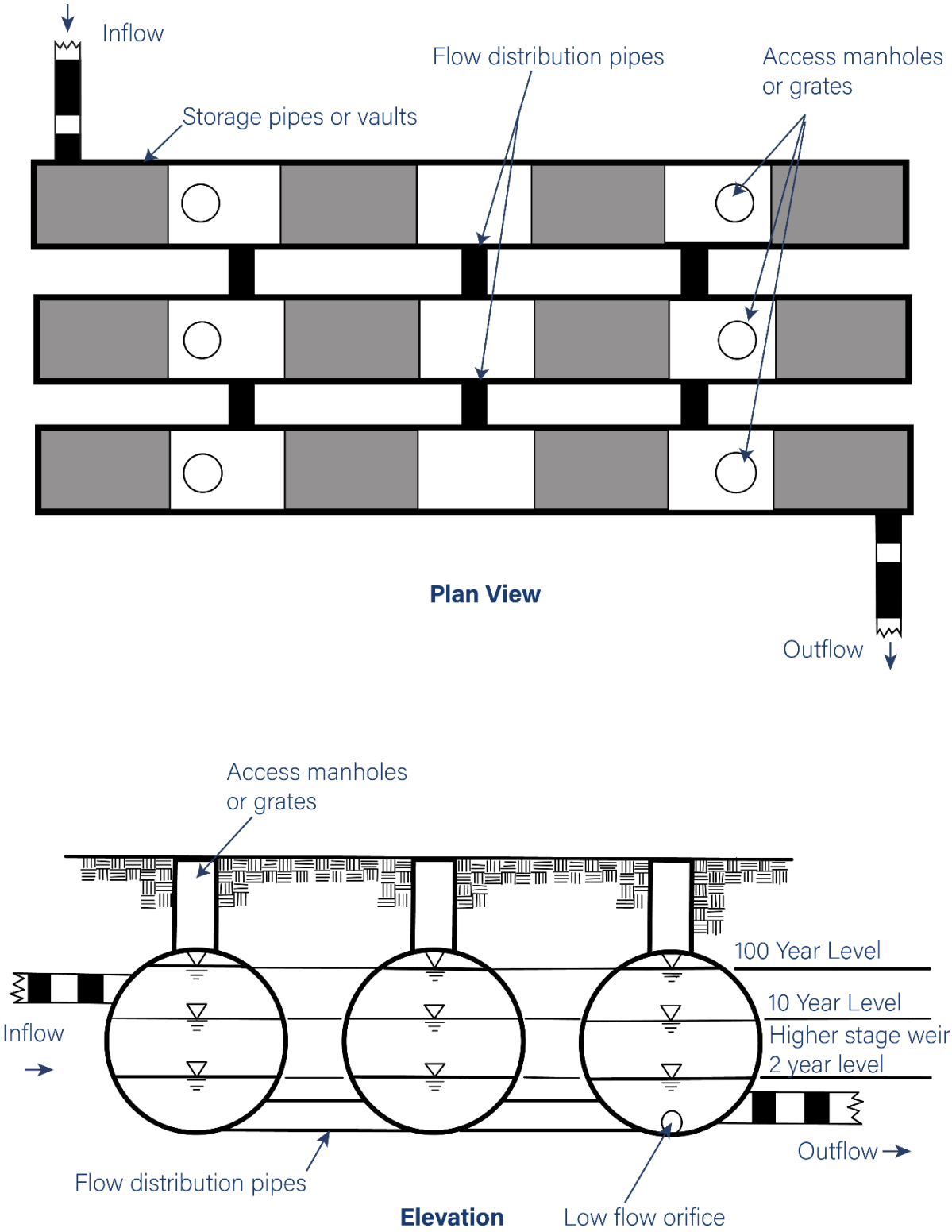
Capital Cost	**High**
Maintenance Burden	**High**
Land Requirement	**Low**

Description

Underground detention facilities are subsurface storage structures designed to temporarily store stormwater runoff and release it slowly at pre-development peak flow rates. Like aboveground dry detention basins, underground detention facilities are designed to drain completely between storm events, thereby providing storage capacity for subsequent events. Underground detention facilities are typically designed as on-line systems to attenuate peak flow rates. They provide little, if any, pollutant removal (i.e., settling of coarse sediment) and are susceptible to re-suspension of sediment during subsequent storms. They are not designed to provide infiltration and therefore cannot be used to meet the Standard 1 retention performance criterion of this Manual.

Underground detention systems are typically used at sites where land availability or land costs preclude the use of surface stormwater detention system. They are often used below parking lots, roads, and other paved areas. Underground detention structures are typically made of concrete (vaults or tanks), large diameter solid pipes, enclosed arches made of plastic, steel, or metal (aluminized steel, aluminum, and others), or other modular systems. Figure 13-35 is a schematic of an underground detention pipe system.

Figure 13-35. Underground Detention Pipe System Schematic



The underground structures described in the Underground Infiltration System section of this chapter can also be used as detention facilities if they are fully enclosed or used with a liner to prevent infiltration or interaction with groundwater. Open-bottom underground structures or perforated pipe should be designed as underground infiltration systems in accordance with the guidance provided in Chapter 10 and the Underground Infiltration System section of this chapter.

Advantages

- Efficient use of space in urban areas and for retrofits.
- Quick installation using prefabricated modular systems.
- Systems are durable with a long life with effective pretreatment and routine maintenance.
- Greater public safety as compared to deep surface storage ponds or basins.
- Ground provides insulation from freezing and some cooling of runoff from paved surfaces.
- Suitable for use as part of a stormwater treatment train, particularly in combination with off-line retention and treatment stormwater BMPs.
- Useful in stormwater retrofit applications to provide additional temporary storage volume and attenuate peak flows (not for retention or treatment).

Limitations

- Require extensive, costly excavation.
- Material and maintenance costs are high compared to surface detention systems.
- Routine maintenance can be overlooked because the practice is not readily visible.
- Strictly for water quantity control to attenuate peak flows, limit downstream flooding, and provide some degree of channel protection.
- Not suitable for treatment. Most underground detention systems have detention times of less than 24 hours, providing insufficient settling of particles, and minimal stormwater treatment. These systems are also susceptible to re-suspension of settled material by subsequent storms.
- Not suitable for stormwater retention or runoff reduction since underground detention systems drain completely between storms and do not provide infiltration.

Siting Considerations

- **Drainage Area:** Underground detention systems can be used on sites with a wide range of drainage areas. The maximum recommended drainage area to a single underground detention system is 25 acres.

- **Groundwater and Bedrock:** The system should be at or above the seasonal high groundwater table (SHGT) and bedrock. Anti-buoyancy measures may be needed if systems are designed at or below the water table.

- **Land Uses:** Underground detention systems are typically used at sites where land availability or land costs preclude the use of surface stormwater detention system. They are often used below parking lots, roads, and other paved areas. They should be installed in locations that are easily accessible for maintenance and should not be in areas or below structures that cannot be excavated in the event the system needs to be replaced.

- **Receiving Waters:** Underground detention systems are preferred over surface stormwater detention basins for sites that discharge to coldwater streams due to cooling of runoff in subsurface storage as opposed to a surface pool of water, which is more susceptible to warming and thermal impacts. Discharges from underground detention systems should not be located within 200 feet from a public water supply reservoir or 100 feet from streams tributary to a public water supply reservoir.

Soil Evaluation

- Conduct an evaluation of the soil characteristics and subsurface conditions at the location of the proposed system including soil type, depth to the seasonal high groundwater table, and depth to bedrock. Perform test pits or soil borings in accordance with the soil evaluation guidance in Chapter 10.

Design Recommendations

Pretreatment

- Incorporate pretreatment measures at locations where runoff enters the underground detention system in accordance with the Pretreatment BMPs section of this Manual.

- Acceptable pretreatment measures are those that are suitable for piped drainage systems and include deep sump hooded catch basins,[91] oil grit separators, and proprietary pretreatment devices.

- Pretreatment measure(s) should treat at least the Water Quality Flow (WQF).

Storage

- Storage capacity and discharge rate from the system will depend on the peak runoff attenuation requirement (2-year, 10-year, 25-year and 100-year, 24-hour events) and design guidance of the product manufacturer.

- Deeper and larger excavated areas require more fill for maintaining the integrity of plastic or metal pipe. Pipes require more fill than concrete structures, thus using more excavated area. Pipes also store less water than concrete vaults per unit of land surface. For

[91] Only recommended for space constrained sites where no other Pretreatment BMPs are feasible.

underground pipe storage systems, use the largest pipe diameter possible, which can cost-effectively increase storage capacity.

- Access manholes should be provided for system maintenance. Manholes should be placed, at a minimum, near the inlet and outlet of the system and in intermediate locations. The number of manholes depends on maintenance methods and design guidance of the product manufacturer.
- A high water table can cause structures to displace due to uplift forces. In areas with high groundwater, buoyancy and anchoring requirements should be considered and addressed in the design.
- The detention system should completely drain within 48 hours after the end of a storm.
- Pipes and floors of vaults should be designed with a maximum of 2% slope.
- Follow manufacturer recommendations for minimum cover above the underground storage system to accommodate required loading conditions.
- Use appropriate bedding/foundation below the structure to support the design load associated with the structure, water storage, and adjacent backfill weight and to maintain its integrity during construction. Follow manufacturer recommendations related to bedding/foundation design.

Conveyance

- Stormwater should be conveyed to and from all stormwater management practices safely and to minimize erosion potential.

Inlet

- Design the inlet in accordance with the Inlet and Outlet Controls section of this Manual and in accordance with design guidance of the product manufacturer.

Outlet & Overflow

- Design the outlet and any overflows in accordance with the Inlet and Outlet Controls section of this Manual and in accordance with design guidance of the product manufacturer.
- A low flow orifice or weir should be used within the storage system or inside a separate outlet control structure, with the size of the orifice sufficient to avoid clogging (recommended minimum orifice diameter of 6 inches, although orifice diameters as small as 3 inches are allowed if required to provide the necessary hydraulic control). The low flow orifice should be protected from clogging using a trash rack.

- The system and outlet control structure should be sized to convey up to the 100-year, 24-hour storm event, at a minimum, to the storm drainage system or stabilized channel.
- Emergency surface overflows should be designed to convey or bypass flows in excess of the 100-year event in case the outlet becomes clogged.

Liner

- A liner may be needed to prevent infiltration or interaction with groundwater if open-bottom storage structures or perforated pipe are used.
- If used, should consist of a 30 mil (minimum) HDPE or PVC liner, or one of the alternative liner systems described in Chapter 10 with the approval of the review authority.

Construction Recommendations

- The designing qualified professional should develop a detailed, site-specific construction sequence.
- The designing qualified professional should inspect the installation during the following stages of construction, at a minimum:
  - After excavation of the system
  - After placement and leveling of aggregate below the storage structure, placement of the structure(s) and inspection ports/manholes, and placement of backfill above the structure(s)
  - After installation of bypass, outlet/overflow, and inlet controls
  - After the system has been backfilled
- The designing qualified professional should provide an as-built plan of the completed system along with a certification that the system was designed in accordance with the guidance contained in this Manual and other local or state requirements and that the system was installed in accordance with the approved plans.
- The entire contributing drainage area should be completely stabilized prior to directing any flow to the system. Adequate vegetative cover must be established over any pervious area adjacent or contributing to the system before runoff can be accepted.
- Erosion and sediment controls should be in place during construction in accordance with the Connecticut Guidelines for Soil Erosion and Sediment Control and the Soil Erosion and Sediment Control (SESC) Plan developed for the project.
- The system should be fenced off during the construction period.
- The system should be excavated to the dimensions, side slopes, and elevations shown on the plans.

Maintenance Needs

- Underground infiltration systems should be designed with easy access to all components of the system for maintenance purposes. Refer to Chapter 7 for general design considerations to reduce and facilitate system maintenance.
- Detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance should be identified on the plans and in the Stormwater Management Plan.
- Maintenance should be detailed in a legally binding maintenance agreement.
- Maintain underground structures in accordance with the manufacturer's guidelines.
- Typical maintenance includes removal of accumulated oil and grease, floatables, and sediment from the pretreatment structure using a vacuum truck and removal of accumulated sediment from the underground detention system using a high-pressure water nozzle (i.e., JetVac process) and vacuum truck.
- Confined space safety procedures as required by OSHA regulations must be followed by workers entering an underground stormwater storage facility.

Recommended Maintenance Activities

- Inspect after major storms (1 inch or more of precipitation) in the first few months following construction.
- Inspect the pretreatment structure twice a year.
- Inspect the remainder of the system annually.
- Refer to Appendix B for maintenance inspection checklists, including items to focus on during inspections.
- Remove sediment from the pretreatment structure when it accumulates to more than 50% of the design depth.
- Remove sediment from the storage structures when the sediment accumulation exceeds 2 inches throughout the length of the structures or when drawdown time exceeds 48 hours after the end of a storm event, indicating that the outlet may be clogged.

Inlet and Outlet Controls

Inlet and outlet control measures manage runoff into and out of structural stormwater Best Management Practices (BMPs), respectively. This section presents inlet and outlet controls that can be used with the BMPs in this Manual. Refer to the specific BMP design sections in Chapter 13 - Structural Stormwater BMP Design Guidance for further information relative to inlet and outlet controls that are best suited for a given type of BMP and site-specific application.

Inlet and Outlet Controls Included in this Section

- Inlet Control Types
  - Level Spreader
  - Inlet Curb Cut Opening
  - Inlet Structure
  - Piped Flow Entrance
  - Flow Diversion Structure
- Outlet Control Types
  - Outlet Curb Cut Openings
  - Raised Overflow Structures or Risers
  - Outflow Weirs
  - Outlet Pipes/Culverts
- Inlet and Outlet Protection
  - Stone Rip Rap Apron
  - Stone Rip Rap Stilling Basin or Plunge Pool

Inlet Controls

General Design Guidance

In addition to the design guidance outlined below for the respective inlet control types, the following general criteria should be considered when designing inlet controls for stormwater BMPs:

- Flow velocities should not exceed 3 feet per second for grassed surfaces and 1 foot per second for mulched surfaces.
- Inlet areas should be stabilized to ensure that non-erosive conditions exist for at least the 1-year, 24-hour design storm event.
- If designing the BMP as an on-line system, inlet controls should be designed to accommodate flows in excess of the Water Quality Flow (WQF).[92] At a minimum, inlet controls for on-line BMPs should be designed to accommodate flows generated by the 10-year, 24-hour design storm event.
- If designing the BMP as an off-line system, the flow diversion structure should be designed to convey the WQF to the BMP and allow larger flows to bypass the system.

[92] Use of the term Water Quality Flow (WQF) in this section refers to the peak flow associated with the Required Retention Volume, which is either 100% or 50% of the site's Water Quality Volume (WQV) depending on the applicable retention/treatment requirement as described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

- Design the inlet to resist incursion by vehicles and bicycles for BMPs located along roads, parking lots, and other areas with vehicle and bicycle traffic.
- Design the inlet to resist blockage from trash, debris, and sediment in addition to ice and snow.
- Design inlet structures and diversion structures to withstand the effects of freezing, frost in foundations, erosion, and flotation due to high water conditions.

Level Spreader

Level spreaders collect stormwater from an upgradient impervious surface and distribute it uniformly over the ground surface, typically over a pretreatment vegetated filter strip, as sheet flow prior to entering a downgradient stormwater BMP. Level spreaders promote uniform sheet flow to maximize pollutant removal and infiltration. Level spreaders also reduce the energy and velocity of runoff, which reduces the potential for erosion.

Many level spreader design variations exist, including level stone-filled trenches, curbing, concrete weirs, etc. All level spreader designs operate on the same basic principles:

- Stormwater enters the spreader through overland flow, a pipe, ditch, or swale
- The flow is distributed throughout a long linear shallow trench or behind a low berm
- Stormwater flows over the berm/ditch uniformly along the entire length of the spreader.

Inflow level spreaders (i.e., level spreaders that are part of an inlet control measure) are typically used with pretreatment vegetated filter strips to promote filtering and infiltration and with other stormwater BMPs where concentrated flow presents design constraints, such as with some Filtering BMPs.

Figure 13-36 through Figure 13-38 show several examples of common level spreader designs. Figure 13-36 and Figure 13-37 are concrete level spreader designs, while Figure 13-38 is a stone-filled trench level spreader design.

Key design considerations for level spreaders include:

- Concentrated flow may enter the level spreader at a single or multiple points, with appropriate energy dissipation, and leave as uniformly distributed sheet flow.
- The maximum contributing drainage area for a level spreader should be 2.5 acres for maximum efficiency.
- Flow should be uniformly distributed and crest over the downgradient edge of the spreader along its entire length. The downgradient edge over which flow is distributed

must be level. Small variations in height (of more than 0.25 inch) will result in concentrated flow and erosion.

- Stormwater flowing over the lip of a level spreader should have a maximum velocity of 1 foot per second for the water quality storm and 3 feet per second for the 10-year, 24-hour design storm to maintain non-erosive velocities over the downgradient vegetated surface.
- Calculate the required length of the level spreader so that the flow velocity over the level spreader is equal to or less than the maximum allowable velocity in the downgradient area.
    - For a thick vegetated surface immediately downgradient of the level spreader such as a vegetated filter strip or pretreatment swale (see Pretreatment BMPs), the length of the level spreader should be selected to convey 0.25 cfs per linear foot of spreader during the design storm event. This equates to 4 feet of length for every 1 cfs of flow. This design specification is based on maximum flow velocities and a water depth of approximately 1 inch flowing over the lip of the level spreader. For example, a level spreader designed for a peak flow rate of 5 cfs would need to be 20 feet long.
- The minimum length for a level spreader shall be 6 feet.
- Level spreaders should not be constructed in newly deposited fill as these areas are most susceptible to erosion. Undisturbed earth is more resistant to erosion than fill.
- Level spreaders consisting of stone-filled trenches (Design Example 3) should be placed immediately upgradient of a vegetated filter strip and be 12 inches wide and 18 to 24 inches deep, filled with 1.5-inch diameter AASHTO No. 4 stone. The stone should be clean (washed and free from dirt and debris), crushed, and angular. Non-woven filter fabric should be placed on the sides and bottom of the trench.

Figure 13-36. Level Spreader Design Example 1

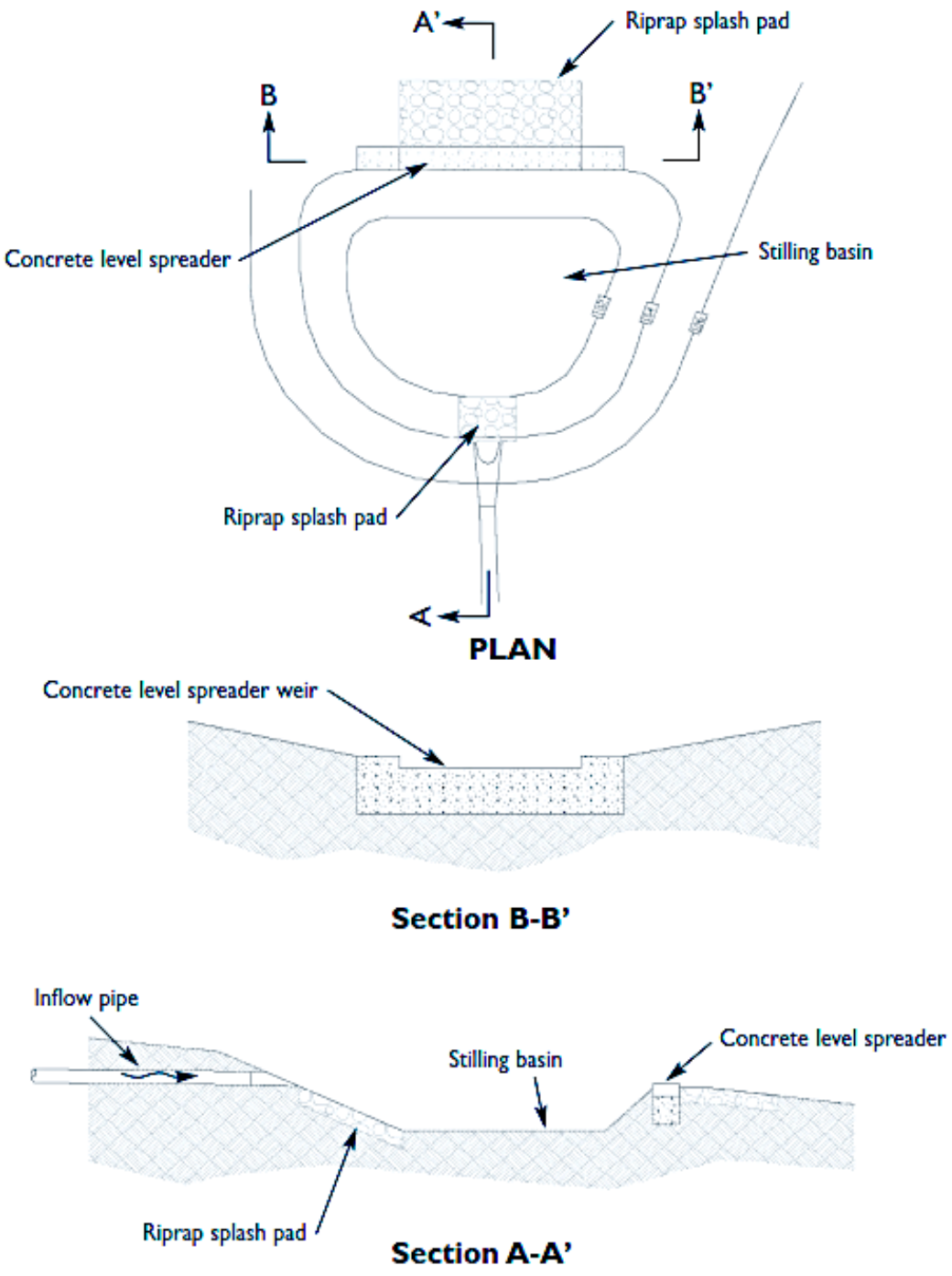


Figure 13-37. Level Spreader Design Example 2

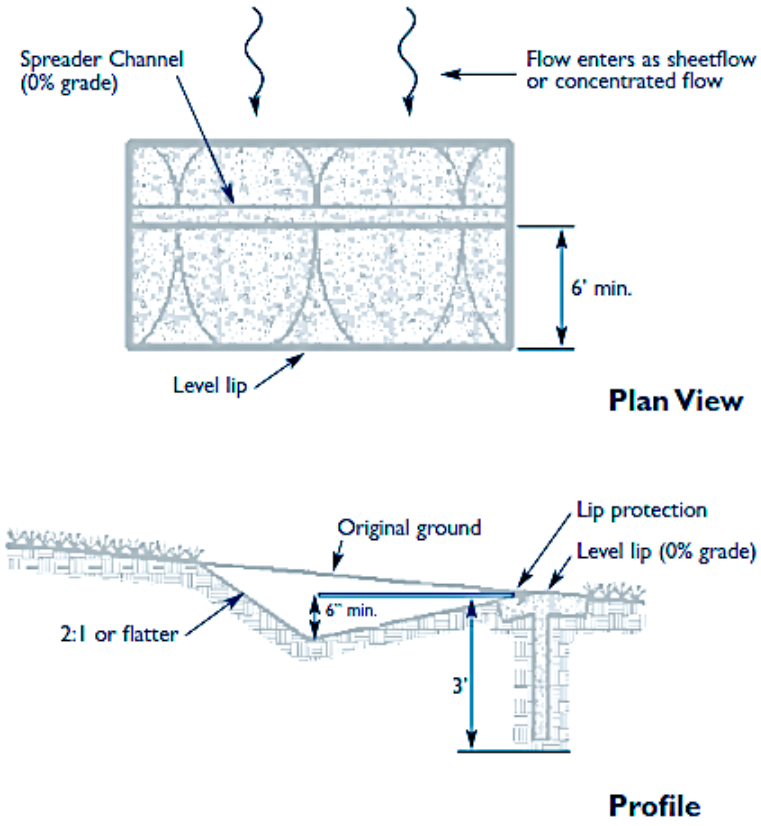
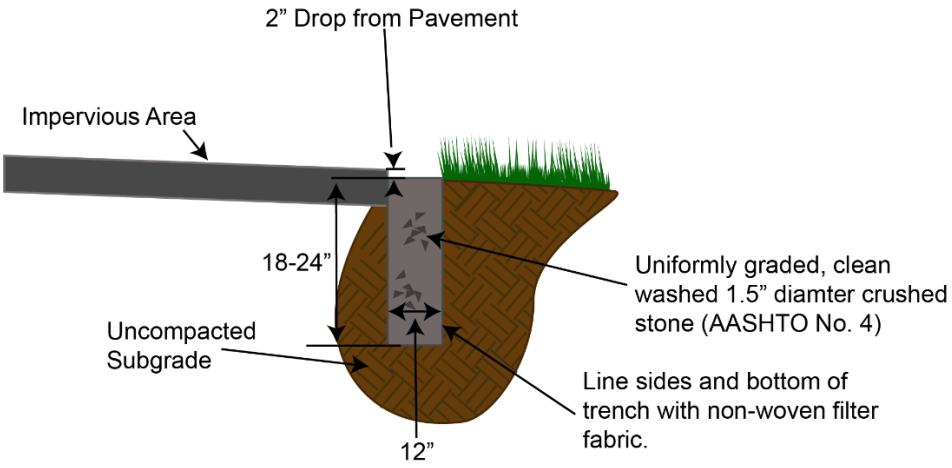


Figure 13-38. Level Spreader Design Example 3



Source: Adapted from Pennsylvania Stormwater Best Management Practices Manual.

Inlet Curb Cut Opening

Inlet curb cut openings are used in locations where stormwater BMPs are installed along curbed streets, parking lots, or landscaped islands. In certain situations, stormwater overflow discharges out of the BMP via the same curb cut opening through which it entered. Once stormwater fills the BMP, stormwater overflow will be directed back out through the curb opening to an existing drain structure that will then function as an overflow structure. Figure 13-39 show several examples of common inlet curb cut openings.

Key design considerations for inlet curb cut openings include:

- Curb cuts should be transition-style and have a width not less than 18 inches to prevent clogging.
- If designing the BMP as an on-line structure, design the opening width to prevent flow from bypassing the opening. Slope the bottom of the curb cut to drain toward the BMP and create a low point in the pavement in front of the opening by creating a small rectangular area with a lower elevation than the surrounding pavement (i.e., depressed curb inlet).
- Provide a minimum 2-inch drop in grade between the curb cut entry point and the downgradient finished surface/grade.
- Woody plants should not be placed directly in the entrance flow path. Woody plants can restrict and concentrate flows and be damaged by erosion around the root ball.
- Stabilize the area downstream of the curb cut opening to prevent erosion. Concrete (e.g., a splash pad), paver blocks, or grouted stone should be used to armor the flow path to the base of the BMP.

Inlet Structure

Inlet structures may be used to capture runoff, slow runoff velocities, settle solids and convey runoff to a downstream stormwater BMP. A deep sump catch basin (see design guidance for deep sump hooded catch basins in the Pretreatment BMPs section of Chapter 7) is an example of an inlet structure (Figure 13-40).

Key design considerations for inlet structures include:

- The recommended minimum sump depth for deep-sump structures is 48 inches.
- Utilize hoods to minimize floatable pollutants discharged to the BMP.

Figure 13-39. Typical Inlet Curb Cut Openings

Curb cut openings at inlets to bioretention basins designed to capture runoff from adjacent parking areas.

Curb cut opening at inlet to roadside bioswale. The single opening serves as the inlet and overflow.

Installation of depressed concrete pad in front of inlet curb opening to create a low point that helps convey gutter flow into the bioswale (left photo). Curb cut opening to direct road runoff beneath the adjacent sidewalk into a stormwater BMP (right photo).

Figure 13-40. Deep Sump Catch Basin Inlet Structure

Piped Flow Entrance

Runoff may discharge to a stormwater BMP via a pipe or culvert. The following should be considered when designing piped flow entrances:

- Include energy dissipation measures to dissipate energy and distribute runoff. The energy dissipation measure should extend the entire width of the piped flow entrance and extend into the bottom of the BMP. Acceptable energy dissipation measures include grouted stone riprap aprons, concrete splash pads, and forebays/stilling areas created using concrete/granite curbing or gabion weir/baffles. When using concrete/granite curbing or gabion weir/baffles, consider potential tailwater impacts.
- Woody plants should not be placed directly in the entrance flow path. Woody plants can restrict or concentrate flows and be damaged by erosion around the root ball.

Flow Diversion Structure

Stormwater BMPs can be designed to receive all the flow from a given area (on-line) or to receive only a portion of the flow (off-line). Flow diversion structures, also called flow splitters, are designed to divert flows up to the peak flow rate associated with the water quality storm (i.e., the Water Quality Flow or WQF) from a conveyance system to an off-line BMP. Flows in excess of the WQF bypass the BMP and continue through the conveyance system downgradient of the BMP. Refer to Appendix D of this Manual for the recommended procedure for calculating the WQF.

Flow diversion structures are typically manholes or vaults equipped with weirs, orifices, or pipes to bypass flows in excess of the design flow. Several design options exist. Figure 13-41 through Figure 13-43. Flow Diversion Structure Design Example 3 show common examples of flow diversion structures for use upstream of off-line stormwater BMPs. Other equivalent designs that achieve the result of diverting flows in excess of the WQF around the BMP, including bypasses or overflows located inside the BMP, are also acceptable. Refer to the Guidelines for the Use Hydrodynamic Separators on CTDOT Projects (4/2021) for additional diversion examples.

Key design considerations for flow diversion structures include:

- Size the low flow outlet to convey flows up to the WQF to the stormwater BMP.
- Set the top elevation of the diversion weir or the overflow outlet at the maximum water surface elevation associated with the WQF, or the water surface elevation in the downstream stormwater BMP when the entire WQV is being held in the BMP, whichever elevation is higher. Consider tailwater conditions when modeling bypass flows.
- Determine the diversion structure dimensions required to divert flows in excess of the WQF using standard equations for a rectangular sharp-crested weir, uniform flow in pipes or channels, or orifice depending on the type of diversion structure.
- Provide sufficient freeboard in the diversion structure to accommodate the maximum water surface elevation in the diversion structure and in the BMP. Avoid surcharging the BMP under higher flow conditions.
- Design diversion structures to minimize clogging potential and to allow for ease of inspection and maintenance. Maintenance access should be provided to both sides of diversion weir for cleaning by a vacuum truck.

Figure 13-41. Flow Diversion Structure Design Example 1

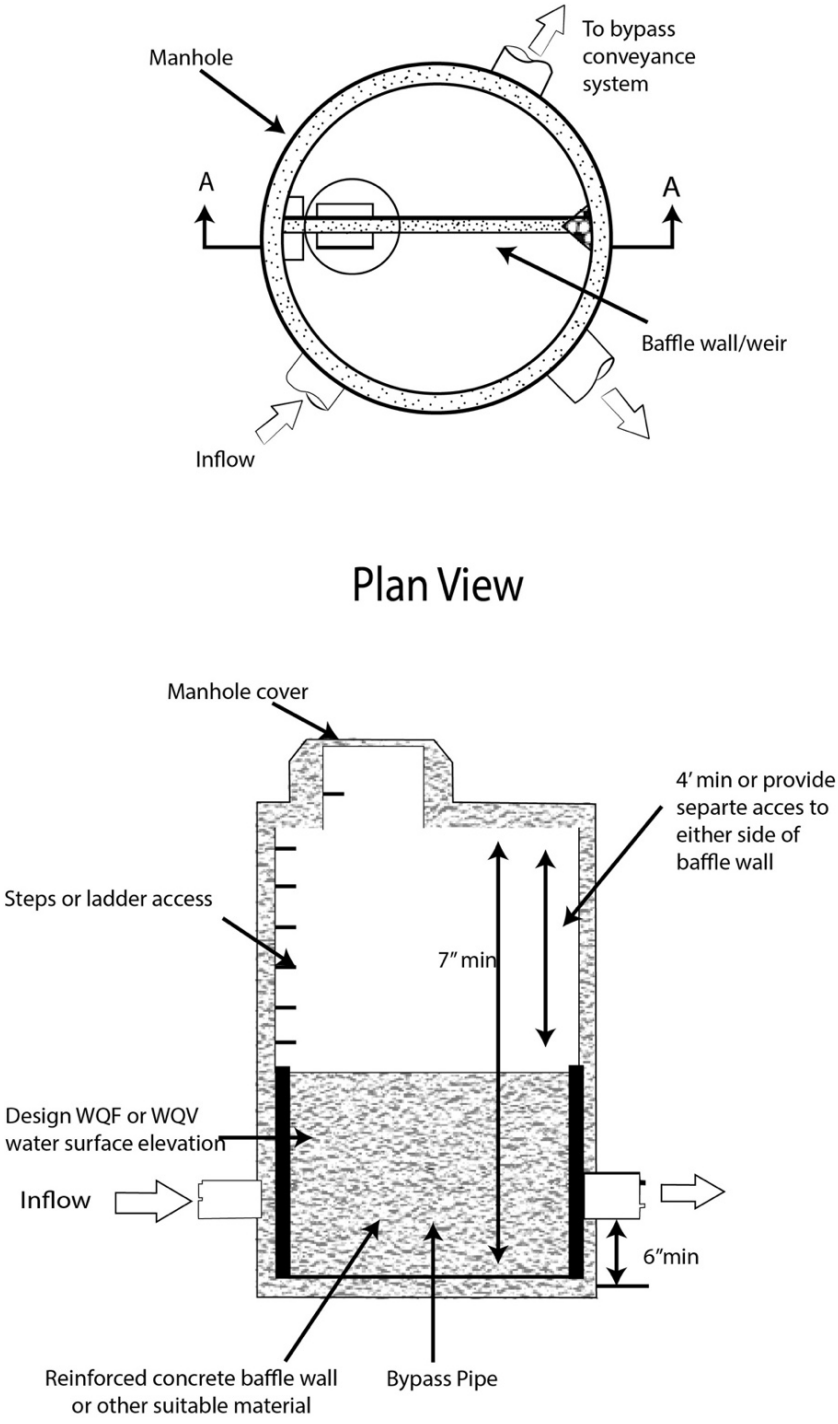


Figure 13-43. Flow Diversion Structure Design Example 2

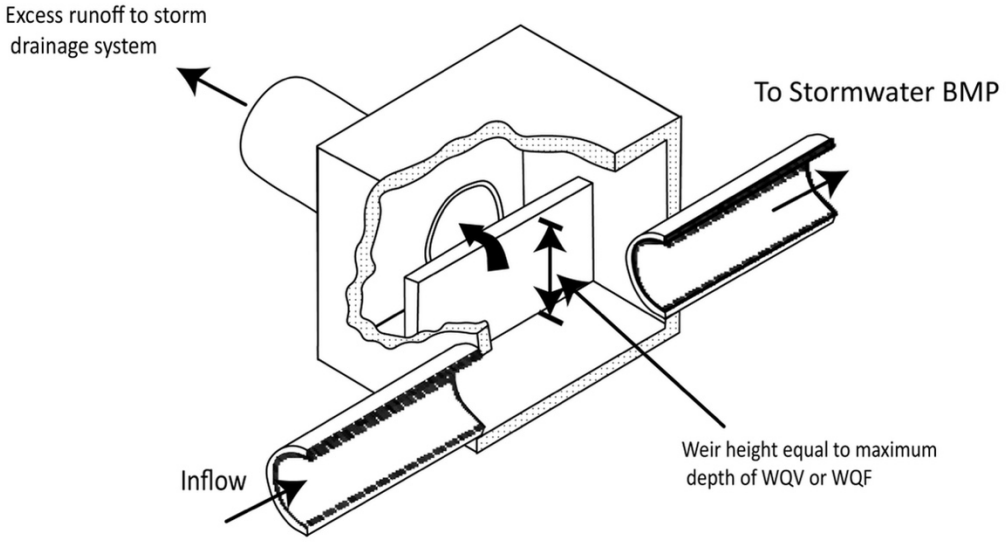
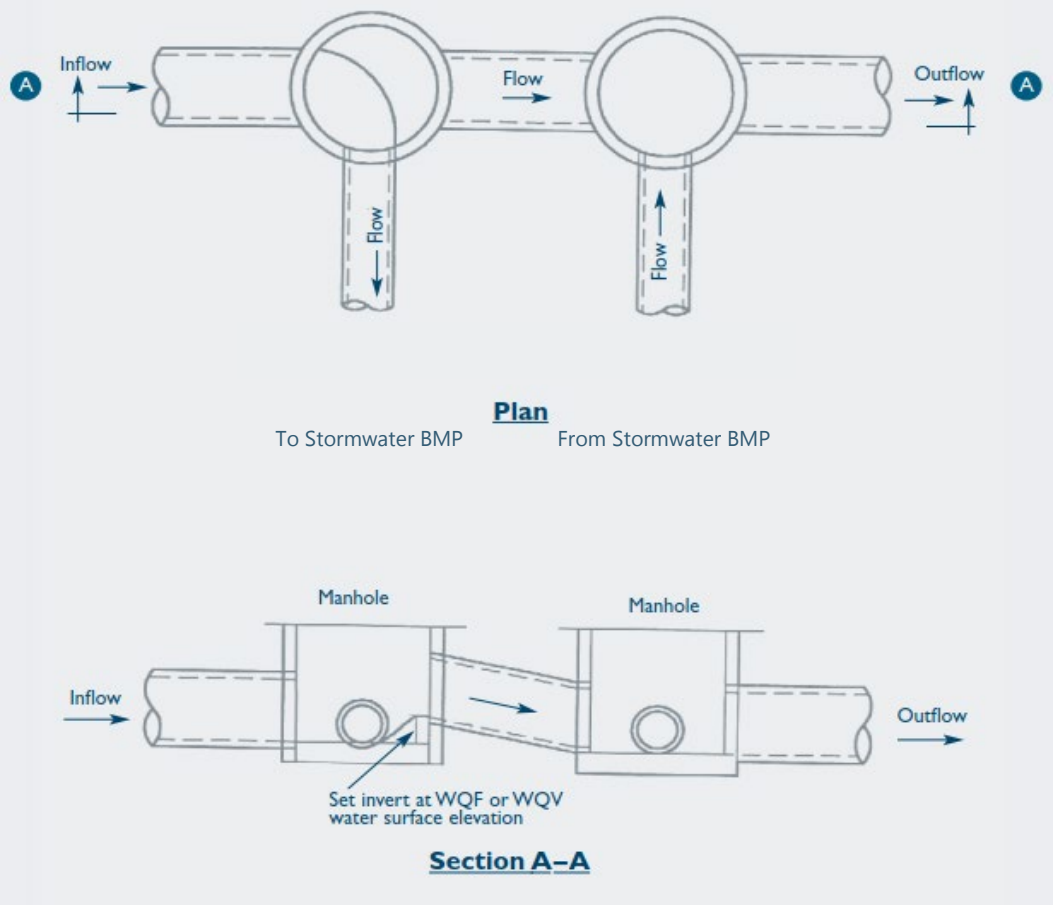


Figure 13-42. Flow Diversion Structure Design Example 3



Outlet Controls

General Design Guidance

In addition to the design criteria outlined below for the respective outlet control types, the following general criteria should be considered when designing outlet controls for BMPs:

All on-line stormwater BMPs must have a provision for outlet/overflow, as follows:

- An outlet control structure should be provided for runoff in excess of the WQF or WQV. The outlet control structure should be designed with openings to safely pass the 10-year, 24-hour design storm, at a minimum, with adequate freeboard.
    - For BMPs without a perimeter constructed earthen berm (e.g., bioretention swale), design the outlet/overflow structure of an on-line BMP to safely convey flows from the 10-year storm event (at minimum) with 6 inches of freeboard (unless noted otherwise in individual BMP design sections).
    - For BMPs with a perimeter constructed earthen berm, design the outlet/overflow structure of an on-line BMP to safely convey flows from the 100-year storm event with 3 inches of freeboard (unless noted otherwise in individual BMP design sections).
- For on-line BMPs, the outlet control structure should be designed as a multi-stage outlet structure positioned to meet each control requirement independently (e.g., retention/treatment of stormwater, conveyance of larger storms, peak runoff attenuation, emergency overflow, etc.).
    - For water quality purposes, the elevation of the lowest outlet should be set at, or slightly above, the design storage elevation, which is the elevation of ponded water associated with the Required Retention Volume (100% or 50% of the site's WQV).
- Overflow spillways should be a minimum of 8 feet wide, 1 foot deep, and have side slopes no steeper than 3(H):1(V).
- Discharge from an outlet should be conveyed to either a stormwater structure (e.g., manhole), drainage system, or stabilized discharge point.
    - Confirm that the conveyance system/storm drain network has adequate capacity to receive the proposed flow and that the system meets the stormwater quantity control requirements described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

Protection from Clogging

Protection from clogging is required for any orifice size utilized as part of the outlet control structure. Small orifices, typically less than six inches in diameter, used for slow-release applications can be susceptible to clogging. The following design measures should be taken to minimize the potential for clogging.

- The low-flow orifice should be adequately protected from clogging by a trash rack. The orifice diameter should always be greater than the thickness of the trash rack openings. The trash rack area should be at least ten times the area of the outlet opening being protected from clogging.
    - The minimum recommended orifice size is 3 inches.
    - Orifice diameters smaller than 3 inches should only be allowed on a case-by-case basis as demonstrated by the designer and/or upon approval from the review authority.

Outlet Curb Cut Openings

Outlet curb cut openings (Figure 13-44) can be used as a type of outlet control for BMPs located along streets with a gradual but consistent slope. Excess volume above the designed ponding depth flows out of the outlet curb cut opening installed at the downstream end of the facility. The following should be considered when designing outlet curb cut openings:

- Set the crest of the outlet curb opening at or above the elevation of the shallow ponding depth; and at least 3 inches below the inlet elevation to prevent overtopping of the BMP during the design storm.

Raised Overflow Structures or Risers

Raised overflow structures or risers can be designed as single-stage or multi-stage vertical structures consisting of orifices and/or weir openings set at different elevations to meet stormwater management requirements. The following should be considered when designing raised overflow structures and risers:

- Single-stage structures should consist of a vertical (riser) overflow structure or riser pipe with an open top that is covered by a “beehive” grate (Figure 13-45), domed riser grate, or trash rack. The crest of the overflow structure is set at or slightly above the design storage elevation associated with the WQV.

Figure 13-44. Roadside Bioswale with Inlet and Outlet Curb Cut Openings

Figure 13-45. Typical Dome Grate Overflow/Outlet Structure

Outflow Weirs

Outflow weirs typically consist of stabilized overflow spillways or structural weirs constructed from gabions, concrete, or curbing. Outflow weirs promote sedimentation by slowing flow velocities as water ponds behind the weir. They also provide a means of uniformly distributing runoff as it is discharged, helping to decrease concentrated flow and reduce velocities as the water travels downstream. In certain situations, these types of weirs may be designed with notches to limit or restrict overflow to desired locations or match pre-development peak flow rates. The following should be considered when designing outflow weirs:

- Account for structural stability during extreme conditions in addition to flow velocities and upstream hydrostatic pressure from ponded water.
- Select materials that withstand design flow velocities and exposure to the elements.

Outlet Pipes/Culverts

An outlet pipe/culvert from a BMP should be designed to convey controlled flow in excess of the Water Quality Flow to either a stormwater structure, drainage system, or approved discharge point. Confirm that the conveyance system/storm drain network has adequate capacity to receive the proposed flow and that the system meets the stormwater quantity control requirements described in Chapter 4 - Stormwater Management Standards and Performance Criteria.

Inlet and Outlet Protection

Inlet and outlet protection should be installed to dissipate energy and limit erosion. Typical inlet and outlet protection measures include level spreaders, stone/riprap aprons, stone riprap stilling basins or plunge pools, concrete pads or splash blocks, and non-degradable turf reinforcement matting designed to reduce the velocity, energy, and turbulence of the flow. Other options may be considered if allowed by the review authority. These measures can be used when highly erosive velocities are encountered at inlet and outlet locations, at the bottom of steep slopes, or where the discharge of sheet flow or non-erosive flow to down-gradient locations is required.

Provide stable and non-erosive energy dissipating devices at inflow and outlet locations where concentrated flow velocities are considered erosive. Flow velocities should not exceed 3 feet per second for grassed surfaces and 1 foot per second for mulched surfaces.

Stone Riprap Apron

Stone riprap aprons are commonly used for energy dissipation due to their relatively low cost and ease of installation. A flat stone riprap apron can be used to prevent erosion at the transition from a pipe, culvert, or spillway outlet to a natural channel. Riprap aprons will provide adequate protection if there is sufficient length and flare to dissipate energy by expanding the flow. To facilitate removal of sediment and minimize vandalism potential, stone riprap aprons may be grouted.

- The aprons should be designed for the water quality storm for off-line stormwater BMPs and for the 10-year, 24-hour storm event at a minimum for on-line BMPs.
- If the apron is installed at an inlet location within the BMP that will be part of a sediment forebay, the stone riprap should be grouted to facilitate maintenance.
    - If grouted, provide at least two weep holes (2.5 inches in diameter) for every 25 square feet of surface area in the bottom of the forebay to facilitate low level drainage.
    - If grouted riprap is used, stone riprap should conform to State of Connecticut Department of Transportation Standard Specifications, Section M.12.02 (Riprap). Grout should be a non-shrink grout having a 4,000 psi 28-day compressive strength and a 2,400 psi 7-day compressive strength in accordance with State of

Connecticut Department of Transportation Standard Specifications, Section M.03.05.

Stone Riprap Stilling Basin or Plunge Pool

A riprap stilling basin or plunge pool is a pre-shaped scour hole lined with riprap that functions as an energy dissipator. Like a riprap apron, a riprap stilling basin can be used to prevent erosion at the transition from a pipe or box culvert outlet to an earthen channel.

- The appropriate inlet and outlet protection type should be based on site characteristics such as slope, available area, and aesthetics.
- A key design issue is the interface between the end of the inlet/outlet protection structure and the adjacent downstream area, which is typically vegetated. Vegetation should be well established at this interface. Turf reinforcement matting may be used at this interface to provide additional structure for vegetation.
- Vegetation/plantings can be used to obscure views of inlet/outlet protection structures if aesthetics is a concern.

Appendix A – Stormwater Regulation

As noted in Chapter 1 - Introduction, this Manual has no regulatory authority but rather provides guidance to address the various regulations (federal, state and local) regarding post-construction stormwater management. This appendix provides a summary of the various stormwater management programs in Connecticut with regulatory authority. The table below summarizes the applicable regulations, provides an overview of the program, and defines the party responsible for implementation ("End User").

Federal/ State/ Local	Program	Program Overview	End User
Federal	Clean Water Act (CWA) Section 303 Water Quality Standards and Implementation Plans	Under Section 303 of the CWA, states are required to adopt surface water quality standards, subject to review and approval by the U.S. EPA, and identify surface waters that do not meet these water quality standards following the installation of minimum required pollution control technology for point sources discharging to surface water bodies. These impaired water bodies must be ranked by the states and a Total Maximum Daily Load (TMDL) must be established for the pollutant(s) that exceed the water quality standards. A TMDL both specifies a maximum amount of pollutant that the surface water body can receive and allocates that amount, or load, among point and nonpoint sources, including stormwater discharges.	Federal and State
Federal	CWA Section 319 – Nonpoint Source Management Program	CWA Section 319 addresses the need for federal guidance and assistance to state and local programs for controlling nonpoint sources of pollution, including stormwater runoff. Under Section 319, states, territories and Indian Tribes receive federal grant money to support various activities that address nonpoint source pollution control. These activities include technical and direct financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the effectiveness of specific nonpoint source implementation projects.	Federal and State
Federal	CWA Section 401 – Water Quality Certification	Section 401 of the CWA requires applicants for a federal license or permit to obtain a certification or waiver from the state water pollution control agency (EPA, states and authorized tribes) for any activity which may result in a	Federal and State

Federal/ State/ Local	Program	Program Overview	End User
		discharge into navigable waters of the state or tribal lands, including wetlands, watercourses, and natural and man-made ponds. This waiver certifies that the discharge will comply with the applicable provisions of the CWA and Connecticut's Water Quality Standards. Examples of federal licenses and permits for which water quality certification is required include U.S. Army Corps of Engineers Section 404 dredge and fill permits, Coast Guard bridge permits, and Federal Energy Regulatory Commission permits for hydropower and gas transmission facilities.	
Federal	Section 402 – National Pollutant Discharge Elimination System (NPDES)	The NPDES program was established under Section 402 of the CWA and specifically targets point source discharges by industries, municipalities, and other facilities that discharge directly into surface waters. Stormwater discharges are addressed under the NPDES Stormwater Program. The NPDES permitting program is administered in Connecticut by DEEP through a series of permits noted below in this table.	Federal and State
Federal	Coastal Zone Act Reauthorization Amendments	Section 6217 of the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 (16 U.S.C. §1455b) is designed to address the problem of nonpoint source pollution in coastal waters. Under Section 6217, states and territories with approved Coastal Zone Management Programs, including Connecticut, are required to develop Coastal Nonpoint Source Pollution Control Programs or face funding sanctions in both their coastal programs and their nonpoint programs established under Section 319 of the Clean Water Act.	Federal and State

Federal/ State/ Local	Program	Program Overview	End User
		The program must describe how the state or territory will implement management measures to reduce or eliminate nonpoint source pollution, including stormwater runoff, to coastal waters. These management measures must conform to those described in the U.S. EPA publication Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.	
State	Connecticut Industrial Stormwater Permit	The General Permit for the Discharge of Stormwater Associated with Industrial Activity ("Industrial Stormwater General Permit") regulates industrial facilities with point source discharges that are engaged in specific activities listed in the permit. To register for this program, these facilities must submit a registration form, and implement a Pollution Prevention Plan (PPP). The PPP must include information about the site, an inventory of exposed materials, a summary of potential pollutants, a description of and schedule for implementation of storm water control methods, storm water monitoring, and site inspection.	State and Permittees
State	Construction Stormwater General Permit	The General Permit for the Discharge of Stormwater and Dewatering Wastewaters from Construction Activities ("Construction Stormwater General Permit") requires developers and builders to implement a Stormwater Pollution Control Plan to prevent the movement of sediments off construction sites into nearby water bodies and to address the impacts of stormwater discharges from a project after construction is complete.	State and Permittee

Federal/ State/ Local	Program	Program Overview	End User
State	General Permit for the Discharge of Stormwater Associated with Commercial Activity	The General Permit for the Discharge of Stormwater Associated with Commercial Activity ("Commercial General Permit"), found only in Connecticut, requires operators of large paved commercial sites such as malls, movie theaters, and supermarkets to undertake actions such as parking lot sweeping and catch basin cleaning to keep stormwater clean before it reaches water bodies.	State and Permittee
State	General Permit for the Discharge of Stormwater from Small Municipal Separate Storm Sewer Systems	The General Permit for the Discharge of Stormwater from Small Municipal Separate Storm Sewer Systems ("MS4 General Permit") requires each municipality to take steps to keep the stormwater entering its storm sewer systems clean before entering water bodies. One important element of this permit is the requirement that towns implement public education programs to make residents aware that stormwater pollutants emanate from many of their everyday living activities, and to inform them of steps they can take to reduce pollutants in stormwater runoff.	
State	Connecticut Coastal Zone Management Plan	Per the requirements of the federal CZARA (noted above) Connecticut and other coastal zone states are required to have a Coastal Zone Management Plan and an assessment of that plan ever five years after the adoption of said plan. The plans and the assessments there after are required to review nine key elements, one of which is Cumulative and Secondary Impacts, this is where stormwater is assessed and considered.	

Federal/ State/ Local	Program	Program Overview	End User
		Additionally, Connecticut management plan includes the Water Quality Certification and Coastal Permit Program, noted below, these permits and water quality certifications are required to consider stormwater impacts. Connecticut's latest assessment can be found here: https://coast.noaa.gov/czm/enhancement/	
State	Coastal Individual Permits[93]	The DEEP's Land and Water Resources Division (LWRD) regulates all activities conducted in tidal wetlands and in tidal, coastal, or navigable waters in Connecticut under the Structures, Dredging and Fill statutes, Connecticut General Statutes (CGS) Sections 22a-359 - 22a-363h, inclusive, and the Tidal Wetlands statutes, CGS Sections 22a-28 - 22a-35, inclusive. The major objectives of the permit program are to avoid or minimize navigational conflicts, encroachments into the state's public trust area, and adverse impacts on coastal resources and uses, consistent with Connecticut's Coastal Management Act (CCMA), CGS Sections 22a-90 - 22a-112, inclusive. Certain activities require an "individual" permit specific to the proposed work. These activities typically include new construction and other work for which a detailed review of potential	Permittee, State and Army Corp of Engineers

[93] In 2012, the jurisdiction of the coastal zone was modified from the high tide line to a "coastal jurisdiction line" it is anticipated this line will continue to be revised with the updated information regarding sea level rise. See the details of this zone here: https://portal.ct.gov/DEEP/Coastal-Resources/Coastal-Permitting/Coastal-Jurisdiction-Line-Fact-Sheet

Federal/ State/ Local	Program	Program Overview	End User
		environmental impacts is needed. Many of the applications require a Stormwater Management Plan.	
State	Coastal General Permits[13]	General permits are issued to authorize certain minor activities. Because the environmental impacts of those activities are understood, detailed permit reviews are generally not required. There are three kinds of coastal general permits: Minor Coastal Structures, Coastal Maintenance, and Coastal Storm Response. The following structures and activities may be eligible for authorization through a general permit: • Small residential docks having no navigational or environmental impacts • Boat moorings • Osprey nesting platforms and perch poles • Residential flood hazard mitigation • Buoys and markers for navigation and certain recreational activities • Swim floats • Pump-out facilities at marinas • Coastal remedial activities May require a Stormwater Management Plan.	State and Permittee
State	Coastal Certificate of Permissions	The DEEP's Land and Water Resources Division (LWRD) regulates all activities conducted in tidal wetlands and in tidal, coastal, or navigable waters in Connecticut under the Structures, Dredging and Fill statutes, Connecticut General Statutes (CGS) Sections 22a-359 - 22a-363h,	State and Permittee

Federal/ State/ Local	Program	Program Overview	End User
		inclusive, and the Tidal Wetlands statutes, CGS Sections 22a-28 - 22a-35, inclusive. The major objectives of the permit program are to avoid or minimize navigational conflicts, encroachments into the state's public trust area, and adverse impacts on coastal resources and uses, consistent with Connecticut's Coastal Management Act (CCMA), CGS Sections 22a-90 - 22a-112, inclusive. Minor activities related to previously authorized work may be eligible for a Certificate of Permission (COP). These activities include maintenance dredging and substantial maintenance of existing structures. In some cases, maintenance of unauthorized activities that were completed prior to specific dates may also be eligible for a COP. In addition, certain environmentally beneficial activities, such as the removal of derelict structures and restoration of degraded tidal wetlands, may be approved through the COP process. COPs are issued within 45 days, or within 90 days if additional information is requested by LWRD to complete its review. COP applications can be completed and submitted through our on-line portal, ezFile. May require a Stormwater Management Plan.	
State	Flood Control Management Certification	Any state agency proposing an activity within or affecting a floodplain or that impacts natural or man-made storm drainage facilities must submit a flood management certification. Such activities include, without limitation: a) any structure, obstruction or encroachment proposed for emplacement within the floodplain area; b) any proposal for site development	State

Federal/ State/ Local	Program	Program Overview	End User
		which increases peak runoff rates; c) any grant or loan which affects land use, land use planning or the disposal of state properties in floodplains; or d) any program regulating flood flows within the floodplain. (For more information see: Sections 25-68h-1 through 25-68h-3 of the Regulations of Connecticut State Agencies (RCSA))	
State	Section 401 Water Quality Certification	Under Section 401 of the CWA, States must administer and regulate any applicant for a federal license or permit who seeks to conduct an activity that may result in any discharge into the navigable waters, including all wetlands, watercourses, and natural and man-made ponds. Such persons must obtain certification from DEEP that the discharge is consistent with the federal Clean Water Act and the Connecticut Water Quality Standards. Any conditions contained in a water quality certification become conditions of the federal permit or license. In making a decision on a request for 401 Water Quality Certification, DEEP must consider the effects of proposed discharges on ground and surface water quality and existing and designated uses of waters of the state.	State, Army Corp of Engineers and Permittees
State	Water Diversion Permits	The Water Diversion Program regulates activities that cause, allow or result in the withdrawal from, or the alteration, modification or diminution of, the instantaneous flow of the waters of the state through individual and general permits. The Water Diversion Policy Act is codified in Section 22a-365 through 22a-379 of the Connecticut General Statutes as well as Sections 22a-372-1, 22a-377(b)-1 and 22a-377(c)-1	State and Permittees

Federal/ State/ Local	Program	Program Overview	End User
		to 22a-377(c)-2 of the Regulations of Connecticut State Agencies. You must apply for a permit if, among other things, you propose to: • withdraw groundwater or surface water in excess of 50,000 gallons of per day; • collect and discharge runoff, including storm water drainage, from a watershed area greater than 100 acres; • transfer water from one public water supply distribution system or service area to another where the combined maximum withdrawal from any source supplying interconnection exceeds fifty thousand (50,000) gallons during any twenty-four hour period; • expand a registered public water supply service beyond a service area as identified (1) within registration documents, (2) in a water supply plan submitted prior to October 1, 2016, or (3) beyond an exclusive service area identified on the Department of Public Health's 2016 Public Water Supply Management Area maps; • relocate, retain, detain, bypass, channelize, pipe, culvert, ditch, drain, fill, excavate, dredge, dam, impound, dike, or enlarge waters of the state with a contributing watershed area greater than 100 acres; • transfer water from one water supply distribution system to another in excess of 50,000 gallons per day; • or modify a registered diversion.	

Federal/ State/ Local	Program	Program Overview	End User
State	Dam Safety Program	The mission of the DEEP Dam Safety Regulatory Program is to ensure the safety of dams to protect life, property, and the environment by ensuring that all dams are designed, constructed, operated, and maintained safely and effectively. Dam Safety Statutes & Regulations. The Dam Safety Statutes were last substantially revised by Public Act 2013-197, which authorized changes regarding Emergency Action Plans (EAPs) and inspection requirements: • Dam owners in the State of Connecticut are now responsible for hiring a consultant to conduct regular dam inspections. • The owners of high hazard (Class C) and significant hazard (Class B) dams must file an EAP every two years. The Dam safety program manages two kinds of permits individual permits and general permits for releases, construction, repairs or other modifications to dams (including stormwater impoundments). This program also requires a 401 certification and thereby, stormwater impacts may need to be considered.	State, Dam Owners and Permittees
State	Standards for Public Drinking Water	Regulations of Connecticut State Agencies 19-13-B102 provide the authority and requirements for the protection of public drinking water. This includes the protection of sources from stormwater, the delineation of protected areas, and when necessary treatment of water supplies when contaminated from stormwater events.	State (DPH)

Federal/ State/ Local	Program	Program Overview	End User
State	Connecticut Nonpoint Source Program	As noted above the federal Clean Water Act §319 establishes a national program to control nonpoint sources (NPS) of water pollution. The U.S. Environmental Protection Agency defines NPS pollution as that which is "caused by diffuse sources that are not regulated as point sources and are normally associated with precipitation and runoff from the land or percolation." To help address NPS pollution, §319(h) authorizes the EPA to award grants to states and tribes with EPA-approved NPS management programs.	State and Grantees
State and Local	Aquifer Protection Area Program	Connecticut's Aquifer Protection Area Program protects major public water supply wells in sand and gravel aquifers to ensure a plentiful supply of public drinking water for present and future generations. Aquifer Protection Areas (sometimes referred to as "wellhead protection areas") are being designated around the state's 127 active well fields in 80 Towns in sand and gravel aquifers that serve more than 1000 people. Land use regulations will be established in those areas to minimize the potential for contamination of the well field. The regulations restrict development of certain new land use activities that use, store, handle or dispose of hazardous materials and requires existing regulated land uses to register and follow best management practices. The Aquifer Protection Area Program responsibilities are shared by the state DEEP, the municipalities and the water companies.	State and Municipalities

Federal/ State/ Local	Program	Program Overview	End User
		The municipal aquifer protection manual includes consideration of stormwater management plans.	
Local	Inland Wetlands and Watercourse Act	The Act creates a land-use regulatory process which considers the environmental impacts of proposed development activities. A person proposing to conduct an activity that will likely impact or affect an inland wetland or watercourse must first obtain a permit from the municipal inland wetlands agency. In the case of a state agency activity, or when an activity is conducted on state land, a permit is required from the Department of Energy and Environmental Protection (DEEP). Assisted by the State, Connecticut's 169 municipalities apply and enforce the law through a local Wetlands Agency.	State, Local and Permittees
Local	Municipal Zoning and Planning	Post construction stormwater controls must be considered for many projects to be approved by the local municipal zoning and planning commissions. Considerations for impacts on receiving waters are an important element of the commissions' reviews.	Local

Appendix B – Structural Stormwater BMP Maintenance Inspection Checklist

Included in this Appendix:

- Standard checklist that can be used during maintenance inspections of most types of structural stormwater Best Management Practices (BMPs). Not all system components will be applicable to every BMP. For proprietary stormwater BMPs, use inspection checklists provided by the system manufacturer.
- An additional blank page is provided for non-standard system components not shown on the standard inspection checklist.
- Complete a separate inspection checklist for each stormwater BMP at a given site and provide a site plan or sketch showing the locations of each stormwater BMP.
- Additional inspection and maintenance resources.

INSPECTION CHECKLIST

DATE/ TIME: _____

INSPECTOR: _____

TYPE OF BMP: _____

WEATHER DURING INSPECTION: _____

_____

LOCATION: _____

TYPE OF INSPECTION (check if applicable):

Storm Event ☐ Complaint Response ☐ Routine ☐

AS IS BUILT PLANS AVAILABLE: Yes ☐ No ☐

PRECIPITATION AMOUNT IN 24 HR PRIOR TO INSPECTION: _____

INLET	APPLICABLE: Yes ☐ No ☐
Circle or note applicable element(s): level spreader, inlet curb cut opening, inlet structure, piped flow entrance, flow diversion structure _____	Guidance on what to look for: -Accumulated debris/ sediment at the inlet and within the structure (if applicable) -Structural damage or erosion
CONDITION: Satisfactory ☐	Unsatisfactory ☐

RECOMMENDED MAINTANENCE	**NOTES**
_____ _____ _____ _____ _____ _____ _____ _____ _____ _____	_____ _____ _____ _____
	DATE FOR FOLLOW UP
	_____

PRETREATMENT

APPLICABLE: Yes ☐ No ☐

Circle or note applicable element(s):
sediment forebay, pretreatment vegetated filter strip, deep sump pump catch basin, oil grit separator, proprietary treatment device

_____

Guidance on what to look for:
-Accumulated debris/ sediment
-Structural damage or erosion

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

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DATE FOR FOLLOW UP

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BASIN CELL

APPLICABLE: Yes ☐ No ☐

Circle or note applicable element(s):
infiltration trench, infiltration basin, bioretention, sand filter, subsurface gravel wetland

_____

Guidance on what to look for:
-Accumulated debris
-Damage (e.g. erosion/ animal burrowing)
-Overgrown/ dead vegetation
-Standing water
-Condition of wetland vegetation

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

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DATE FOR FOLLOW UP

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FILTER BED

APPLICABLE: Yes ☐ No ☐

Circle or note applicable element(s):
bioretention, sand filter, tree filter, dry water quality swale, permeable pavement

_____

Guidance on what to look for:
- Accumulated debris/ sediment
-Overgrown/ dead vegetation and weeds
-Standing water above filter bed
-Erosion/ rutting in upgradient areas
-Cracks or damage to permeable pavement

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

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DATE FOR FOLLOW UP

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SUBSURFACE RESERVOIR/ OBSERVATION WELL

APPLICABLE: Yes ☐ No ☐

Circle or note applicable element(s):
infiltration trench, underground infiltration system, dry well, bioretention, tree filter, dry water quality swale, subsurface gravel wetland*

_____

Guidance on what to look for:
-Standing water in the

*if underdrain present

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

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DATE FOR FOLLOW UP

Berm/ Weir APPLICABLE: Yes ☐ No ☐

Circle or note applicable element(s):
stormwater ponds, stormwater wetlands including subsurface gravel wetland, water quality swales

Guidance on what to look for:
-Debris sediment buildup
-Damage (e.g. erosion, cracks, spalling, seepage/ weeps, failure, animal burrows)

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

NOTES

DATE FOR FOLLOW UP

Outlet APPLICABLE: Yes ☐ No ☐

Circle or note applicable element(s):
outlet curb cut openings, raised overflow structures or risers, outflow weirs, outlet pipes/ culverts, stone riprap apron, stone riprap stilling basin or plunge pool

Guidance on what to look for:
-Accumulated debris/ sediment at the outlet and within the structure (if applicable)
-Structural damage or erosion

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

NOTES

DATE FOR FOLLOW UP

Maintenance Access APPLICABLE: Yes ☐ No ☐

All BMPs are appliable
Guidance on what to look for:
-Access to pretreatment and all parts of BMP that require routine maintenance or sediment removal
-Structural damage or erosion access road
-Overgrown/ dead vegetation preventing or impeding access by maintenance personnel or equipment

CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

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DATE FOR FOLLOW UP

Other: _____

Note applicable element(s):

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CONDITION: Satisfactory ☐ Unsatisfactory ☐

RECOMMENDED MAINTANENCE

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DATE FOR FOLLOW UP

Inspection and Maintenance Resources

Bioretention

https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_of_bioretention_and_other_stormwater_infiltration_practices

https://www.epa.gov/sites/default/files/2016-11/documents/final_gi_maintenance_508.pdf

Detention Basin

https://s3.amazonaws.com/bethtwpassets/Bethelehem+SWM+Guideline.pdf

http://water.rutgers.edu/Projects/GreenInfrastructureChampions/Talks_2020/8_Handouts/8_DetentionBasinMaintenanceGuidelines.pdf

Dry Well

https://www.cbf.org/document-library/presentation-webinar-materials/CBF_Dry_Well_011614.pdf

https://www.youtube.com/watch?v=bfIb0R-cYfs

Grass Swale

https://www.aacounty.org/departments/public-works/wprp/bmp_maintenance/Archive/Grass%20Swale%20Maintenance-2.pdf

https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_of_dry_swale_(grass_swale)

https://www.cbf.org/document-library/cbf-guides-fact-sheets/CBF_Vegetated-Swale_01161476fc.pdf

https://www.epa.gov/sites/default/files/2016-11/documents/final_gi_maintenance_508.pdf

Infiltration Trench

https://www.cbf.org/document-library/presentation-webinar-materials/CBF_Infiltration_Trench_011614.pdf

https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_of_Infiltration_trench&redirect=no

Permeable Pavement

https://askhrgreen.org/wp-content/uploads/2015/04/PermeablePavement.pdf

https://www.montgomerycountymd.gov/DEP/Resources/Files/PostersPamphlets/Porous-Pavement-Maintenance.pdf

https//stormwater.pca.state.mn.us/index.php/Operation_and_maintenance_of_permeable_pavement

https://www.perviouspavement.org/downloads/pervious_maintenance_operations_guide.pdf

https://www.cbf.org/document-library/cbf-guides-fact-sheets/CBF_Pervious-Pavement_0116142c76.pdf

Rain Barrel

https://montgomerycountymd.gov/DEP/Resources/Files/PostersPamphlets/Rain-Barrels.pdf

https://www.cbf.org/document-library/cbf-guides-fact-sheets/CBF_Rainbarrels_011614e420.pdf

Sand Filter

https://stormwater.pca.state.mn.us/index.php/Operation_and_maintenance_of_filtration

Stormwater Pond

https://www.cbf.org/document-library/cbf-guides-fact-sheets/CBF_Pervious-Pavement_0116142c76.pdf

Stormwater Wetland

https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_(O%26M)_of_stormwater_treatment_wetland_practices

https://www.cbf.org/document-library/cbf-guides-fact-sheets/CBF_Pervious-Pavement_0116142c76.pdf

https://www.fayettevillenc.gov/home/showdocument?id=8085

Tree Box Filter/Tree Trench

https://stormwater.pca.state.mn.us/index.php?title=Operation_and_maintenance_(O%26M)_of_tree_trenches_and_tree_boxes

https://megamanual.geosyntec.com/npsmanual/treeboxfilters.aspx

https://archives.lib.state.ma.us/bitstream/handle/2452/803682/on1103924280-task_3_deliverables.pdf?sequence=5&isAllowed=y

https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/UNHSC%20Biofilter%20Maintenance%20Guidance%20and%20Checklist%201-11_0.pdf

Appendix C – BMP Performance Curves and Static Storage Volume Calculation Methods

Sources of EPA Region 1 Stormwater BMP Performance Curves

The BMP Performance Curves are included in a variety of MS4 Stormwater General Permits and tools developed by EPA Region 1 and/or state agencies in New England.

- New England Stormwater Retrofit Manual
- EPA MS4 General Permit for Massachusetts (Appendix F, Attachment 3)
- EPA MS4 General Permit for New Hampshire (Appendix F, Attachment 3)
- EPA Best Management Practice Accounting and Tracking Tool (BATT)
- Rhode Island Department of Transportation (RIDOT) Stormwater Control Plan Calculator
- University of New Hampshire Stormwater Center BMP Performance Fact Sheets
- EPA BMP Performance Curves for Fecal Indicator Bacteria
- EPA Technical Information for Use and Application of Performance Curves for Indicator Bacteria

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Infiltration Trench	**Infiltration Trench** Static Storage Volume = 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.
	Dry Well **Infiltrating Catch Basin** **Underground Infiltration System (Chambers)** Static Storage Volume = water storage volume of storage structures and void space volume 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.
	Permeable Pavement (no underdrain) Static Storage Volume = 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)

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Infiltration Trench (continued)	**Tree Filter (no underdrain)** Static Storage Volume = ponding water storage volume and void space volume of soil filter media and gravel/stone layers (pea gravel and stone reservoir) if stone reservoir is used. If stone reservoir is not included, exclude pea gravel and stone from the static storage volume calculation.	The following equation for bioretention systems may be used. Refer to manufacturer's design guidance for manufactured tree filters for additional guidance. $V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ 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)
Infiltration Basin	**Infiltration Basin** Static Storage Volume = 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)

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Infiltration Basin (continued)	**Dry Water Quality Swale (no underdrain)** Static Storage Volume = water storage volume of swale and void space volume of soil filter media and gravel/stone layers (pea gravel and stone reservoir) if stone reservoir is used. If stone reservoir is not included, exclude pea gravel and stone from the static storage volume calculation.	$V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ 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)
	Bioretention (no underdrain) Static Storage Volume = ponding water storage volume and void space volume of soil filter media and gravel/stone layers (pea gravel and stone reservoir) if stone reservoir is used. If stone reservoir is not included, exclude pea gravel and stone from the static storage volume calculation.	$V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ 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)

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Biofiltration	**Bioretention (with underdrain)** **Tree Filter (with underdrain)** Static Storage Volume = Ponding water storage volume and void space volume of soil filter media and stone/gravel layers (pea gravel and stone reservoir)	$V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ 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) The above equation for bioretention systems may be used for tree filters. Refer to manufacturer's design guidance for manufactured tree filters for additional guidance.
	Surface Sand Filter (with underdrain) Static Storage Volume = 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)

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Biofiltration (continued)	**Dry Water Quality Swale (with underdrain)** Static Storage Volume = Water storage volume of swale and void space volume of soil filter media and gravel/stone layers (pea gravel and stone reservoir)	$V = (L * W * D_{ponding}) + (L * W * D_{soil} * n_{soil}) + (L * W * D_{stone} * n_{stone})$ 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)
Gravel Wetland	**Subsurface Gravel Wetland** **Shallow Wetland** Static Storage Volume = pretreatment volume plus volume of ponding and volume of void space in subsurface gravel/stone bed	$V = (A_{pretreatment} * D_{pretreatment}) + (A_{wetland} * D_{ponding}) + (A_{ISR} * D_{stone} * n_{stone})$ V = static storage volume (cubic feet) $A_{pretreatment}$ = pretreatment surface area (square feet) $A_{wetland}$ = surface area of wetland (square feet) $A_{Internal\ Storage\ Reservoir}$ = surface area of internal storage reservoir (square feet) $D_{pretreatment}$ = maximum ponding depth in pretreatment area (feet) $D_{ponding}$ = maximum ponding depth above wetland floor (feet) D_{stone} = depth of gravel/stone bed (feet) n_{stone} = porosity of gravel/stone (use default value of 0.4)

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Porous Pavement	**Permeable Pavement (with underdrain)** Static Storage Volume = 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)
Wet Pond	**Wet Pond** **Micropool Extended Detention Pond** **Wet Extended Detention Pond** **Multiple Pond System** **Wet Water Quality Swale** Static Storage Volume = permanent pool volume prior to high flow bypass (excludes pretreatment volume)	$V = A_{pond} * D_{pond}$ V = static storage volume (cubic feet) A = average area between maximum ponding depth and bottom of pond (square feet) $D_{ponding}$ = maximum ponding depth (feet) Static storage volume can also be calculated based on microtopography (proposed contours) and the elevation of the high flow bypass or overflow.
Dry Pond	**Dry Extended Detention Basin** **Extended Detention Shallow Wetland Pond/Wetland System** Static Storage Volume = ponding volume prior to high flow bypass (excludes pretreatment volume)	$V = A_{pond} * D_{pond}$ V = static storage volume (cubic feet) A = average area between maximum ponding depth and bottom of pond (square feet) $D_{ponding}$ = maximum ponding depth (feet) Static storage volume can also be calculated based on microtopography (proposed contours) and the elevation of the high flow bypass or overflow.

BMP Performance Curve Category[1]	Stormwater BMP Type Connecticut Stormwater Quality Manual	Static Storage Volume Equation[2]
Impervious Cover Disconnection	**Impervious Area Disconnection** **Vegetated Filter Strip** **Vegetated Buffer** **Qualifying Pervious Area (QPA)**	Use of BMP performance curves is based on the ratio of impervious area to pervious area instead of static storage volume.

[1] BMP categories and nomenclature used with EPA Region 1 BMP Performance Curves and EPA Region 1 MS4 Stormwater General Permits.

[2] Static Storage Volume is also commonly referred to as "Design Storage Volume (DSV)" in the context of the EPA Region 1 BMP Performance Curves and EPA Region 1 MS4 Stormwater General Permits. Other porosity values may be used for subsurface aggregate layers (bioretention soil, sand, pea gravel, stone, etc.) in lieu of those recommended in the table above as determined from testing of the proposed materials.

Appendix D – Water Quality Flow Calculation Method

The Water Quality Flow (WQF) is the peak rate of discharge associated with the water quality storm or Water Quality Volume (WQV). This section describes the recommended method for calculating the WQF when designing flow diversion structures for off-line stormwater Best Management Practices (BMPs). The WQF is also used for the design of stormwater BMPs that are sized based on flow rate rather than volume, including grass channels and proprietary stormwater BMPs such as hydrodynamic separators, catch basins inserts, and media filters.

The WQF should be calculated using the design WQV and a modified Runoff Curve Number for small storm events. This method is used to estimate peak discharges for small storm events based on the approach described in Claytor and Schueler (1996).[94] This method is more appropriate than: 1) the traditional Natural Resources Conservation Service (NRCS) Curve Number methods, which are valuable for estimating peak discharge rates for storms greater than 2 inches but can significantly underestimate runoff from small storm events, and 2) the Rational Formula, which should only be used with reliable intensity, duration, and frequency (IDF) tables or curves for the storm and region of interest (Claytor and Schueler, 1996).

The design WQV (either 100% or 50% of the WQV depending on the applicable retention/treatment requirement, as described in Chapter 4), converted to watershed inches, should be substituted for the runoff depth (Q) in the NRCS TR-55 Graphical Peak Discharge Method.

1. Compute the NRCS Runoff Curve Number (CN) using the following equation, or graphically using Figure 2-1 from TR-55 (USDA, 1986)[95] (see Figure 1 below):

$$CN = \frac{1000}{\left[10 + 5P + 10Q - 10 * (Q^2 + 1.25 * Q * P)^{1/2}\right]}$$

where:

CN = Runoff Curve Number

[94] Claytor, R. and T. Schueler. 1996. Design of Stormwater Filtering Systems. Center for Watershed Protection. Ellicott City, MD.

[95] Soil Conservation Service. 1986. Urban Hydrology for Small Watersheds. USDA Soil Conservation Service Technical Release No. 55. Washington, D.C.

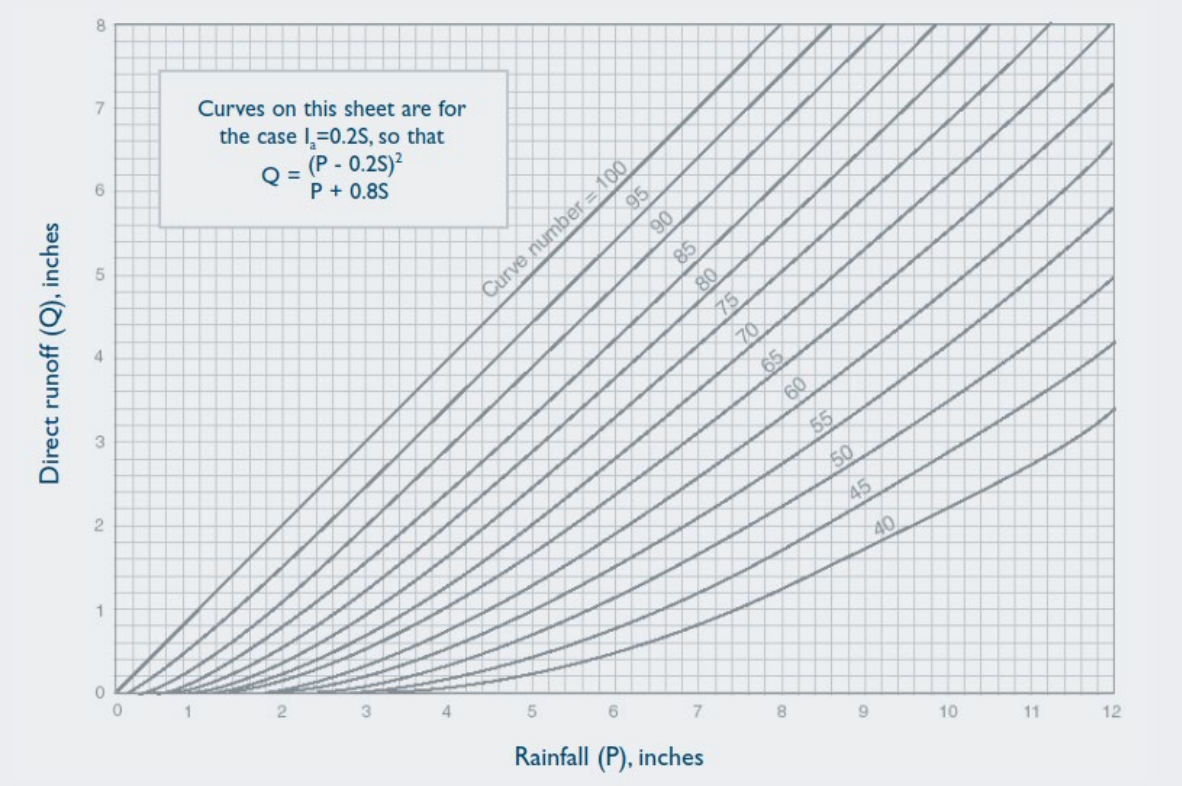
P = Design precipitation, inches (1.3 inches[96] for 100% of the WQV and 0.65 inches for 50% of the WQV)
Q = Runoff depth (in watershed inches)

$$Q = \frac{WQV\ (cubic\ feet)}{Drainage\ Area\ (acres)} * \frac{12\ inches}{foot} * \frac{acre}{43{,}560\ square\ feet}$$

where:

WQV = design Water Quality Volume (100% or 50% of the WQV)

Figure 1. Graphical Solution of Runoff Equation



Source: Figure 2-1 from TR55 (USDA, 1986).

Once the modified CN is calculated, either follow Steps 2 and 3 below or use a stormwater hydrologic/hydraulic model (e.g., HydroCAD or similar software) to calculate peak discharge (WQF). **This modified CN must be used when using a stormwater hydrologic/hydraulic model or analysis method to calculate the WQF.**

[96] Per NOAA Atlas 14, Upon the release of the next generations of this product the most recent value should be used.

2. Compute the time of concentration (t_c) based on the methods described in Chapter 3 of TR-55. A minimum value of 0.167 hours (10 minutes) should be used. For sheet flow, the flow path should not be longer than 100 feet.

3. Using the computed *CN*, t_c, and drainage area (A) in acres, compute the peak discharge for the design water quality storm (i.e., WQF) as follows, which is based on the procedures described in Chapter 4 of TR-55:

    - Read initial abstraction (I_a) from Table 4-1 in Chapter 4 of TR-55 (see Figure 2 below); compute I_a/P (P = 1.3 inches for 100% of the WQV and 0.65 inches for 50% of the WQV).

Figure 2. Initial Abstraction (I_a) Values for Runoff Curve Numbers

Curve number	I_a (in)	Curve number	I_a (in)	Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	55	1.636	70	0.857	85	0.353
41	2.878	56	1.571	71	0.817	86	0.326
42	2.762	57	1.509	72	0.778	87	0.299
43	2.651	58	1.448	73	0.740	88	0.273
44	2.545	59	1.390	74	0.703	89	0.247
45	2.444	60	1.333	75	0.667	90	0.222
46	2.348	61	1.279	76	0.632	91	0.198
47	2.255	62	1.226	77	0.597	92	0.174
48	2.167	63	1.175	78	0.564	93	0.151
49	2.082	64	1.125	79	0.532	94	0.128
50	2.000	65	1.077	80	0.500	95	0.105
51	1.922	66	1.030	81	0.469	96	0.083
52	1.846	67	0.985	82	0.439	97	0.062
53	1.774	68	0.941	83	0.410	98	0.041
54	1.704	69	0.899	84	0.381		

Source: Table 4-1 in Chapter 4 of TR-55 (USDA, 1986).

    - Read the unit peak discharge (q_u) from Exhibit 4-III in Chapter 4 of TR-55 (see Figure 3 below) for the appropriate t_c.

    Note: NRCS has not developed unit peak discharge curves for the NOAA Atlas 14 rainfall distributions, including the NOAA_D rainfall distribution, which has replaced the NRCS Type III distribution for use in Connecticut for peak flow rate calculations (see Chapter 4 of this Manual). The NRCS Type III rainfall distribution may be used for calculating the WQF using the TR-55 Graphical Peak Discharge method. The NOAA_D rainfall distribution is slightly less intense than the NRCS Type III distribution, so the resulting peak discharge will be conservative. The NOAA_D rainfall distribution should be used for calculating peak flow rates associated with stormwater quantity control design storms (2-year, 10-year, and 100-year, 24-hour events) described in Chapter 4.

    - Substituting the design WQV, converted to watershed inches, for runoff depth (Q), compute the WQF from the following equation:

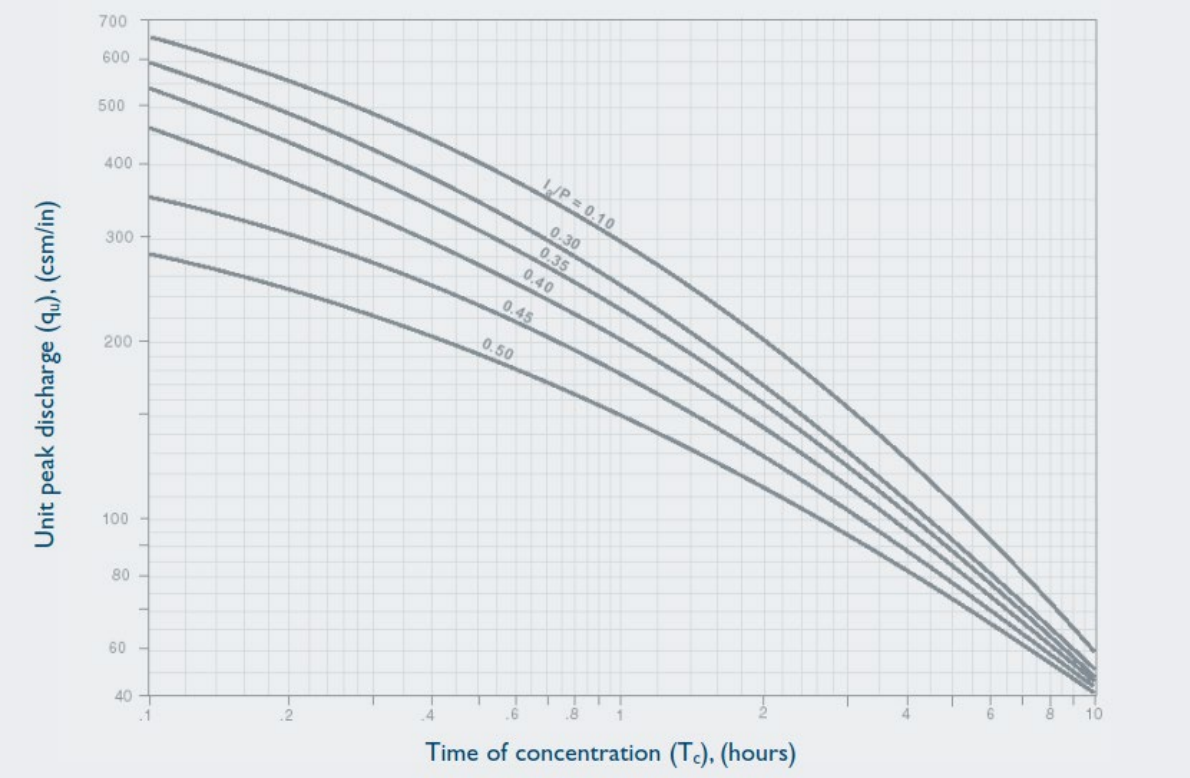
$$WQF = (q_u)(A)(Q)$$

where:

WQF = Water Quality Flow (cubic feet per second, cfs)
q_u = unit peak discharge (cfs, per square mile, per inch of runoff, csm/in)
A = drainage area (square miles)
Q = runoff depth (in watershed inches)

$$Q = \frac{WQV\ (cubic\ feet)}{Drainage\ Area\ (acres)} * \frac{12\ inches}{foot} * \frac{acre}{43{,}560\ square\ feet}$$

Figure 3. Unit Peak Discharge for NRCS Type III Rainfall Distribution



Source: Exhibit 4-III in Chapter 4 of TR-55 (USDA, 1986).

Appendix E – Stormwater Management Plan Checklist

Stormwater Management Plan Checklist

Title of Plan Reviewed: _____

Reviewer Name: _____ Review Date: _____

Completeness Summary

Section	Completed?	Notes
Report		
Summary of Compliance		
Design Calculations		
Design Drawings		
Soil Erosion & Sediment Control Plan		
Operations & Maintenance Plan		
Other Supporting Documents		

Detailed Checklist by Section

Report: General & Summary Information

Section		Completed?	Notes
General	Applicant Name		
	Applicant Address		
	Applicant Contact Information		
	Site Location Address/Information		
	Site Location Map		
	Current Use and Zoning of Property		
	Proposed Use of Project		
Summary	Project Description and Purpose		
	Project Schedule (Include phasing if applicable)		
	Applicable Permits and Approvals		
	Applicable Regulation Requirements		

Report: Existing Conditions

	Section	Completed?	Notes
Existing Conditions	Site area, ground cover, vegetation, existing development features (roads, buildings, utilities, septic systems, etc.)		
	Site topography (2-foot contours based on aerial or field survey), slopes, drainage patterns, drainage systems, drainage areas, and stormwater discharge locations		
	Existing impervious area and DCIA		
	On-site and adjacent waterbody information ➢ Water quality classifications Water quality impairments and Total Maximum Daily Loads		
	Site soils as identified by USDA NRCS mapping or soil scientist ➢ Soil types Hydrologic Soil Groups		
	Soil evaluation results ➢ Initial screening information ○ Test pits and soil borings results (i.e., USDA soil textural class, depth to bedrock, depth to seasonal high groundwater, and Significant subsurface or geologic features) Field infiltration (if applicable)		
	Other site constraints (i.e., site contamination)		
	On-site and off-site critical resources[97] ➢ Inland wetlands and watercourses, tidal wetlands, and associated regulatory setbacks ➢ Streams ➢ Lakes/ponds ➢ Vernal pools ➢ Coastal waters (Connecticut Coastal Jurisdiction Line) ➢ Coldwater streams ➢ Drinking water supply areas ➢ Tree canopy ➢ Steep slopes (≥25%) Conservation easement areas		
	Locations of 100-year floodplain, floodway, and flood elevations from current FEMA mapping		
	Land uses and development adjacent to the site		

[97] Watershed scale map with the site boundaries identified and these attributes identified is preferable.

Report: Proposed Conditions

Section		Completed?	Notes
Proposed Conditions	Type of project or activity (new development, redevelopment, linear project, retrofit)		
	Proposed ground cover, vegetation, development features (roads, buildings, utilities, septic systems, etc.)		
	Proposed drainage area boundaries and design points		
	Proposed activities classified as Land Uses with Higher Potential Pollutant Loads (LUHPPLs)		
	Proposed impervious area and DCIA		
	Proposed area of land disturbance		
	Coastal Jurisdiction Line (CJL) for properties fronting coastal, tidal, or navigable waters		

Report: Applicable Stormwater Management Standards

Section		Completed?	Notes
Stormwater Management Standard	Standard 1 – Runoff Volume and Pollutant Reduction ➢ LID Site Planning and Design ➢ Stormwater Retention and Treatment		
	Standard 2 – Stormwater Runoff Quantity Control ➢ Design Storm Rainfall Depth and Distribution ➢ Peak Runoff Attenuation ➢ Conveyance Protection ➢ Emergency Outlet Sizing		

Report: Proposed LID Site Planning

	Section	Completed?	Notes
Proposed LID Strategies	Avoided Impacts ➢ Minimizing Soil Compaction ➢ Minimizing Site Disturbance ➢ Protecting Sensitive Natural Areas ➢ Preserving Vegetated Buffers ➢ Avoiding Disturbance of Steep Slopes ➢ Siting on Permeable and Erodible Soils ➢ Protecting Natural Flow Pathways ➢ Conservation and Compact Development		
	Reduced Impacts ➢ Reducing Impervious Surfaces (Roads, Cul-de-sacs, Sidewalks, Driveways, Buildings, Parking Lots) ➢ Preserving Pre-development Time of Concentration ➢ Use of Low Maintenance Landscaping		
	Managed Impacts at the Source ➢ Disconnecting Impervious Surfaces - Impervious Area (Simple) Disconnection ➢ Conversion of Impervious Areas to Pervious Areas ➢ Source Controls		

Report: Proposed Structural Stormwater BMPs

	Section	Completed?	Notes
Proposed Stormwater BMPs	Description of proposed structural stormwater BMPs and why they were selected ➢ Location, size, types by drainage area/design point ➢ Design criteria		

Summary of Compliance: Standard 1

	Section	Completed ?	Notes
Standard 1 - Runoff Volume and Pollutant Reductions	LID Site Planning and Design ➢ LID Site Planning and Design Opportunities and Constraints Plan ➢ Completed LID Site Planning and Design Checklist ➢ Total LID Site Planning and Design credits and DCIA reduction		
	Stormwater Retention and Treatment ➢ Impervious area and Directly Connected Impervious Area (DCIA) ➢ Retention and Treatment Required ○ Water Quality Volume and Water Quality Flow ○ Required Retention Volume ➢ Retention and Treatment Provided including Maximum Extent Achievable Documentation ○ Explanation of site limitations ○ Description of the stormwater retention practices implemented ○ Explanation of why this constitutes the Maximum Extent Achievable ○ Alternate retention volume ○ Description of measures used to provide additional stormwater treatment without retention ○ Use of EPA stormwater BMP performance curves to demonstrate compliance with required average annual pollutant load reductions		

Summary of Compliance: Standard 2

	Section	Completed?	Notes
Standard 2 - Stormwater Runoff Quantity Control	Design Storm Rainfall Depth and Distribution		
	Comparison of pre- and post-development ➢ Runoff volume and peak flow rate ○ 2-year, 10-year, and 100-year, 24-hour storms		
	Downstream Analysis: Comparison of pre- and post-development peak flows, velocities, and hydraulic effects at critical downstream locations (stream confluences, culverts, other channel constrictions, and flood-prone areas) to the confluence point where the 10 percent rule applies		
	Conveyance Protection		
	Emergency Outlet Sizing		

Design Calculations: Standard 1

	Section	Completed?	Notes
Standard 1 - Runoff Volume and Pollutant Reduction	LID Site Planning and Design Credit Calculations		
	Impervious Area and Directly Connected Impervious Area (DCIA)		
	Water Quality Volume, Water Quality Flow, and Required Retention Volume		
	Structural Stormwater BMP Sizing Calculations ➢ Static and dynamic sizing methods (infiltration systems) ➢ Drain time and groundwater mounding analysis (infiltration systems) ➢ Required versus provided design volumes Pollutant specific load reductions (BMP performance curves) where Standard 1 cannot be met by retention alone		

Design Calculations: Standard 2

	Section	Completed?	Notes
Standard 2 - Stormwater Runoff Quantity Control	Stormwater Runoff Calculations for Pre-Development and Post-Development (with and without stormwater BMPs) Conditions ➢ Design storm depth and duration, recurrence interval, and rainfall distribution ➢ Runoff volume and peak flow rate (2-year, 10-year, and 100-year, 24-hour storms) ➢ Runoff Curve Number ➢ Time of Concentration (and associated flow paths)		
	Routing analysis for proposed stormwater BMPs including drainage routing diagram		
	Conveyance protection (including flow velocity calculations and outlet protection sizing) and emergency outlet sizing calculations		
	Downstream analysis hydrograph routing calculations		
	Storm drain system conveyance calculations		

Design Drawings: Existing Conditions

Section		Completed?	Notes
Existing (Pre-Development) Conditions Plan	Location of existing man-made features on or adjacent to the site, such as roads, buildings, driveways, parking areas, other impervious surfaces, drainage systems, utilities, easements, septic systems, etc.		
	Surveyed locations of property boundaries and easements		
	Drainage systems and sanitary sewers should include rim and invert elevations of all structures and sizes and connectivity of all pipes		
	Vegetative communities on the site, including locations of tree canopy		
	Site topography (2-foot contours based on aerial or field survey), slopes, drainage patterns, conveyances systems (swales, storm drains, etc.), drainage area boundaries, flow paths, times of concentration		
	Locations of existing stormwater discharges		
	Areas of steep (25% or greater) slopes		
	Perennial and intermittent streams		
	Inland wetlands and watercourses (and associated regulatory setbacks) as defined by a soil scientist in the field and flags located by a licensed land surveyor		
	Locations of vernal pools		
	Locations of 100-year floodplain, floodway, and flood elevations from current FEMA mapping		
	Locations of soil types as identified by USDA NRCS mapping or soil scientist, test pit and soil boring locations, and field infiltration testing locations		
	Areas of site contamination		
	Location, size, type of existing structural stormwater BMPs and conveyance systems		
	Limits of developable area based on site development constraints		
	Coastal Jurisdiction Line (CJL) for properties fronting coastal, tidal, or navigable waters		

Design Drawings: Proposed Conditions

	Section	Completed?	Notes
Proposed (Post-Development) Conditions Plan	Location of proposed man-made features on or adjacent to the site such as roads, buildings, driveways, parking areas, other impervious surfaces, drainage systems, utilities, easements, septic systems, etc.		
	Surveyed locations of property boundaries and easements		
	Drainage systems and sanitary sewers should include rim and invert elevations of all structures and sizes and connectivity of all pipes		
	Vegetative communities on the site, including proposed limits of clearing and disturbance		
	Site topography (2-foot contours based on aerial or field survey), slopes, drainage patterns, conveyances systems (swales, storm drains, etc.), drainage area boundaries, flow paths, times of concentration		
	Locations of proposed stormwater discharges/design points		
	Perennial and intermittent streams		
	Inland wetlands and watercourses (and associated regulatory setbacks) as defined by a soil scientist in the field and flags located by a licensed land surveyor		
	Locations of vernal pools		
	Locations of 100-year floodplain, floodway, and flood elevations from current FEMA mapping		
	Locations and results of on-site soil evaluation (test pits/soil borings and field infiltration testing)		
	Areas of site contamination		
	Development envelope and areas of site preserved in natural condition		
	Location, size, type of proposed structural stormwater BMPs and conveyance systems. Structural BMPs should have rim, invert, and contour elevations and pipe sizes and construction material.		
	Locations of soil erosion and sedimentation controls		
	Locations of non-structural source controls		
	LID Site Planning and Design Opportunities and Constraints Plan		
	Structural Stormwater BMP Design Details and Notes		
	Coastal Jurisdiction Line (CJL) for properties fronting coastal, tidal, or navigable waters		

Other Plans

	Section	Completed?	Notes
Soil Erosion & Sediment Control Plan	See the Soil Erosion and Sediment Control Guidelines https://portal.ct.gov/DEEP/Water/Soil-Erosion-and-Sediment-Control-Guidelines/Guidelines-for-Soil-Erosion-and-Sediment-Control		
Operation & Maintenance Plan	Detailed inspection and maintenance requirements/tasks		
	Inspection and maintenance schedules		
	Parties legally responsible for maintenance (name, address, and telephone number)		
	Provisions for financing of operation and maintenance activities		
	As-built plans of completed structures		
	Letter of compliance from the designer		
	Post-construction documentation to demonstrate compliance with maintenance activities		
	Other considerations if needed		

Other Supporting Documents

Section		Completed?	Notes
Other Supporting Documents	Completed Stormwater Management Plan Checklist		
	LID Site Planning and Design Checklist (Chapter 5 – Low Impact Development Site Planning and Design Strategies)		
	NRCS Soils Mapping		
	Soil Evaluation Documentation (Test Pits/Soil Borings and Field Infiltration Testing Results)		
	DCIA Tracking Worksheet required by the reviewing authority to satisfy MS4 Permit requirements		
	Groundwater impacts for proposed infiltration structures		
	Reports on wetlands and other surface waters (including available information such as Maximum Contaminant Levels [MCLs], Total Maximum Daily Loads [TMDLs], 303(d) or 305(b) impaired waters listings, etc.)		
	Water quality impacts to receiving waters		
	Water quality impacts to receiving waters		
	Impacts on biological populations/ecological communities including fish, wildlife (vertebrates and invertebrates), and vegetation		
	Flood study/calculations		
	Other permits and approvals issued for the project		

Appendix F – Planting Guide

Summary

This appendix provides an overview of planting considerations for structural stormwater Best Management Practices (BMPs), with the goal of selecting plants that are well-suited for a specific design and site. This planting guide provides information on incorporating native plantings that are well-adapted to site conditions and plants that are most tolerant to site limitations. The guidance also includes several examples of planting pallets to meet aesthetic and functional goals.

Maintenance and Care Considerations

As with any element of a stormwater BMP, plantings require maintenance and care. This care can be simplified with careful consideration of planting needs. The following key concepts can help ensure success, reduce maintenance needs, and create an aesthetically pleasing stormwater BMP:

- **Planting schedule.** Newly established trees will be stressed when planting in high heat and low water conditions, while many perennials will be stressed by a late frost.
- **Planting methods.** There are some simple tricks of the trade to help plantings become more self-sufficient. For example, coercing some tree roots to grow deeper into soils by setting up a system for deep watering rather than surface watering.
- **Intercropping.** While the term intercropping primarily applies to large-scale agriculture, the principles can be applied to any garden or landscaping. Planting nitrogen fixers can reduce fertilization needs or improve poor soil, and planting ground covers can reduce erosion, weeding and watering needs, and more.
- **Planting Tolerance.** Each plant has an ability or limited ability to handle various chemicals, moisture, and temperature extremes. The simplest way to address this is to implement native plants well-conditioned to the site conditions.

Each of these concepts is described in greater detail in the sections below, including additional resources to find further information. In addition to being strategic with site design to minimize maintenance, there are also methods to make maintenance of plantings easier. The table below outlines routine maintenance needs and some considerations to make maintenance easier.

Maintenance Consideration	Frequency	Level of Expertise Required	Other Tips
Watering	Initial planting may need more frequent watering (i.e., weekly or every other week).	None	➢ Training roots to grow deep with underground watering can make your planting less dependent on your efforts. ➢ Mulching and setting drip lines beneath (avoiding top watering) can help reduce waste to evapotranspiration and make each watering more efficient. ➢ Timing planting during shoulder seasons where rain is more likely to occur can reduce watering needs. ➢ Companion planting with ground cover can help reduce evaporation much like mulching.
Weeding & Trash Removal	Trash removal is location dependent. Weeding typically will need to be monthly but can be strategically reduced see column to right.	Minimal knowledge of weeds versus desirable plantings.	➢ Some traditional weeds can be beneficial neighbors, consider allowing those that do provide benefits to your planting to sustain and only eliminate those that may be damaging to your site, such as an invasive like bittersweet. ➢ Mulching and ground cover can reduce the need to frequently weed and water
Fertilization	Annual	Some gardening knowledge. Fertilizer should only be used in quantities necessary for specific plantings.	➢ Timing with optimal weather conditions can limit run off and root burn. ➢ Companion planting can reduce fertilization needs, see the plant list below.
Structure Stabilization	Annual /Additional as needed per storm frequency	Some knowledge in landscape design (or engineering if design is complex)	➢ Cover crops can help stabilize sloping sides and reduce maintenance needs.
Soil Health	Project start and as needed (if needed).	Minimal knowledge needed if test is sent to a lab.[98]	

[98] Connecticut Agriculture Experiment Station offers free soil testing to Connecticut residents.

Safety Consideration

Before beginning construction of any kind, one must assure the safety of those involved in site construction as well as long-term maintenance of the site including stormwater management measures. Consider access for maintenance – what are the risks at the site and can they be mitigated? Consider what may lay below ground at the site. Anyone using power or mechanized equipment who disturbs the earth on or below the surface must call the clearinghouse for a location request. You must call for a locate request at least two full working days but not more than 30 days before any excavation starts excluding holidays & weekends). There are two ways to access this free service:

1. File an online e-ticket at https://www.cbyd.com/
2. Call 811

Planting Selection

When selecting plants, the primary considerations are the local environmental factors and the intended function of the site. When considering these factors, also account for the conditions that the proposed stormwater BMP will create as well as the natural landscape around the site. Below is a list of essentials and potential site considerations:

- **USDA Plant Hardiness Zone.** This is the standard by which landscapers, gardeners, and homeowners can determine which plants will survive at a given location.
- **Frequency of flooding,** whether creating an intentionally planted wet area like a stormwater pond/wetland or evaluating the natural tendency for the site to flood. Not all plants will tolerate flooding; as such, consider the flooding characteristics of the site in addition to the hydrologic conditions that are needed for a specific type of stormwater BMP.
- **Soil Health.** Soil health plays an important role in planting success. If at all possible, limiting the disturbance of the top organic layer is optimal. When this is not possible, there are many plants that can tolerate differing levels of soil quality.
- **Site stabilization.** Consider the effectiveness for the proposed plantings to provide site stabilization. Cover crops and plants with deeper root structure can often function and survive better than many other species.
- **Salinity.** Considering salt tolerance of plant species can mean the difference between a self-sustaining landscape and costly replantings in many sites near roads and sidewalks or coastal sites.
- **Pollutants of concern.** Many plant species are particularly adapted to filtration of particular pollutants and have even been utilized at contaminated sites for these qualities. Knowing the specific potential pollutants of a site will help select plants for optimal

pollutant removal. EPA's Phytoremediation Guide provides a helpful consolidation of phytoremediation resources.

- **Sun Exposure.** Different plant species have differing needs for sunlight. Consider the sun exposure of the site and if the site is to include trees or shrubs that will introduce shading.

In addition to considering site environmental conditions, plant diversity is key to successful functioning and reduced maintenance. A monoculture is far more susceptible to disease and pests and can be more costly in the long run. Plant diversity can provide additional benefits by ensuring a healthier pollinator population, better site stabilization, and less maintenance and fertilization (see the section below on planting companions intercropping for further information). It is also important to avoid introducing invasive species and, where possible, restricting plant selection to native species to help retain diverse, productive landscaping.

As noted above, when developing planting plans choosing plants that can tolerate and thrive in similar or complementary conditions (i.e., shade tolerant plants that will survive beneath shade of tree, or sets of wet tolerant plants for sites like stormwater ponds/wetlands) is necessary for success of the design. There is a plethora of plant databases that provide detailed plant needs, planting instructions, and native status. This authors of this Manual have reviewed and recommend the following to obtain reliable up-to-date information:

- https://plants.usda.gov/
- https://plantdatabase.uconn.edu/
- https://can-plant.ca/ecommerce/woody-plants
- https://plants.ces.ncsu.edu/plants
- https://www.arborday.org/trees/treeguide
- https://www.fs.usda.gov/treesearch/
- https://www.conncoll.edu/the-arboretum/ecological-landscaping/
- https://wetland-plants.sec.usace.army.mil/nwpl_static/v34/home/home.html
- https://www.ct-botanical-society.org/gardening-with-natives/

The additional resources below provide further information for function-specific design and specific maintenance guidance.

- https://nemo.uconn.edu/raingardens/
- https://ct.audubon.org/conservation/plant-native-species
- https://portal.ct.gov/DEEP/Invasive-Species/Invasive-Species
- https://cipwg.uconn.edu/
- https://www.pollinator.org/guides
- https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5368392.pdf
- https://www.conncoll.edu/the-arboretum/ecological-landscaping/
- https://www.wildflower.org/plants/index.php
- https://www.pca.state.mn.us/sites/default/files/pfsd-section2.pdf
- http://www.newmoonnursery.com/plan

- https://cipwg.uconn.edu/wp-content/uploads/sites/244/2013/12/CTCoastal_planting.pdf

Intercropping & Planting Companions

As noted above, the term "intercropping" is typically used in the context of large-scale agriculture, but intercropping principles can be applied to any garden or functional landscaping including stormwater BMPs. "Planting companions" is a more popular term with landscaping and small scale-gardening and can be incredibly useful but can also lead to a variety of unconfirmed sources and information that may be too experimental for the purposes of users of this Manual. Therefore, the focus of this section highlights how intercropping can be beneficial to landscaping/gardening and for stormwater BMPs. As noted by Oliver Duchene et al.:

> *"Intercropping is a powerful way to promote a more diversified plant community in the field, thereby enabling complementary and facilitative relationships."* [99]

Enabling the complementary and facilitative relationships can aid in reducing costs, maintenance needs, increase survivorship of plantings, increase biodiversity, and more. This co-beneficial partnership of plants, while a modern application to commercial farming and government guidance, is far from new knowledge that can be credited to First Nations all around the America's but even right those right here in the Northeast.[100, 101] As such, these practices are not only beneficial financially and sustainably, but also culturally. Some of the key benefits of intercropping with regards to stormwater control are:

- **Attracting Pollinators.** Providing pollinator pathways through landscaping can be aesthetic and provide the additional support needed to assure success of pollinator populations. Even simple actions like allowing for dandelions, clovers and other species commonly found in New England Lawns can be beneficial for pollinators.[102, 103]

- **Deterring or Distracting Pests.** Introducing plants that are either attractive to pests to keep them from your preferred plants or plants that will naturally deter pests can be an

[99] Duchene, Olivier, Vian, Jean-François, and Celette, Florian. legume for agroecological cropping systems: Complementarity and facilitation processes and the importance of soil microorganisms. A review. Agriculture, Ecosystem and Environment. 240,149-616 (2017) https://doi.org/10.1016/j.agee.2017.02.019

[100] Kimmerer,R.W. Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants. Milkweed Editions October 2013.

[101] Kimmerer, R. W Native Knowledge for Native Ecosystems. Journal of Forestry. 98(8):4-9 (2000)

[102] Gathof, A.K., Grossmann, A.J., Herrmann, J. *et al.* Who can pass the urban filter? A multi-taxon approach to disentangle pollinator trait–environmental relationships. *Oecologia* 199, 165–179 (2022). https://doi.org/10.1007/s00442-022-05174-z

[103] https://www.pollinator-pathway.org/about

effective and cost reducing approach. Common Yarrow is a good example, as it will attract insects that are predators to aphids[104, 105] and deter other pests such as mosquitoes.[106]

- **Reducing Watering Needs.** The physical structure of some plants' growing habits can be beneficial. Ground covers can reduce evapotranspiration and runoff and increase infiltration into the soil surrounding other plantings. By reducing the water loss, scheduled waterings can be significantly reduced if not even eliminated in many cases. Several studies have noted reduced water stress and even instances of negating the impacts of arid conditions when utilizing ground cover crops interplanted among the desired plantings.[107, 108, 109]

- **Reducing Fertilization Needs.** Nitrogen is necessary for plant growth but is often applied in such a way that is causes water quality problems. Including plants that are efficient nitrogen fixers can greatly reduce the need for synthetic or fossil-based fertilizer. One study found that this practice, if applied to the world's grain legumes, could reduce the global (for all uses) requirements for fossil-based fertilizers by 26%.[110] Many plants, grasses

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[104] Torsten Meiners, Elisabeth Obermaier, Hide and seek on two spatial scales – vegetation structure effects herbivore oviposition and egg parasitism, *Basic and Applied Ecology*, Volume 5, Issue 1, 2004, Pages 87-94, https://doi.org/10.1078/1439-1791-00182

[105] N. J. Bostanian ,H. Goulet,J. O'Hara,L. Masner &G. Racette Intercropping with Towards Insecticide Free Apple Orchards: Flowering Plants to Attract Beneficial Arthropods. *Bioscience Control and Technology*. Volume 14: Issue 1, 2003, Pages 25-37 https://doi.org/10.1080/09583150310001606570

[106] Jaenson TG, Pålsson K, Borg-Karlson AK. Evaluation of extracts and oils of mosquito (Diptera: Culicidae) repellent plants from Sweden and Guinea-Bissau. *J Med Entomol.*;43(1), Pages 113-9. 2003 https://doi.org/10.1093/jmedent/43.1.113

[107]Nelson, William C. D., Hoffmann, Munir P., Vadez, Vincent, Rötter, Reimund P., Koch, Marian and Whitbread, Anthony M. Can intercropping be an adaptation to drought? A model-based analysis for pearl millet–cowpea. *Journal of Agronomy and Crop Science*. 00, Pages 1-18, 2021 https://onlinelibrary.wiley.com/doi/epdf/10.1111/jac.12552

[108] Baker, Sophie, "Intercropping for Water Conservation: Environmental and Economic Implications of a Sustainable Farming Practice in California's Central Valley" (2020). Scripps Senior Theses. 1583. https://scholarship.claremont.edu/scripps_theses/1583

[109] Nyawade, S.O., Karanja, N.N., Gachene, C.K.K. *et al.* Intercropping Optimizes Soil Temperature and Increases Crop Water Productivity and Radiation Use Efficiency of Rainfed Potato. *Am. J. Potato Res.* 96, 457–471 (2019). https://doi.org/10.1007/s12230-019-09737-4

[110] Jensen, E.S., Carlsson, G. & Hauggaard-Nielsen, H. Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. Agron. Sustain. Dev. 40, 5 (2020). https://doi.org/10.1007/s13593-020-0607-x

and trees have associative relationships with nitrogen fixing bacteria, like clover, switch grass and grey alder, that can provide beneficial nitrogen inputs into the soils.[111, 112]

- **Increasing Biodiversity.** Biodiversity is not only increased by directly diversifying the plant species, but also increases the biodiversity of soil microbes and pest predators in certain conditions.[113, 114]

Planting Palette Examples

Utilizing these principles outlined in this appendix, four planting palette guides are provided in this section for vegetated stormwater BMPs. Designers should use these planting palette guides as determined appropriate and applicable for a given site. These palettes are not exhaustive and are only provided here as examples.

The planting palette guides are guided checklists intended to meet a variety of site needs, including low-maintenance and, where needed, salt-tolerant vegetation. The examples provided in these palette guides are limited to native plants, which are preferred wherever practicable. If non-native species are used, careful and thorough research is required to ensure that invasive species are not introduced. These palettes also include pollinators to support biodiversity and improve the ecosystem by cleaning air, purifying water and soil, and preventing erosion. Note that these palettes are provided as a starting point; it is the ultimate responsibility of the designer to select vegetation that is suited for the project location. Additional and more specific planting palettes that may be useful can be found in the RIDOT Linear Stormwater Manual.

[111] Roley SS, Duncan DS, Liang D, Garoutte A, Jackson RD, Tiedje JM, Robertson GP. Associative nitrogen fixation (ANF) in switchgrass (Panicum virgatum) across a nitrogen input gradient. PLoS One. 13(6), (2018) https://doi.org/10.1371/journal.pone.0197320

[112] Nancy A. Eckardt and David D. Biesboer. Ecological aspects of nitrogen fixation (acetylene reduction) associated with plants of a Minnesota wetland community. Canadian Journal of Botany. 66(7): 1359-1363. https://doi.org/10.1139/b88-190

[113] Viviana Alarcón-Segura, Ingo Grass, Gunnar Breustedt, Marko Rohlfs, Teja Tscharntke. Strip intercropping of wheat and oilseed rape enhances biodiversity and biological pest control in a conventionally managed farm scenario. Journal of Applied Ecology. 59 (6) pages 1513-1523. https://doi.org/10.1111/1365-2664.14161

[114] Lian T, Mu Y, Jin J, Ma Q, Cheng Y, Cai Z, Nian H. Impact of intercropping on the coupling between soil microbial community structure, activity, and nutrient-use efficiencies. PeerJ. 8 (7) (2019). https://doi.org/10.7717/peerj.6412

Figure A-1. Planting Palette Example A

Location Suitability	**Legend** Sunny; Partly Shaded; Directly Adjacent to Roadways; Wet Areas						
BMP Suitability	Dry Water Quality Swale	Dry Extended Detention Basin	Stormwater Pond	Bioretention	Infiltration Trench	Infiltration Basin	Filter Strip

Plant Photo	Name	Attributes		Notes
	Ceanothus americanus, New Jersey Tea	• Nitrogen fixing • Can grow nutritionally poor soils • Beneficial for pollinators & wildlife • Quick to establish	• Salt tolerant • Deep roots provide good erosion control • Drought tolerant • Best for upland zone • Prefers well drained soils	Spacing 4-5 Feet
	Lobielia cardinalis, Cardinal Flower	• Prefers Wet to Moist Soil • Best for Wet meadow, Emergent or Submergent Zones	• Somewhat tolerant of salt and urban pollution	Spacing 18- 24 inches
	Juncus tenuis, Path Rush	• Drought and flooding tolerant • Tolerant of compacted soils • Moderately tolerant of salt • Nitrogen fixing	• Good for nesting birds • Good cover crop to reduce weeding needs • Deer Resistant	Spacing 12 inches
	Asclepias tuberosa, Butterfly Weed	• Beneficial for pollinators • Drought tolerant • Best for upland zone • Moderate salt tolerance	• Deer resistant • Best to seed in fall	Spacing 18-24 inches
	Coreopsis tinctoria Nutt, Golden Tickseed	• Beneficial for Pollinators • Flooding tolerant prefers moist soil • Best for wet meadow and emergent zones	• Moderate salt tolerance	Sow at least 2 lb of pure live seed per acre

Figure A-2. Planting Palette Example B

Location Suitability	**Legend** Sunny	Partly Shaded	Directly Adjacent to Roadways	Wet Areas		
BMP Suitability	Stormwater Pond	Bioretention	Infiltration Trench		Infiltration Basin	Filter Strip

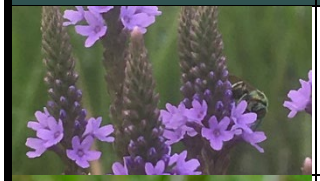
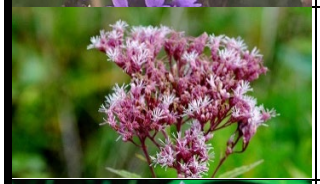
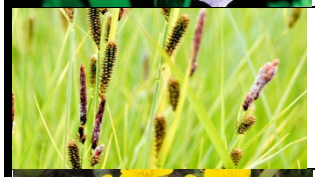
Plant Photo	Name	Attributes		Notes
	*Verbena hastata,* Swamp Verbena	• Livestock will not eat • Beneficial for pollinators • Quick to establish • Prefers wet to moist soil	• Best for wet meadow, emergent or submergent zones • Moderate salt tolerance • Nitrogen fixing	Spacing 12-24 inches
	*Eupatorium maculatum,* Spotted Joe Pye Weed	• Prefers wet to moist soil • Best for wet meadow, emergent or submergent zones • Prefers sandy soils but will grow in non-sandy wetlands	• Beneficial for pollinators • Drought tolerant • Fibrous roots can make it ideal for erosion control	Spacing: 4-5 feet on center
	Iris versicolor, Harlequin Blueflag	• Preference for acidic soils • Good filter of excess nutrients • Deer resistant • In wet soils will thrive without fertilizer • Wet to moist soils	• Best for wet meadow, emergent or submergent zones • Roots can be good erosion control	Spacing 2-3 Feet
	*Carex stricta,* Tussock Sedge	• Drought tolerant for short periods • Prefers standing water or moist soils • Deer resistant	• Nitrogen Fixing • Best for wet meadow, emergent or submergent zones • Good filter for water clarity	Spacing 1-3 Feet
	Caltha palustris, Marsh Marigold	• Beneficial for pollinators • Flooding tolerant, prefers moist soil • Best for wet meadow and emergent zones • Deer resistant	• High salt tolerance • Alkaline tolerant • Beneficial for wood ducks • Good ground cover	Spacing 12 inches

Figure A-3. Planting Palette Example C

Location Suitability		**Legend** Sunny; Partly Shaded; Directly Adjacent to Roadways; Wet Areas	
BMP Suitability	Bioretention	Dry Extended Detention Basin	
Plant Photo	**Name**	**Attributes**	**Notes**
	Cercis canadensis L. Eastern Redbud	• Provides flowers in early spring • Tolerates a wide range of pH but will grow best in alkaline soils • Grows deep tap root in first few years if conditions are conducive • Rounded vase shape provides good summer shade • Known to be wind and ice tolerant • Not salt tolerant • Drought tolerant	Spacing 20-30 Feet
	Phlox divaricata L. Wild Blue Phlox	• Beneficial for pollinators • Good ground cover • Tolerant of wide range of soil types and pH • Shade tolerant, good for beneath trees • Drought tolerant • Deer resistant	Spacing 12 inches
	Phlox subulata, Moss Phlox	• Beneficial for Pollinators • Drought tolerant • Deer resistant • Prefers sun • Tolerant of nutrient poor soils • Moderately salt tolerant • Mildly alkaline tolerant • Good ground cover	Spacing 12-24 inches

Photo Sources:
Palette A (Top-Bottom): EPA.GOV via wikicommons, Judy Gallagher, CC BY 2.0 via Wikimedia Commons, Stefan.lefnaer, CC BY-SA 4.0 via wiki commons https://www.conservect.org/product/crccd-butterfly-weed/, https://www.fs.fed.us/wildflowers/plant-of-the-week/coreopsis_tinctoria.shtml
Palette B (Top – Bottom): HLWolfe, CC BY-SA 4.0 via Wikimedia Commons, Joshua Mayer CC BY-SA 2.0 Wikimedia Commons , Government of Quebec via Wikimedia Commons , gmayfield10, CC BY-SA 2.0 , via Wikimedia Commons, Eppu, CC BY 4.0 via Wiki Commons
Palette C (Top-Bottom): Wil540 art, CC BY-SA 4.0 via Wikimedia Commons, Cbaile19, via Wikimedia Commons , Agnieszka Kwiecień, Nova, CC BY-SA 4.0, via Wikimedia Commons

Appendix G – Climate Change Considerations

Overview and Purpose

Climate change (i.e., increasing precipitation and temperature and sea level rise) and its implications for stormwater management design and implementation were important considerations during the revision of this Manual for the following reasons:

- Previous guidance regarding design storm precipitation (e.g., 10-, 25-, and 100-year storms) is no longer relevant due to the shift in climate and precipitation that has been observed since the development of the original Connecticut Stormwater Quality Manual.
- Increasing trends in precipitation also include observed and projected increases in average precipitation amounts, which has implications for smaller, more frequent storms including the water quality storm.
- Rising sea levels have begun and are projected to continue to result in rising groundwater levels in coastal areas of Connecticut and elsewhere along the eastern coast of the United States.[115, 116] Rising groundwater has implications for stormwater infiltration and treatment practices along Connecticut's coast.
- The design life of many stormwater BMPs and related stormwater infrastructure is intended to be well over 20 years. Over this period, it is possible the design limits could be exceeded as a result of changing precipitation conditions, thereby reducing the effectiveness of the stormwater BMP or resulting in failure of the stormwater infrastructure.

This Manual incorporates various climate change and resilience considerations for stormwater management design and implementation:

- Preserving pre-development site hydrology using LID site planning and design strategies and structural stormwater BMPs
- Updated design storm precipitation for stormwater quantity and quality control

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[115] Jasechko, S., Perrone, D., Seybold, H. et al. Groundwater level observations in 250,000 coastal US wells reveal scope of potential seawater intrusion. Nat Commun 11, 3229 (2020). https://doi.org/10.1038/s41467-020-17038-2

[116] Bjerklie, D.M., Mullaney, J.R., Stone, J.R., Skinner, B.J., and Ramlow, M.A., 2012, Preliminary investigation of the effects of sea-level rise on groundwater levels in New Haven, Connecticut: U.S. Geological Survey Open-File Report 2012–1025, 46 p., at http://pubs.usgs.gov/of/2012/1025/.

- Sea level rise and other considerations for stormwater BMP siting and design in coastal areas
- Design considerations for mitigating the potential negative impacts of climate change on stream temperatures and nutrient loads.

This appendix provides additional details regarding climate change and stormwater impacts in Connecticut, including the basis for the selected approach to incorporating updated design storm precipitation and other climate change considerations into this Manual.

Evaluating Design Storm Approaches

Approach

During the development of this Manual, the Workgroup evaluated various approaches to updating design storm precipitation in Connecticut by considering: 1) observed changes in precipitation since the release of the original Connecticut Stormwater Quality Manual in 2004, and 2) potential future changes in precipitation, both for projects designed today and at some point in the future, over the design life of the stormwater infrastructure.

The Workgroup evaluated design storm approaches in stormwater manuals of other states within the region. The Workgroup reviewed these approaches both in terms of current design storm precipitation and consideration of future precipitation and climate change (see Table G-1). It is also important to note that while the current versions of the other state stormwater manuals did not explicitly include consideration of climate change and future precipitation, several states had related guidance on resilient infrastructure design accounting for future climate change (e.g., Resilient MA Action Team guidance documents including Climate Resilience Design Standards and Guidelines Tool, and New Jersey Climate Resiliency Strategy) and several states (Massachusetts and New Hampshire) were in the process of updating their manuals and/or design storm precipitation to account for ongoing and future climate change effects. Furthermore, many states were considering creating a more concrete connection between stormwater management and climate change and actively researching potential avenues to do so. The activities of the Governor's Council on Climate Change and associated policy recommendations, as well as research and precipitation projections developed by the Connecticut Institute for Resilience and Climate Adaptation (CIRCA), were also reviewed to inform the design storm approach for Connecticut and the revised Manual. Based on the stated goals of the Manual update and the Workgroup's review, it was clear that Connecticut's revision of this Manual needed to consider both observed and potential future changes in precipitation as a result of climate change.

Table G-1. Design Storm Precipitation Approaches of State Stormwater Management Programs in the Northeast U.S.

State	Stormwater Quantity Control Design Storm		Water Quality Design Storm and Water Quality Volume
	Consideration for Observed Increase in Design Storm Precipitation Due to Climate Change?	Consideration for Future Increase in Design Storm Precipitation Due to Climate Change?	
Connecticut	No (TP-40)	No	Initial 1 inch of rainfall over contributing drainage area, runoff coefficient approach to calculate runoff
Massachusetts	No (TP-40) Proposed NOAA Atlas 14+ in updated guidance	Yes Proposed NOAA Atlas 14+ in updated guidance	Initial 1 inch of runoff from contributing impervious area
Rhode Island	Yes (NRCC)	No	Same as Massachusetts
New Hampshire	Yes (NRCC)	Updated design storms for climate change is a stated goal of the ongoing manual update	Same as Connecticut
Vermont	Yes (NOAA Atlas 14)	No	Same as Connecticut
Maine	Yes (NRCC)	No	Initial 1 inch of runoff from impervious area plus 0.4 inch of runoff from pervious area
New York	Yes (NRCC)	No	Initial 1 to 1.5 inches of rainfall over contributing drainage area, runoff coefficient approach to calculate runoff
New Jersey	Yes (NOAA Atlas 14)	No	1.25-inch, 2-hour rainfall, rainfall runoff modeling to calculate runoff

TP-40: National Weather Service Technical Paper 40 (out of print, last updated for Connecticut in 1977)

NRCC: Extreme Precipitation in New York and New England, Northeast Regional Climate Center

NOAA Atlas 14: NOAA Atlas 14 Volume 10 Version 3, Precipitation-Frequency Atlas of the United States, Northeastern States. NOAA, National Weather Service, 2015, revised 2019. https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

NOAA Atlas 14+: 90% of the upper limit of the 90th percentile confidence interval (NOAA Atlas 14)

Options Evaluated

Stormwater Quantity Control Design Storm

As described above, the Workgroup evaluated several alternative approaches for updating the stormwater quantity control design storm precipitation (24-hour design storm depths) in the revised Manual (Table G-2).

The first three options in Table G-2 utilize NOAA Atlas 14 values (median, 90% of the upper limit of the 90% confidence interval, or the upper limit of the 90% confidence interval), which are readily available from the NOAA Atlas 14 Precipitation Frequency Data Server web tool. NOAA14+ and NOAA14++ reflect the upper range of current extreme precipitation.

The fourth option in Table G-2 is similar to the approach used by Massachusetts in the RMAT Climate Resilient Design Standards and Guidelines Tool in which downscaled GCM precipitation estimates are used to estimate statewide or regional percent increases to the NOAA Atlas 14 median values. To help evaluate this alternative approach for Connecticut, the Connecticut Institute for Resilience & Climate Adaptation (CIRCA) provided downscaled estimates of 24-hour maximum precipitation for Hartford, New London, Bridgeport, and a statewide ensemble average. Downscaled precipitation estimates were provided for baseline (1970-1999) conditions and mid-century (2040-2069) and late century (2070-2099) future planning horizons, as well as for four different return periods (10-yr, 20-yr, 50-yr, and 100-yr). The estimates were derived using the Multivariate Adaptive Constructed Analogs (MACA) climate downscaling method as described in the Connecticut Physical Climate Science Assessment Report (PCSAR).[117] The NOAA Atlas 14 median values were then multiplied by the ratio of future to baseline statewide average downscaled precipitation estimates to derive estimated future 10-year and 100-year 24-hour rainfall depths. This "NOAA14 Future Downscaled" method accounts for anticipated future increases in precipitation associated with climate change projections, using the relative change in downscaled precipitation as the basis for increasing the NOAA Atlas 14 precipitation frequency estimates.

In addition to 24-hour rainfall depths, the rainfall distribution – how rain falls during a storm event – is also important in calculating the peak flow rates of stormwater runoff. Precipitation events typically begin with a lighter intensity, followed by a period of higher-intensity rainfall, and then gently tapering off. The USDA NRCS developed synthetic rainfall distributions from historical records from the different regions of the country based on the assumption that the rain distribution is bell-shaped. The NRCS rainfall distributions were grouped into four types according to the applicable regions. Type III distributions historically have been used in Connecticut, where tropical storms produce large 24-hour rainfall events.

[117] Connecticut Physical Climate Science Assessment Report (PCSAR), Observed trends and projections of temperature and precipitation, August 2019, Connecticut Institute for Resilience and Climate Adaptation and University of Connecticut Atmospheric Sciences Group.

Table G-2. Alternative Approaches Considered for Updating Stormwater Quantity Control Design Storm Precipitation

Alternative	Description	Advantages	Disadvantages
NOAA Atlas 14	NOAA Atlas 14 (median values)	• Reflects observed increases in precipitation to date (e.g., 2014) • Easy to use - values reported directly from Atlas 14 website • Values already adopted in CT DEEP Stormwater General Permits and by CTDOT	• Does not account for anticipated future increases in precipitation associated with climate change projections
NOAA Atlas 14+	90% of the upper limit of the 90th percentile confidence interval	• Reflects upper range of current expected storms • Generally consistent with anticipated future increases in precipitation associated with climate change projections • Provides greater resilience for infrastructure than NOAA Atlas 14 median values • Larger stormwater controls better able to accommodate runoff from larger storms, less localized urban flooding • Easy to use - 90th percentile confidence interval values reported from Atlas 14 website	• Results in larger, more expensive stormwater quantity controls such as stormwater basins or subsurface storage (peak flow attenuation)
NOAA Atlas 14++	Upper limit of the 90th percentile confidence interval		
NOAA Atlas 14, Future Downscaled	NOAA Atlas 14 median values multiplied by the ratio of future to baseline downscaled GCM precipitation estimates developed by CIRCA for mid-century and late-century planning horizons	• Accounts for anticipated future increases in precipitation associated with climate change projections • Provides greater resilience for infrastructure than NOAA Atlas 14 median values • Larger stormwater controls better able to accommodate runoff from larger storms, less localized urban flooding • Increase in NOAA Atlas 14 values tied to CT-specific future precipitation estimates	• Results in larger, more expensive stormwater quantity controls such as stormwater basins or subsurface storage (peak flow attenuation) • Requires periodic update of downscaled precipitation estimates by CIRCA

In 2015, the Northeast Regional Climate Center (NRCC) developed updated NRCS rainfall distributions for the Northeast states, including Connecticut. These NRCC rainfall distributions were then replaced in 2018 for use in the NRCS WinTR-55 computer program in CT, as NRCS derived four new regional rainfall distributions (Types N10 A, B, C, and D) from the NOAA data to cover the NOAA Atlas 14, Volume 10 study area, which supersede all previous distributions. Connecticut NRCS recommends the use of the Type N10_D regional rainfall distribution to represent the entire state of Connecticut in WinTR-55. This or site-specific rainfall distributions can be used with the NOAA Atlas 14 estimates of 24-hour precipitation depths. The NRCS Type N10_D rainfall distribution is also recommended for use with other common rainfall runoff and stormwater design programs such as HydroCAD.

Water Quality Design Storm

In Connecticut, the water quality design storm is defined by 1 inch of rainfall over a 24-hour period. The 1-inch rainfall depth was selected as the event whose precipitation total is greater than or equal to 90 percent of all 24-hour storms on an average annual basis. During development of the original Connecticut Stormwater Quality Manual in 2004, rainfall data from the Northeast U.S. indicated that the 90th percentile 24-hour rainfall event was equal to approximately 1 inch. Several of the states in the northeast, including Connecticut, adopted the 1-inch rainfall event in their stormwater manuals.

The volume of runoff generated by the 1-inch rainfall is defined as the Water Quality Volume (WQV) in the 2004 manual, and by reference in the Soil Erosion and Sediment Control Guidelines and the CT DEEP Stormwater General Permits. Conceptually, the WQV is the volume of stormwater runoff from any given storm that should be captured and treated to remove a majority of stormwater pollutants on an average annual basis. The equation used to calculate the WQV uses a volumetric runoff coefficient as a function of impervious area, a rainfall depth of 1 inch, and the drainage area to the specified design point.

The WQV and 90th percentile rainfall concepts were originally developed to treat the majority of 24-hours storms and the associated average annual pollutant load in stormwater runoff. In 2009, EPA released technical guidance on implementing stormwater management requirements for certain federal projects, emphasizing the use of green infrastructure (GI) and low impact development (LID) to preserve pre-development hydrology as closely as possible.[118] The 2009 EPA guidance proposed the use of green infrastructure and LID practices that manage rainfall on-site, and prevent the off-site discharge of runoff from events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible. According to the EPA guidance, the 95th percentile storm event appears to best represent the volume that is fully infiltrated in a natural condition and thus should be managed on-site to restore and maintain pre-development hydrology for duration, rate and volume of stormwater flows.

[118] USEPA. Section 438 Technical Guidance December 2009. Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act. EPA 841-B-09-001. December 2009. www.epa.gov/owow/nps/lid/section438

Retaining runoff from all storms up to and including the 95th percentile storm event (i.e., retention standard) serves to maintain or restore pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites, in addition to providing treatment or pollutant removal. The volume reduction benefits provided by this retention standard result in greater overall pollutant load reduction, since pollutant loads are the product of pollutant concentration and runoff volume.

In 2018, the Northwest Conservation District, working with the Northwest Hills Council of Government through a CIRCA Matching Grant, developed a model Low Impact Development design manual to address stormwater management and the impacts climate change. The Morris, CT manual, a model for other small communities in the state, adopted a locally-applicable 95th percentile rainfall (1.3 inches) as the water quality design storm.

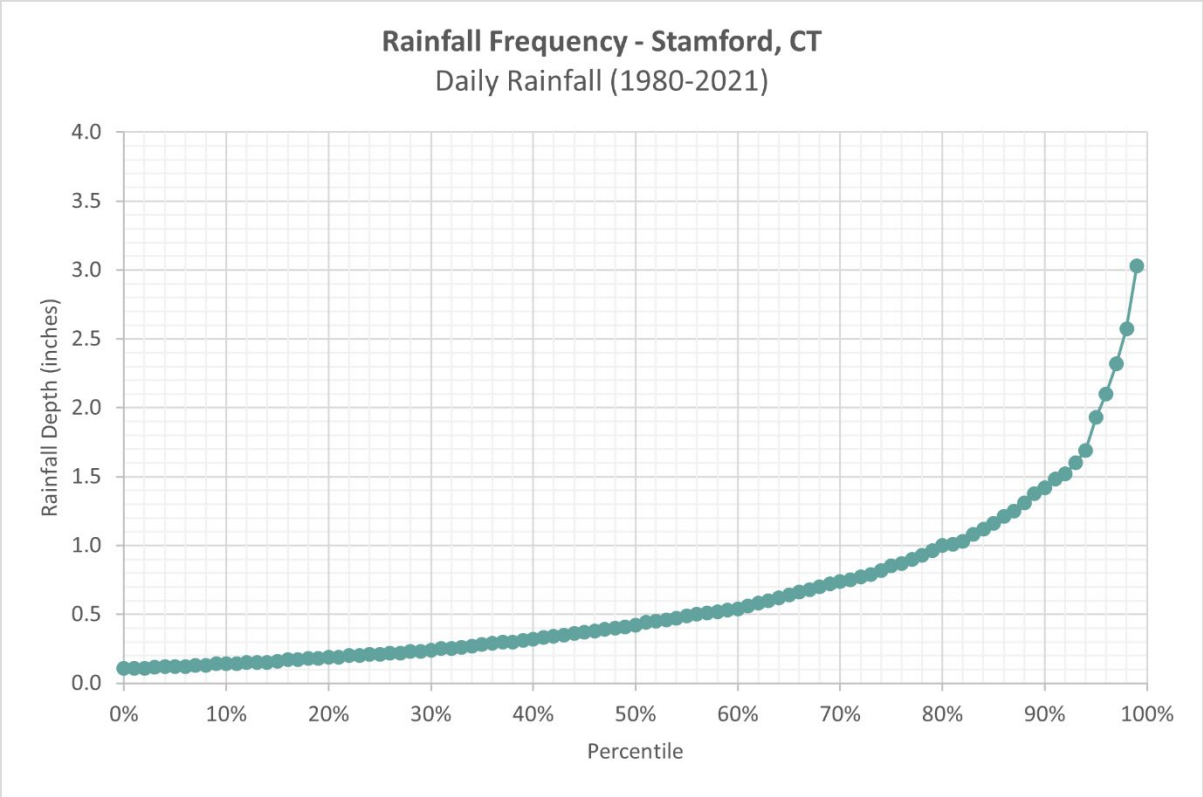
The Workgroup evaluated two options for updating the water quality design storm and associated Water Quality Volume in the revised Manual. The two options, including advantages and disadvantages of each, are summarized in Table G-3.

Table G-3. Alternative Approaches Considered for Updating Water Quality Design Storm Precipitation

Alternative	Description	Advantages	Disadvantages
Updated 90th Percentile 24-hour Rainfall	Update the 90th percentile 24-hour rainfall based on the latest CT rainfall data (at least a 30-year period)	• Reflects current Connecticut rainfall amounts • Better preserves pre-development hydrology (runoff duration, rate, volume, and temperature and groundwater recharge) as the basis for the retention standard in the CT DEEP Stormwater General Permits and this Manual	• Stormwater management cost increases noted as a potential concern
95th Percentile 24-hour Rainfall	Switch to the 95th percentile 24-hour rainfall	• Closer alignment with EPA Guidance • Even more effective in preserving pre-development hydrology	• Would be even more costly and, in some cases, difficult to achieve for constrained sites

The 90th and 95th percentile rainfall events were estimated for three Connecticut locations with long-term daily rainfall records – Hartford, Groton, and Stamford – using daily precipitation observations over an approximately 40-year period of record (1980-2021) and the procedure cited in the 2009 EPA guidance. Small rainfall events (0.1 inch or less and snowfall events that do not immediately melt) were removed from the data sets since these events do not typically cause runoff and could potentially cause bias in the estimates. Figure G-1 shows a cumulative frequency distribution of daily rainfall for one of the three locations analyzed (Stamford).

Figure G-1. Cumulative Frequency Distribution of Daily Rainfall for Stamford, CT (1980-2021)



The 90th percentile rainfall amounts vary from 1.25 to 1.42 inches, with an average of approximately 1.3 inches for the three locations analyzed. This is consistent with the 90th percentile rainfall amounts for New York State (1.0-1.5 inches) estimated by NYSDEC in 2013, as well as 90th percentile rainfall estimates for Boston, MA for the period 1948-2004 (approximately 1.3 inches).[119] The 95th percentile rainfall amounts are generally 30% to 35% higher than the 90th percentile amounts for the Connecticut locations evaluated.

[119] Stormwater Best Management Practices (BMP) Performance Analysis. Revised Document: March 2010 (Original Document: December 2008). Prepared for United States Environmental Protection Agency - Region 1 by Tetra Tech, Inc.

Conclusions

Stormwater Quantity Control Design Storm

The revised Manual replaces the TP-40 24-hour rainfall depths with the NOAA Atlas 14 (and subsequent generations of NOAA precipitation-frequency products[120]) precipitation frequency estimates, at a minimum, for consistency with the CT DEEP Construction Stormwater General Permit and CTDOT design practice. While consideration was given to the use of larger design storm depths to account for observed and projected future increases in precipitation, such as the upper range of current expected storms (e.g., NOAA14+ or NOAA14++) or future climate projections, the Workgroup was concerned that adopting such an approach could be cost-prohibitive and potentially result in site designs with over-engineered stormwater controls rather than greater emphasis on use of non-structural LID site planning and design techniques. CT DEEP will continue to consider new climate resources and tools to inform future updates of design storm precipitation, including adoption of future generations of NOAA precipitation-frequency products, which are expected to reflect increasing trends in observed and future precipitation over time.

Water Quality Design Storm

The revised Manual replaces the 1.0-inch water quality storm with the updated 90th percentile rainfall depth of 1.3 inches to: 1) reflect current Connecticut rainfall amounts, and 2) better preserve pre-development hydrology (runoff duration, rate, volume, and temperature and groundwater recharge) as the basis for the retention standard (using the same WQV calculation method as used in the original manual) in the CT DEEP Stormwater General Permits and this Manual. This revision was deemed to be consistent with more recent rainfall data for Connecticut without being overly burdensome in meeting the stormwater retention and treatment standard for most sites.

Additional Climate Considerations

Ongoing and future projected climate changes will continue to impact stormwater management in Connecticut, as well as related environmental, infrastructure, and community resources, in the following ways:

- More frequent and intense storms can increase stormwater runoff, which can cause more frequent and extreme flooding events and can exacerbate existing, or introduce new, pollution problems. Overwhelmed stormwater management systems can lead to backups that cause localized flooding or lead to greater runoff of contaminants such as trash, nutrients, sediment, and bacteria into local waterways.

[120] As of the writing of this manual, NOAA was developing the "next generation" precipitation-frequency product that is expected to replace NOAA Atlas 14. The new product (NOAA Atlas 15) is anticipated to update current Atlas 14 precipitation frequency estimates based on historical data and reflect the increasing trend in observed precipitation, as well as account for future precipitation information.

- More frequent and intense downpours can also challenge cities with combined stormwater and wastewater drainage systems. These systems can be overwhelmed by large amounts of rainfall or snowmelt and lead to more combined sewer overflows (CSOs) into waterways. An increase in CSOs can reduce water quality and make meeting water quality standards more difficult.

- Increased stormwater runoff and transport of pollutant loads to waterbodies can diminish water quality and threaten drinking water sources. Projected increases in the number of days of precipitation over 1 inch, as well as the total amount of precipitation falling in the heaviest 1% of rainfall events are important factors in determining future pollutant loads to waterbodies.

- Warming air and water temperatures combined with increased precipitation and stormwater pollutant loads will increase the potential for harmful algal blooms, loss of high-quality headwater streams and cold-water habitat, further degradation of impaired waters, and negative impacts on recreational use of waters.

Summary of Climate Change & Its Impacts in Connecticut

- By 2050, average temperatures are expected to increase about 5°F, with increases thereafter dependent on emissions choices now.
- Average precipitation is expected to increase about 8% (4 inches/year).
- Indices of hot weather, summer drought, and extreme precipitation are expected to increase.
- Sea level is expected to rise by up to 20 inches by 2050 and continue increasing after that.
- Small changes in mean sea level have a big impact on the frequency of flooding.
- Areas that experience flooding every few years now should expect flooding multiple times a year by 2050.

Source: Connecticut Institute for Resilience & Climate Adaptation (CIRCA) Fact Sheets

Temperature and Precipitation

Sea Level Rise

- More frequent, intense, and longer-lasting periods of drought, combined with new land development, can exacerbate loss of groundwater recharge, reducing streamflow and affecting water quality, stream ecology, recreational use of waters, and drinking water supplies.

- Sea level rise and increased frequency and intensity of coastal storms has implications for stormwater management systems along the Connecticut coast and tidally influenced areas. According to projections by the Connecticut Institute for Resilience & Climate Adaptation (CIRCA), sea level rise is expected to increase water levels in Long Island Sound by up to 20 inches by 2050 and to continue increasing after that. Continued 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 groundwater elevations will rise in areas that are directly influenced by coastal

waters. Stormwater management systems in these areas are vulnerable to rising sea levels and, backwatering and submerging of outfalls, rising groundwater and reduced infiltration, storm surge inundation of facilities, and additional wind, sand, and salt exposure.