Guidelines for the Design and Construction of Stormwater Management Systems

Developed by the New York City Department of Environmental Protection in consultation with the New York City Department of Buildings

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NYC Environmental Protection

Michael R. Bloomberg, *Mayor*
Carter H. Strickland, Jr., *Commissioner*

Cover: An extensive green roof system installed atop the NYC Department of Parks and Recreation's (DPR) Five Borough Building on Randall's Island. This modular system is one of six variations installed on the roof and covers 800 square feet, consisting of two-foot by two-foot trays with six inches of mineral soil and over 1,500 sedum plugs. DPR has installed 25 green roof systems covering over 29,000 square feet on the Five Borough Building rooftop to feature different types and depths of growing medium and plant selection.

Dear Friends;

The *NYC Green Infrastructure Plan*, released in September 2010, proposed an innovative approach for cost-effective and sustainable stormwater management. A major part of this plan is our commitment to manage the equivalent of an inch of rainfall on ten percent of the impervious areas in combined sewer watersheds by 2030. To that end, DEP is prepared to spend $1.5 billion to construct green infrastructure projects across the city. Yet public investment alone will not achieve our water quality goals, or our desired recreation and development opportunities.

Some of the most cost-effective opportunities are represented by new construction and development, when stormwater source controls can be easily included in designs and built at a fraction of the cost of retrofitting existing buildings. DEP initiated a citywide rulemaking process and worked closely with development, labor, and environmental organizations over two years.

In response to suggestions received in that process, DEP worked with the Department of Buildings to develop an informative guidance document to accompany the rule. The information contained in this document will ease the development community's transition to stricter stormwater release rates when connecting to the City's combined sewer system. These guidelines will continue to evolve as we learn more from our pilot projects and as stormwater regulations change. We welcome feedback about the structure and content of this document.

Together we are proud to say that New York City has taken a critical step toward further improving harbor water quality and making our city greener and greater than ever before.

Sincerely,

Carter H. Strickland, Jr.
Commissioner

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SECTION 1

INTRODUCTION

The New York City Department of Environmental Protection (DEP) is responsible for the city's drainage plan and stormwater management. Through DEP approval of sewer certifications (approval that the City sewer can accept the proposed discharge) and subsequent sewer connection permits (authorization to connect to a sewer), DEP limits the "allowable flow" from development lots to provide adequate capacity in the sewer system based on sewer design criteria.

Recently, DEP has revised its stormwater rules for new development and redevelopment in combined sewer areas. The new performance standard is intended to reduce peak discharges to the city's sewer system during rain events by requiring greater on-site storage of stormwater runoff and slower release to the sewer system. The implementation of DEP's stormwater performance standard over time is expected to provide additional capacity to the existing sewer system, thereby improving its performance. The performance standard is a key element of the New York City Green Infrastructure Plan (the "*NYC Green Infrastructure Plan*") to promote green infrastructure and improve water quality in the city's surrounding waterbodies.

Native beds established on the green roof at DPR's Five Borough Building on Randall's Island.

1.1 Purpose and Scope of Document

DEP's stormwater performance standard is intended to reduce adverse impacts on the city's combined sewer system from runoff during rainstorms that are more severe than sewers and related facilities are designed to handle. When excessive stormwater enters the combined sewer system from impervious surfaces, it can cause combined sewer overflows (CSOs), flooding, and sewer backups. By slowing the flow of stormwater to the sewers, the stormwater performance standard allows the city to manage stormwater runoff from new development and redevelopment more effectively and maximize, to the greatest extent possible, the capacity of the city's combined sewer systems.

These guidelines were developed by DEP, in consultation with the New York City Department of Buildings (DOB), to provide guidance to New York City's development community and licensed professionals for the planning, design and construction of onsite source controls that comply with DEP's stormwater performance standard. The stormwater performance standard was promulgated on [DATE] as an amendment to *Chapter 31 of Title 15 of the Rules of the City of New York, Rule Governing House/Site Connections to the Sewer System Standards for Release Rates ("Chapter 31")*. These guidelines reflect the requirements of these rules and the New York City Construction Codes ("Construction Codes"), as administered by DOB.

While these guidelines are provided to assist the development community, licensed professionals always maintain the responsibility to submit acceptable designs in accordance with all applicable laws, rules, and regulations and property owners are responsible for maintaining onsite constructed systems.

Stormwater Performance Standard

Section 3 of Chapter 31 was revised to include the Stormwater Performance Standard for Connections to Combined Sewer System ("stormwater performance standard"). As a result, the following requirement applies to proposed developments that require a New Building permit from DOB ("new development") in combined sewer areas of the city:

The Stormwater Release Rate must be no more than the greater of 0.25 cfs or 10% of the Allowable Flow or, if the Allowable Flow is less than 0.25 cfs, no more than the Allowable Flow.

For proposed redevelopments in combined sewer areas of the city, the following requirement applies to "alterations," as defined in the Construction Codes and related requirements, for any horizontal building enlargement or any proposed increase in impervious surfaces:

The Stormwater Release Rate for the altered area must be no more than the stormwater release rate for the entire site, determined in accordance with the requirement above, multiplied by the ratio of the altered area to the total site area. No new points of discharge are permitted.

The EPA and Green Infrastructure

The United States Environmental Protection Agency (EPA) suggests that the use of green infrastructure "can be a cost-effective, flexible, and environmentally-sound approach to reduce stormwater runoff and sewer overflows and to meet Clean Water Act (CWA) requirements. Green infrastructure also provides a variety of community benefits including economic savings, green jobs, neighborhood enhancements and sustainable communities" (EPA, 2011).

Figure 1-1: Stormwater chambers were installed prior to filling with soil for the construction of a constructed wetland at a DOT parking lot in Far Rockaway. The wetland area, to be planted in Spring 2012, will allow runoff to infiltrate directly into the subsurface system. The adjacent parking lot is paved with porous pavement and excess flow will be directed to the constructed wetland.

The new stormwater performance standard effectively applies to new development and alterations on medium to large size lots. Smaller development sites generally do not generate runoff in excess of 0.25 cfs and, therefore, are expected to comply with current requirements concerning the Allowable Flow and storage volume requirements, sewer availability, and the connection application process.

DEP allows for different types of stormwater management systems to comply with the stormwater performance standard, including subsurface, rooftop and stormwater recycling systems. These systems store and slowly release stormwater to the sewer system (detention) or dispose of stormwater onsite (retention) through infiltration to soils below, evapotranspiration, and recycling onsite.

For specific systems, compliance with the following requirements allows for required detention volumes to be reduced:

For proposed open-bottom detention systems, DEP will consider requests for reduction of the required stormwater volume to be detained where stormwater will be infiltrated into the below soils. Such requests must be substantiated by soil borings taken at the location of the proposed system in addition to a permeability test performed in situ to demonstrate that the existing soil surrounding and below the system has a favorable rate of permeation. Requests for any volume credits must be shown on the site connection proposal application and reviewed by DEP.

DEP will consider requests for reduction of the required stormwater volume to be detained where stormwater will be recycled for on-site uses. The recycling system shall be independent and shall not result in total site discharge to the sewer system greater than the Stormwater Release Rate at any time. Such recycling systems cannot be modified or disconnected, without the express written approval of DEP. This restriction applies to both current and future owners and other persons in control of the property.

Chapter 31 includes additional applicability criteria and requirements for system maintenance, deed restrictions and regular certifications for proper system operation. In addition, the updated rules allow for reductions in overall site runoff coefficients by maximizing open space, infiltration, and other techniques. *Chapter 31* should be reviewed in its entirety prior to submitting a sewer availability and connection application to DEP. For definitions of terms included in the stormwater performance standard, see *Chapter 31* or the glossary in Appendix A.

THE WATER CYCLE

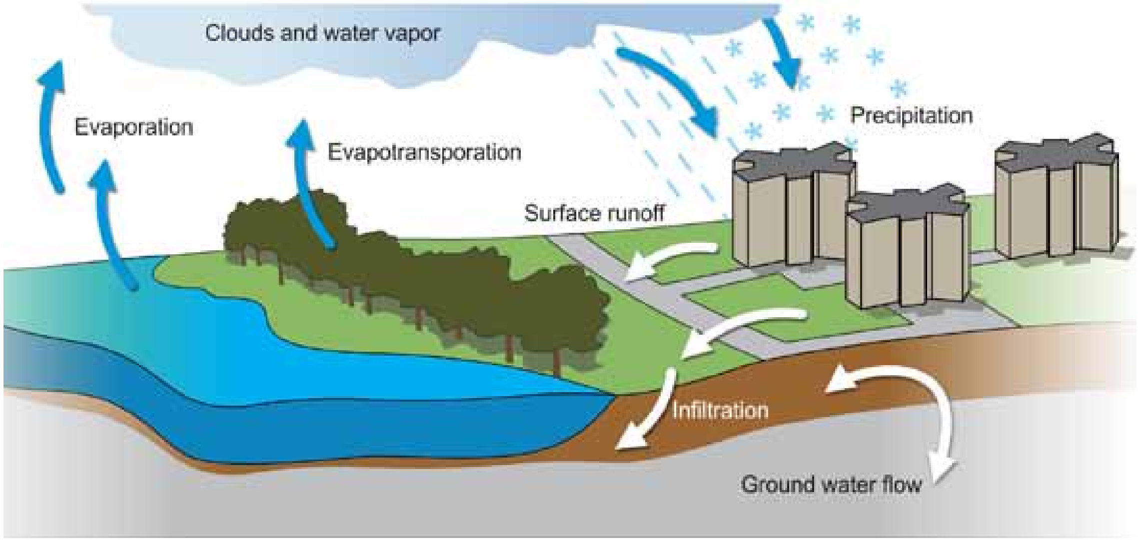


Figure 1-2: Source controls and impervious surface reductions help restore the natural water cycle in New York City's urban environments.

1.2 Stormwater Management in New York City

Urban stormwater runoff results from rain, snow, sleet and other precipitation that lands on rooftops, parking lots, streets, sidewalks, and other surfaces. Of specific concern are impervious surfaces, as they do not allow water to infiltrate into the ground or be utilized by plants, both of which are key elements of the natural water cycle (**Figure 1.2**). Rather, impervious surfaces shed water, which then becomes runoff that eventually enters the city sewer system or is discharged directly to adjacent waterbodies.

Stormwater runoff flows into separate storm sewers or combined sewer systems. In a combined sewer system, stormwater runoff mixes with sanitary flow. If the volume and rate of stormwater and sanitary flow exceeds capacity at wastewater treatment plants (WWTPs), the combined flow overtops the discharge weirs at regulators, causing CSOs in the city's surrounding waterways. If runoff rates exceed the conveyance capacity of the sewer system, sewer back-ups or street flooding may also occur. While these localized events do not typically affect water quality, they are critical quality of life problems that the city seeks to address.

Source Controls

In urban areas, source controls store stormwater onsite and release it at a controlled rate to the sewer system to mitigate the impacts of increased runoff rates associated with development. By detaining and delaying runoff, source controls reduce peak flow rates and city sewers are protected from excessive flows. Green infrastructure is a type of source control that moderates or reverses the effects of development by mimicking hydrologic processes of infiltration, evapotranspiration, and reuse. In these guidelines, the terms source controls and green infrastructure are used interchangeably. In highly urbanized areas such as New York City, development professionals must consider source controls on rooftops, driveways, parking lots, and open spaces. As a result, rooftop and subsurface systems have been identified in these guidelines as two categories of stormwater source controls well-suited for implementation in New York City's dense urban environment.

"Greening" a site with vegetation, as well as using pervious materials, reduces impervious surfaces. Non-paved areas reduce a site's weighted runoff coefficient and calculated developed flow.

Both subsurface and rooftop systems can be designed to retain stormwater by evapotranspiration and infiltration. In particular, rain gardens and vegetated swales are encouraged in the design and construction of onsite source controls to provide stormwater retention. The addition of vegetation provides other benefits for property owners and the surrounding neighborhoods, such as reducing the urban heat island effect, improving air quality, saving energy, increasing property value and mitigating climate change.

Stormwater can also be diverted from the sewer system through the use of systems that recycle stormwater onsite. Rainwater recycling systems (also known as rainwater harvesting) can reduce demand on the city's water supply, as runoff is captured, stored, and repurposed to irrigate planted areas, gardens or green roofs during periods of low rainfall. Rainwater can also be used in place of potable water for supplying water closets and urinals, cooling tower makeup, washing of sidewalks, streets, or buildings, and laundry systems. Recycling systems can range from a simple rain barrel connected to a downspout to several large polyurethane tanks or cisterns connected by a series of pipes. In addition to the requirements of DEP's stormwater performance standard, DOB has established acceptance and maintenance criteria for water recycling systems. (See the New York City Plumbing Code, "Plumbing Code," and Buildings Bulletin 2010-027 for more information.)

Drainage Planning and Sewer Construction

DEP is responsible for the "location, construction, alteration, repair, maintenance and operation of all sewers" and "shall initiate and make all plans for drainage and shall have charge of all public and private sewers in accordance with such plans" per the New York City Charter. Accordingly, DEP maintains the city drainage plan for the proper sewerage and drainage, and approves, oversees, and inspects the construction of public and private sewers and drains to ensure compliance with DEP's design standards.

The existing city drainage plan may require an amendment if significant changes are proposed for an area (mapping or de-mapping of streets, rezoning, and/or re-routing of sewers). Amended drainage plans must include specific information about sewers and drains including size, depth and grade; proposed alterations and improvements in existing sewers; and other detailed information necessary to demonstrate a complete plan for proposed sewerage. Drainage plan amendments must be filed by DEP at the appropriate Borough President, community board and local sewer office (Section 24-503 of the Administrative Code of the City of New York).

All sewer construction must conform to the filed amended drainage plan of record. The city's drainage plan with amendments provides the relevant information to calculate the "Allowable Flow" for proposed new development and alterations that increase the combined, sanitary and/or storm flow generated on the site. *Chapter 23 of Title 15 of the Rules of the City of New York, Rules Governing the Design and Construction of Private Sewers or Drains*, specifies the requirements for the submission of drainage proposals and sewer construction permit applications.

Regulatory Context

In recent years, stormwater management has evolved into a comprehensive, system-wide approach that includes source controls, conveyance, capture, and treatment. Federal and state stormwater regulations continue to become more stringent, and discharges from combined sewer systems affect attainment of CWA

Before

After

Figure 1-3: Pre and post-installation photos of open space converted to rain gardens at NYCHA's Bronx River Houses.

standards in the city's surrounding waterbodies. In addition, changing precipitation patterns and associated flooding are increasing demands on the city's sewer system, potentially limiting housing, business and other development. In response to these regulatory and weather trends, DEP has adopted a comprehensive program of source controls, including green infrastructure, to reduce stormwater demands on the combined sewer system.

Currently, soil disturbances one acre or greater on properties in separately sewered areas must meet New York State Department of Environmental Conservation's (DEC) stormwater requirements for construction activities. DEC updated the New York State Stormwater Management Design Manual in August 2010 to provide designers with guidance on how to select, locate, size and design onsite practices for runoff reductions and water quality treatment. DEC's guidance includes specific criteria for infill projects, land use conversions, construction on existing impervious surfaces and other types of development that are characteristic of New York City in Chapter 9, Redevelopment Projects.

Federal and state regulation of the city's separate storm sewer areas continues to become more stringent, and the city expects new Municipal Separate Storm Sewer Systems (MS4) requirements to be published within the next year. Accordingly, the city expects to revisit this stormwater rule once MS4 obligations are determined in order to add stormwater management requirements that may be required in separately sewered areas. At that time, the city will also revisit the adequacy of stormwater management system in combined sewer areas.

NYC Green Infrastructure Plan

The DEP stormwater performance standard is a key element of the broader NYC Green Infrastructure Plan. This plan, which was unveiled by Mayor Bloomberg on September 28, 2010, presents a "green strategy" to reduce CSOs into surrounding waterways by 40% by 2030. The *NYC Green Infrastructure Plan* builds upon and extends the commitments made previously in Mayor Bloomberg's *PlaNYC* to create a livable and sustainable New York City and, specific to water quality, open 90% of the city's waterways for recreation.

Five key components to reduce the overall costs of CSO improvement strategies are identified in the *NYC Green Infrastructure Plan*: (1) construct cost effective grey infrastructure (e.g. sewer improvements, CSO facilities, and WWTP upgrades); (2) optimize the existing wastewater system through interceptor cleaning and other maintenance measures; (3) control runoff through green infrastructure; (4) institute an adaptive management approach to better inform decisions moving forward; and (5) engage stakeholders in the development and implementation of these green strategies.

The *NYC Green Infrastructure Plan* estimates that managing the first inch of runoff from 10% of the impervious surfaces in combined sewer watersheds through source controls over the next 20 years would reduce CSOs by 1.5 billion gallons per year. To achieve this goal, DEP is partnering with other city agencies, including the New York City Departments of Transportation (DOT), Design and Construction (DDC), Parks and Recreation (DPR), Housing Authority (NYCHA) and School Construction Authority (SCA), to implement source controls based on opportunities identified in the *NYC Green Infrastructure Plan*, such as the right-of-way, schools and housing complexes.

The *NYC Green Infrastructure Plan* also estimates that new development and redevelopment would manage more stormwater onsite by using a variety of technologies, including subsurface detention and infiltration practices, enhanced tree pits, bioinfiltration, vegetated swales, pocket wetlands, porous and permeable pavements, and blue and green roofs. A variety of stormwater-related benefits are expected to accrue incrementally over time with widespread implementation of the above green infrastructure technologies.

1.3 City Development and Review Process

These guidelines are the companion document to DEP's stormwater performance standard, and describe a range of systems developed by DEP and DOB to comply with the performance standard. (See Appendix B for a list of related rules and regulations.)

As part of the city's permitting processes, DEP and DOB review construction drawings, specifications, and calculations for compliance with applicable regulatory requirements. (See Appendix C for a list of required submittals.) DOB specifically regulates construction through the issuance of building construction permits to ensure compliance with the Construction Codes and other applicable rules and regulations.

DEP is responsible for ensuring that proposed source controls meet all requirements as outlined in *Chapter 31*. DEP reviews source controls through the sewer connection permit process for new development and redevelopment. The first step in this process is to determine sewer availability through submittal of house connection proposals (HCP) for 1, 2, or 3 family houses or site connection proposals (SCP) for development other than 1, 2, or 3 family houses. (See Appendix D for the flow chart regarding city permitting processes.)

Similar to DEC's stormwater requirements, proposed stormwater management systems for large developments that include multiple construction phases should be submitted to DEP as part of a "Master Plan" site connection proposal application. A larger common plan of development or sale would, therefore, be considered a single site and the developed flow for the entire site must be restricted to comply with DEP's stormwater performance standard. Applicants may request a pre-submittal meeting with DEP for additional guidance.

DEP reviews HCPs and SCPs for hydraulic calculations of sanitary flow, stormwater release rates and onsite storage volumes. DOB enforces the completion of construction, including source controls, as per the certified construction documents. Following the construction of required source controls, and prior to the issuance of the Certificate of Occupancy (CO) by DOB, DEP will issue the sewer connection permit.

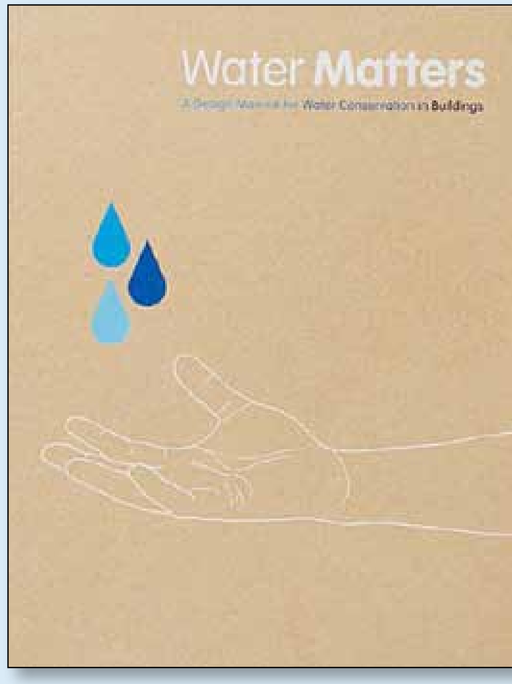
1.4 Types of Stormwater Management Systems

The six source controls described below are commonly submitted by licensed professionals and are expected to be used for compliance with the stormwater performance standard. These systems are very adaptable to different site plans, building configurations, and surface and subsurface conditions. Subsurface systems include open-bottom systems to infiltrate stormwater, where fea-sible, in accordance with these guidelines. Rooftop systems allow for maximized building footprints. Applicants are encouraged to propose infiltration practices, rainwater recycling systems and other innovative source controls, especially as technologies continue to evolve.

Subsurface Systems

Four types of subsurface systems are briefly described below and discussed in more detail in Section 3. Plan views of recommended systems are shown in **Figure 1-5.**

- **Storage vaults, or tanks,** can be constructed from pre-cast concrete structures, concrete rings, culverts, pipes, vendor-provided products, or cast-in-place concrete. Tanks and vaults can be built with or without a bottom slab. If built without a bottom slab, a vault system can promote infiltration.



"Water Matters: A Design Manual for Water Conservation in Buildings"

The NYC Department of Design and Construction's (DDC) *Water Matters* provides guidance for NYC's agencies and licensed professionals to better manage facilities' water supply and sewer discharges. The manual describes ways to reduce the overall demand for potable water consumption and reuse stormwater rather than conveying directly to the sewer system. Strategies are presented to assist professionals in achieving the water efficiency goals of both Local Law 86 and Leadership in Energy and Environmental Design (LEED) certification requirements. Licensed professionals designing buildings for private property owners should refer to DDC's Water Matters for guidance on green infrastructure that may reduce water and sewer charges or achieve LEED certification.

Figure 1-4: The largest green roof in New York City, approximately 2.5 acres, is on the Morgan Mail Processing Facility in Manhattan. (Source: United States Postal Service. All rights reserved. Used with permission.)

- **Gravel beds** are excavated areas filled with uniformly-graded gravel. The void space within the gravel is used to detain water. These systems can also promote infiltration.
- **Perforated pipes** use a combination of pipe storage and gravel storage to provide detention and promote infiltration.
- **Stormwater chambers** are commercially available in a variety of shapes and sizes. These structures detain stormwater within the chamber and gravel surrounding each chamber for structural support. These open-bottom systems also promote infiltration.

Rooftop Systems

Two types of rooftop systems are briefly described below and discussed in more detail in Section 4.

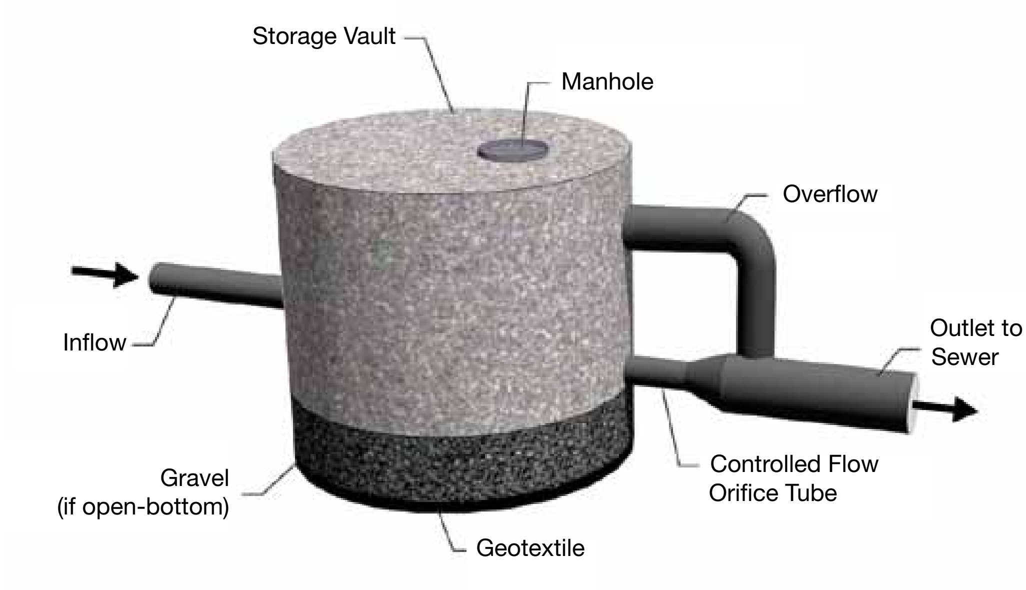
- **Blue roofs,** also known as controlled flow roof drain systems, provide temporary ponding on a rooftop surface and slowly release the ponded water through roof drains. Blue roofs have weirs at the roof drain inlets to restrict flow.
- **Green roofs** consist of a vegetative layer that grows in a specially-designed soil that may sit above a drainage layer. Green roofs detain stormwater in the void space of the soil media and retain stormwater through vegetative uptake and evapotranspiration.

1.5 Selecting an Appropriate System

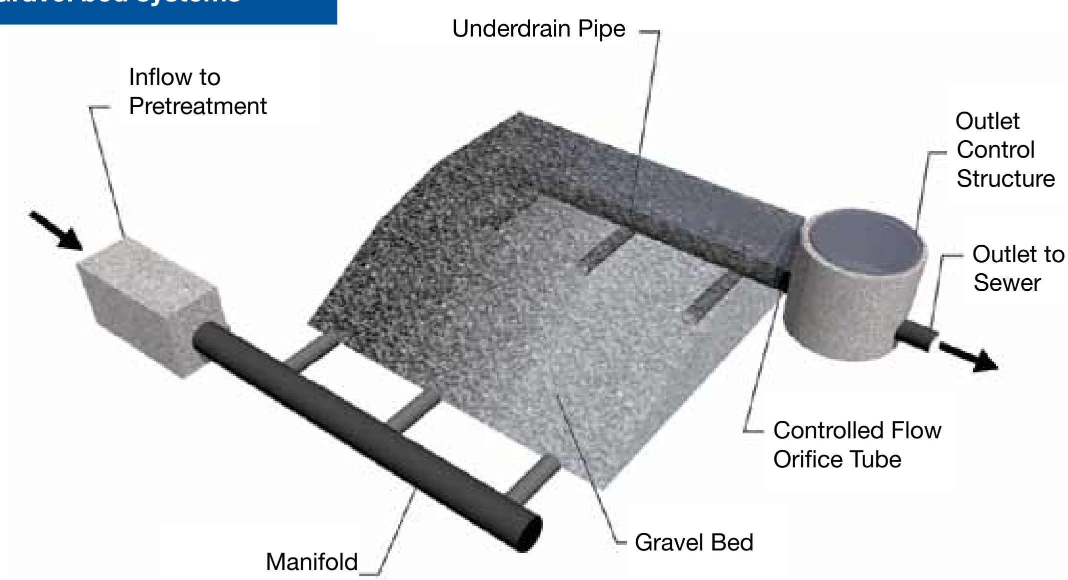
The choice of stormwater management system will depend on the elevation of the existing sewers, multiple site conditions, and the preferences of the developer for the proposed project. A subsurface system may be a preferred option to comply with the stormwater performance standard for sites with large areas outside building footprints. For sites with lot line-to-lot line buildings, either rooftop systems or detention systems within the proposed structure (e.g., basements) are suitable options. In some instances, a combination of two systems—rooftop and subsurface—may be preferred.

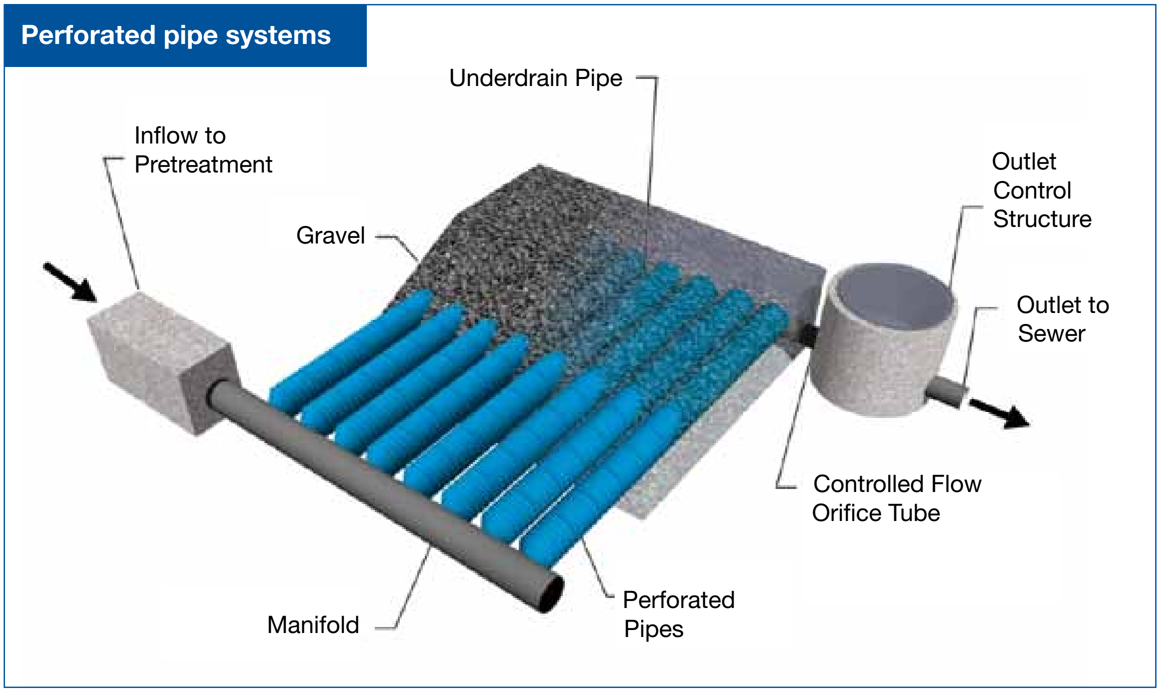
Rainwater recycling or infiltration may be desirable for a reduction of required detention volume at a given site. Factors that influence the

Storage vault systems



Gravel bed systems





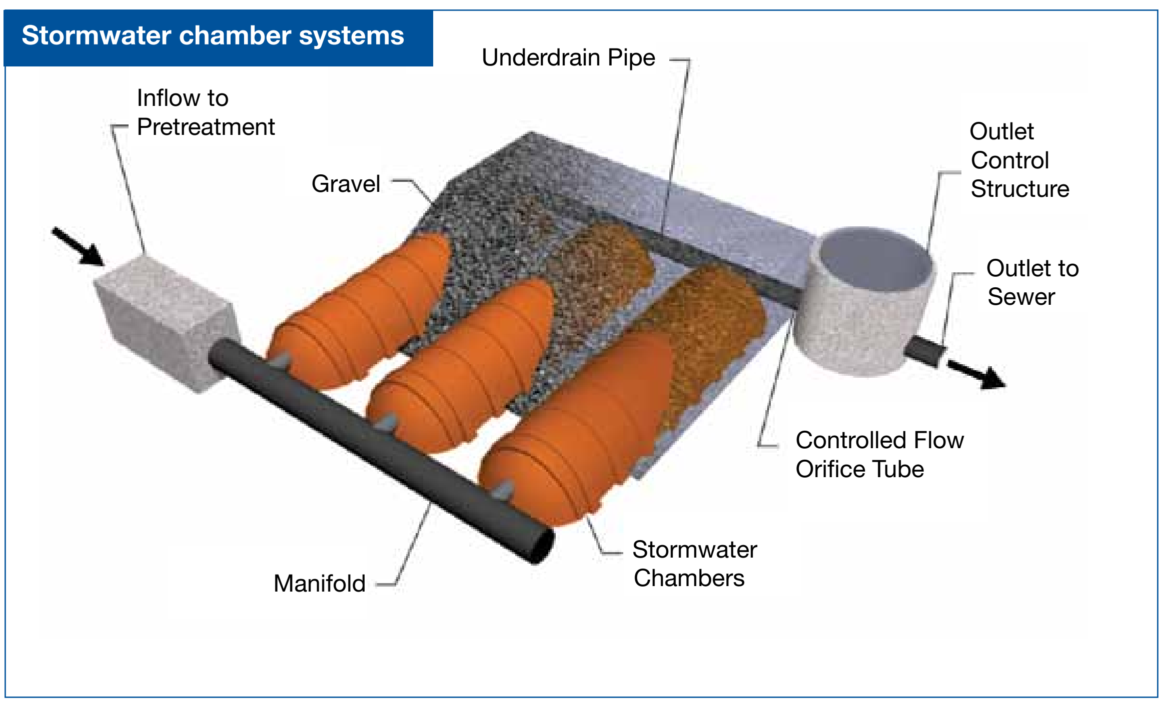


Figure 1-5: Four schematic plan views of typical subsurface stormwater management systems.

feasibility of infiltration include the location of the groundwater table and bedrock, the classification of the subsurface soil, and the demonstrated soil infiltration rate. In addition, rainwater recycling may be feasible where opportunities to use the stored water onsite at a continuous and constant rate throughout the year exist.

Figure 1-6 shows how site and building characterisitcs can be used to determine the appropriate stormwater management system. Sections 3-5 are intended to assist developers further in determining the appropriate system during site planning and building design.

1.6 Responsibilities of the Licensed Professional and Property Owner

These design guidelines have been developed for use as a tool to assist property owners and licensed professionals to comply with current city codes and rules. The City of New York and its Departments of Environmental Protection and Buildings assume no liability for the design or construction of any stormwater management system which may be installed based on these guidelines. Responsibility for site-specific elements of a system design, including structural considerations, hydrology and hydraulics, materials selection and utility coordination, lies solely with the licensed professional of record.

Licensed professionals include engineers, architects, and landscape architects who have a state-approved seal to affix to drawings and specifications submitted to public officials. The licensed professional is also solely responsible for ensuring that all guidelines herein are applied in a manner consistent with all other applicable federal, state, and city codes and regulations. The property owner of the site is responsible for obtaining all required permits. The property owner and their successors must properly maintain onsite stormwater management systems, file a deed restriction, and submit triennial certification of proper operation per *Chapter 31*.

1.7 Document Organization

This section provides introductory material including the regulatory context, an overview of different stormwater management systems, and general considerations on the selection of appropriate control systems. Section 2 provides guidance and calculations for determining required onsite storage volumes and sizing different systems. Section 3 summarizes features relevant to subsurface systems and contains related design calculations, case studies, construction guidance, and operations and maintenance needs. Section 4 provides similar information for rooftop systems. Section 5 discusses design considerations for a variety of combination systems. References and appendices including recommended planting lists for both infiltration practices (Appendix E) and green roofs (Appendix F), at the end of these guidelines supplement these sections.

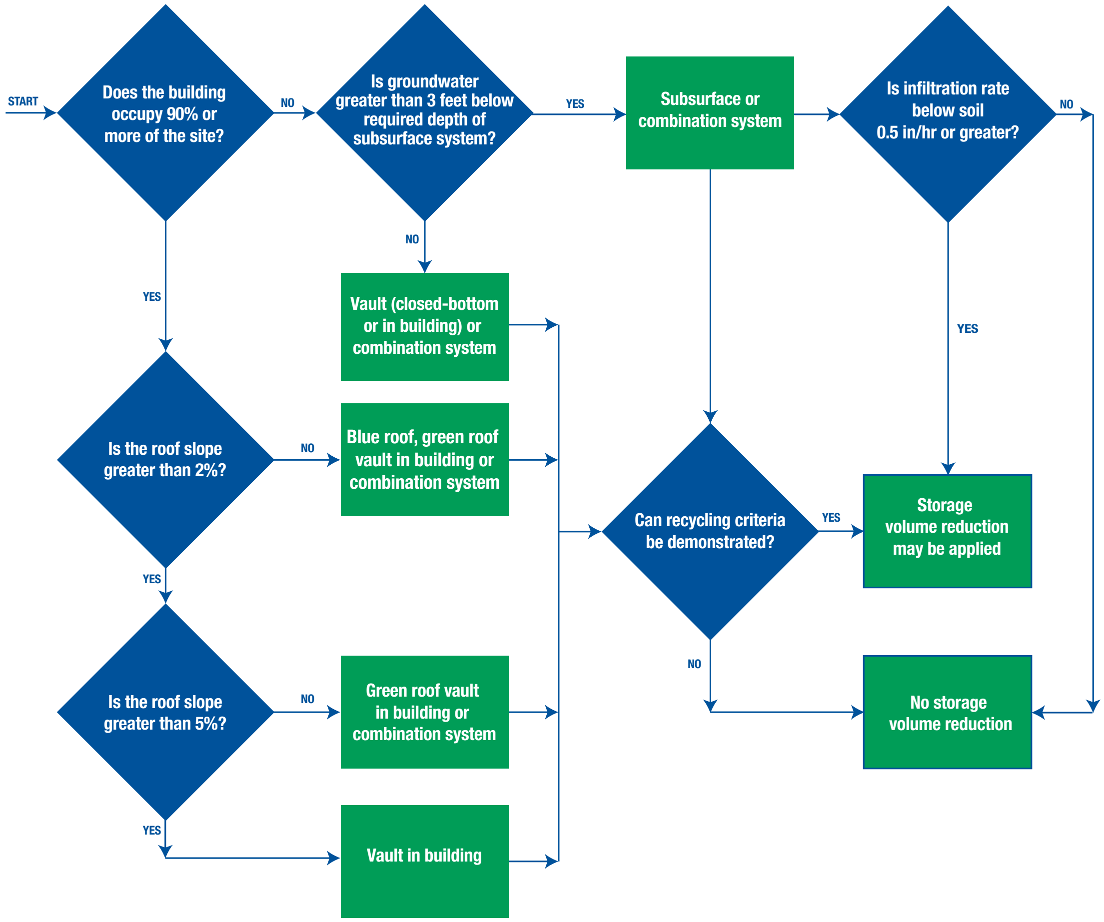


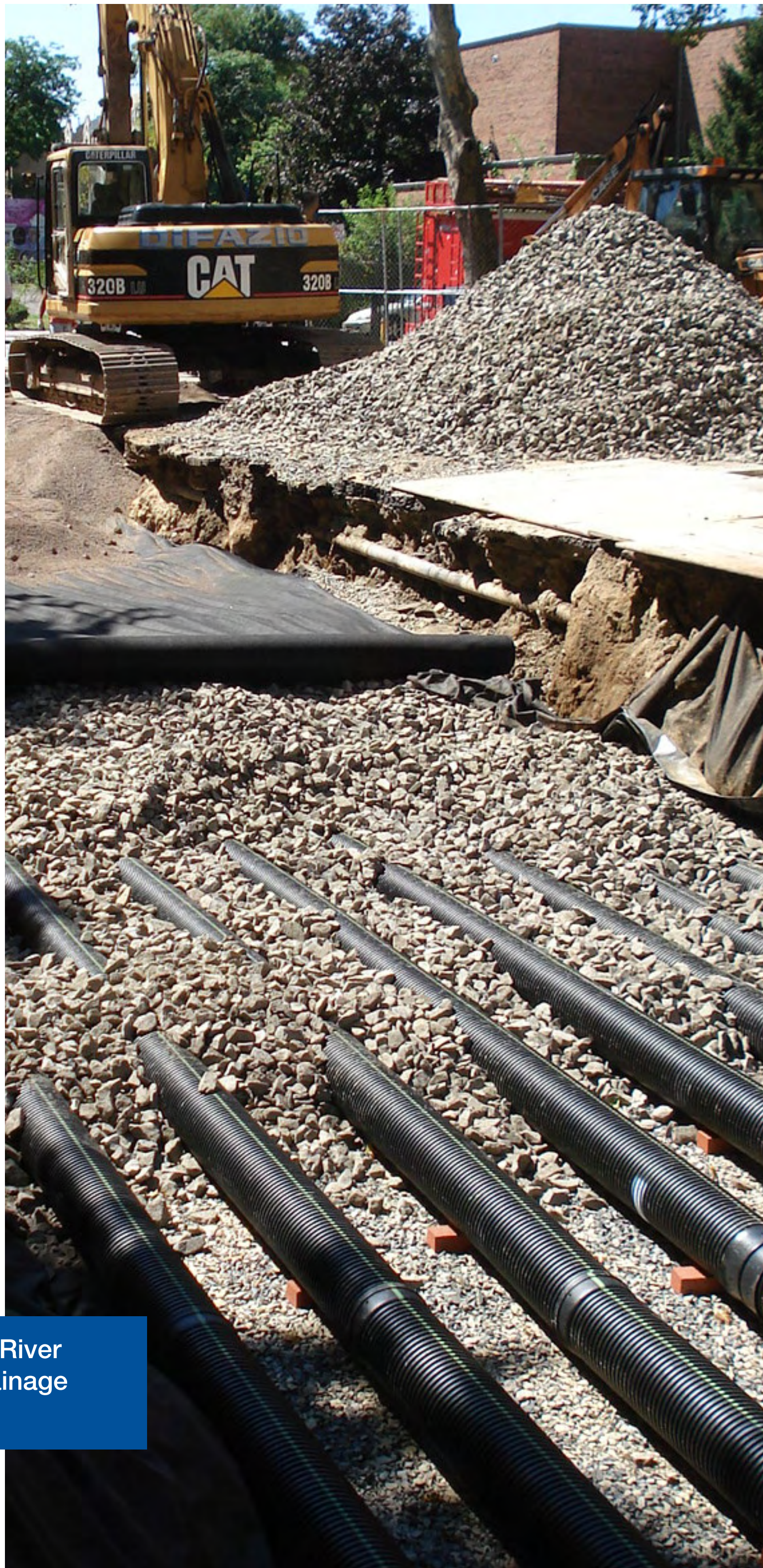
Figure 1-6:
Relevant questions (blue) and conclusions (green) provide general guidance for selecting an appropriate stormwater management system during site planning and building design.

SECTION 2

SIZING STORMWATER MANAGEMENT SYSTEMS

Stormwater management systems must be sized to detain a required volume while achieving the release rate consistent with DEP's stormwater performance standard. DEP's Criteria for Determination of Detention Facility Volume ("DEP's Criteria") provides the necessary steps to calculate required storage volumes and release rates.

This section builds upon DEP's Criteria and describes the calculations necessary to size different subsurface and rooftop systems. This section also provides methods for calculating detention volume reductions that may be applied if proposed infiltration practices or recycling systems meet specific criteria. A stormwater management system calculator will be made available before the effective date of DEP's stormwater performance standard to assist developers and licensed professionals in determining the space requirements for each type of system and designing the most appropriate system for a specific site. The variables used in this section are provided in Appendix G for reference purposes.



A perforated pipe system, installed at NYCHA's Bronx River Houses, captures runoff from a 13,600-square foot drainage area including a parking lot and adjacent sidewalks.

2.1 Calculating Developed Site Flow and Runoff Coefficients

The developed site flow, or the rate of runoff from the site with a proposed new development or alteration, is calculated using the rational method for the total site area, rainfall intensity, and the site's surface coverage, per DEP's Criteria. Once calculated, the developed flow should then be compared to the required release rate, storage volume and storage depth as described below to develop detailed site plans and designs. If the developed flow exceeds the release rate then it must be captured and detained to comply with DEP's stormwater performance standard. If the developed site flow is less than the release rate required by DEP's stormwater performance standard, the developer and licensed professional should refer to the drainage plan of record for the site's allowable flow to the sewer system.

The overall developed site flow can be reduced by minimizing impervious surfaces, maximizing pervious areas, and implementing green infrastructure source controls as part of the proposed development.

Onsite surface coverage is represented in the weighted runoff coefficient, C_W, as follows:

$$C_w = \left(\frac{1}{A}\right)\sum_{k=0}^{n}(A_k C_k)$$

Where:

A = the total site area, acres (ac)

k = the index for each onsite surface coverage type

A_k = the area of each surface coverage type, ac

C_k = the runoff coefficient associated with each surface coverage type

C_w is used directly in the calculation of developed site flow.

$$Q_{DEV} = C_w A_s / 7{,}320$$

Where:

Q_{DEV} = the developed flow, cfs

C_w = the weighted runoff coefficient

A_s = the total site area, ft^2

7,320 = 43,560 ft^2/ac divided by the rainfall intensity of 5.95 in/hr for the event with a 5 year return period and a 6 minute time of concentration

Calculating the developed site flow during site planning and building design allows the developer and licensed professional to consider different combinations of surface coverage types with various runoff coefficients (C-values), and the effect of these combinations on developed site flow. The following C-values should be used to calculate a site's weighted runoff coefficient:

0.95 = roof

0.85 = pavement

0.70 = porous asphalt/concrete and permeable pavers

0.70 = green roof with four or more inches of growing media

0.70 = synthetic turf athletic fields with subsurface gravel bed and underdrain system

0.65 = gravel parking lot

0.30 = undeveloped areas

0.20 = grassed and landscaped areas (including rain gardens and vegetated swales)

The C-values above reflect annual average runoff rates. Any request for variances from the above coefficients should be submitted to DEP for review and approval with appropriate supporting documents such as boring and permeability test results, manufacturer-specified values, and design details.

2.2 Determining the Release Rate, Storage Volume, and Storage Depth

A major element of sizing stormwater management systems is to determine the release rate, storage volume and storage depth to be provided by the system. DEP's Criteria should be used to calculate the release rate, Q_{RR}, storage volume, V_R, and maximum storage depth, S_D, for the different types of systems in these guidelines.

2.3 Subsurface System Sizing Calculations

The design of subsurface systems depends on DEP's Criteria and several other factors, such as the available footprint area onsite, the pretreatment system chosen, and the existing sewer elevation. As calculated in Section 2.2, the maximum storage depth of the subsurface system is controlled by the release rate, Q_{RR}, and the type and diameter of the outlet orifice. The maximum storage depth, S_D, generally ranges from 16 inches to eight feet, depending on lot size and based on a two-inch diameter outlet orifice, the minimum size allowed by DEP.

Site conditions also affect the sizing of subsurface calculations. The bottom of the subsurface system must be located a minimum of three feet above the groundwater table to ensure effective infiltration and prevent possible groundwater infiltration into the sewer system. Boring logs must be submitted to establish groundwater elevations. To minimize the footprint area required to achieve the required storage volume, the facility should be installed flat or with minimum pitch.

The remainder of the steps involved in sizing subsurface systems vary depending on the type of subsurface system selected. The following information includes the specific calculations that should be used to complete the sizing of each type of subsurface system described in these guidelines, while other design considerations specific to each system follow in subsequent sections. Generally, these calculations assume that systems are designed based on a maximum storage depth, S_D, for the chosen orifice size.

2.3.1 Sizing Vault Systems

Storage vaults or tanks can be constructed from from pre-cast concrete structures, concrete rings, culverts, pipes, vendor-provided products, or cast-in-place concrete. They can be built with or without a bottom slab. If built without a bottom slab, vaults can promote infiltration.

DEP's Criteria includes all necessary steps for sizing vaults given the 100% void space provided by vaults for stormwater storage. The required storage volume, V_R, should be equal to or less than the volume of storage provided by either cast-in-place or pre-cast vaults and tanks. As described in DEP's Criteria and similar to the systems described in detail below, the maximum depth of water over the outlet orifice is limited by the release rate. Therefore, the height of the vault is determined by the calculated maximum storage depth, S_D, and required storage volume, V_R.

2.3.2 Sizing Gravel Bed Systems

Gravel beds are excavated areas filled with uniformly-graded gravel. The void space within the gravel is used to detain water. Gravel beds promote infiltration when installed over porous sub-soils.

Components of the gravel bed can include a manifold system to distribute the incoming flow evenly throughout the gravel bed, and underdrain and collector systems to efficiently collect and convey outflow **(Figure 2-1)**. These components are recommended as good practices to improve system performance, but are not required.

The footprint area of the subsurface system is calculated to provide the required storage volume, V_R, and the maximum storage depth, S_D, calculated in Section 2.2.

Calculate System Footprint Area

This section provides the calculation methodology to determine the minimum required footprint area for a gravel bed system and the dimensions of a typical layout.

Based on a maximum gravel void ratio, "e", of 33%, the minimum footprint area, FA_{min}, is calculated using the following equation:

$$FA_{min} = \frac{3V_R}{S_D}$$

FA_{min} = the minimum footprint area, ft^2

S_D = the maximum storage depth of subsurface detention, ft (see Section 2.2)

V_R = the required storage volume, ft^3 (see Section 2.2)

This approach in determining minimum footprint area assumes that the system is being designed for the maximum storage depth. If the system is being designed for less than the maximum storage depth, the actual storage depth should be used.

Layout of the gravel bed system depends on the configuration of the site and building foundation. However, for a typical rectangular layout with a length-to-width ratio of approximately 2:1, the system dimensions can be calculated as:

$$L_G = \sqrt{2FA_{min}}$$

$$W_G = \sqrt{\frac{FA_{min}}{2}}$$

Where:

L_G = the total length of the gravel bed, ft

W_G = the total width of the gravel bed, ft

FA_{min} = the minumum footprint area, ft^2

Design Manifold and Underdrain Piping

As mentioned above, manifold and underdrain piping is not required, but helps to optimize system performance and sustain system function over time. Flow distribution in the gravel bed can be assured with proper sizing and location of manifolds and underdrain perforated pipes. The suggested minimum diameter for a perforated pipe is three inches. Perforated pipes must conform to the requirements of the Construction Codes.

For systems less than ten feet wide, a minimum of one underdrain pipe set at the same size as the header system is recommended. For systems wider than ten feet, but narrower than 20 feet, a minimum of one underdrain pipe set on

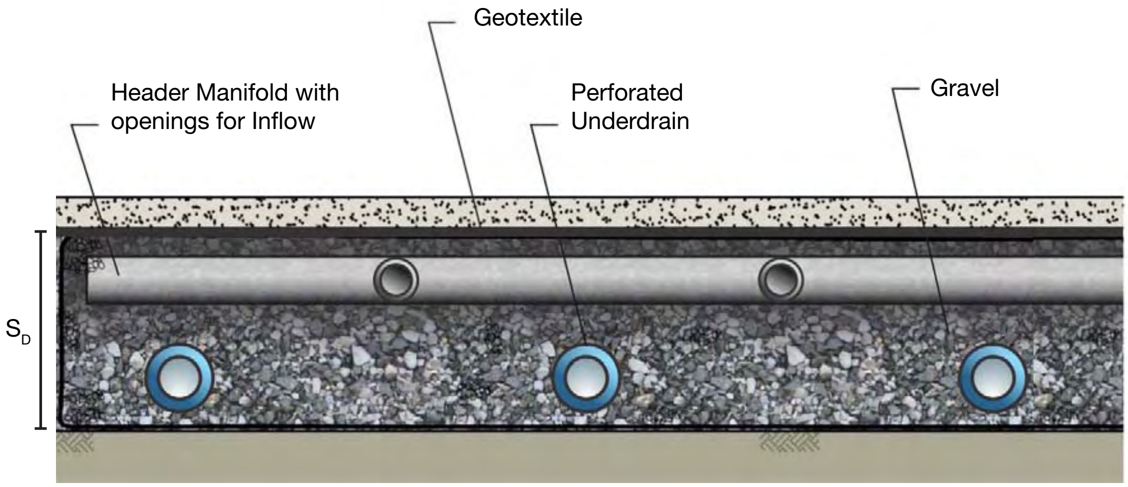


Figure 2-1: Cross-section of a gravel bed system showing the maximum storage depth (S_D), header manifold, and underdrains.

each side of the system is recommended. The distance from the pipe to the edge of the system should equal the depth of the gravel bed system. For wider systems, it is suggested that the underdrain pipes be set a minimum of ten feet apart on center, with the two end lines set as noted above.

Generally, the manifold and underdrain components are not included in the storage volume calculation for gravel bed systems. If volume credit is desired for underdrains, detailed calculations for sizing the underdrains should be provided. If volume credit is desired for manifold systems, detailed calculations should be provided for discussion with DEP.

2.3.3 Sizing Perforated Pipe Systems

Perforated pipe systems function in a similar manner to gravel beds, but consist of a set of parallel perforated pipes embedded in gravel. Detention is provided in both the pipe space and the gravel voids to provide detention and promote infiltration.

The perforated pipe system is sized based on the required volume, V_R, and maximum storage depth, S_D, calculated in Section 2.2. Detailed below is the methodology used to calculate the required length of perforated pipe, which is then used to determine the dimensions of a typical layout for the system.

Calculate Required Perforated Pipe Length

The calculation methodology for the required length of pipe of a perforated pipe system begins with determining the amount of storage per unit length of pipe and gravel that is achieved by the chosen pipe size. The minimum spacing from center to center between parallel pipes **(Figure 2-2)** must comply with manufacturers' specifications. The unit volume, V_L, in ft^3/ft of the perforated pipe and gravel bed, using a gravel void ratio, "e", of 33%, is calculated by the following equation:

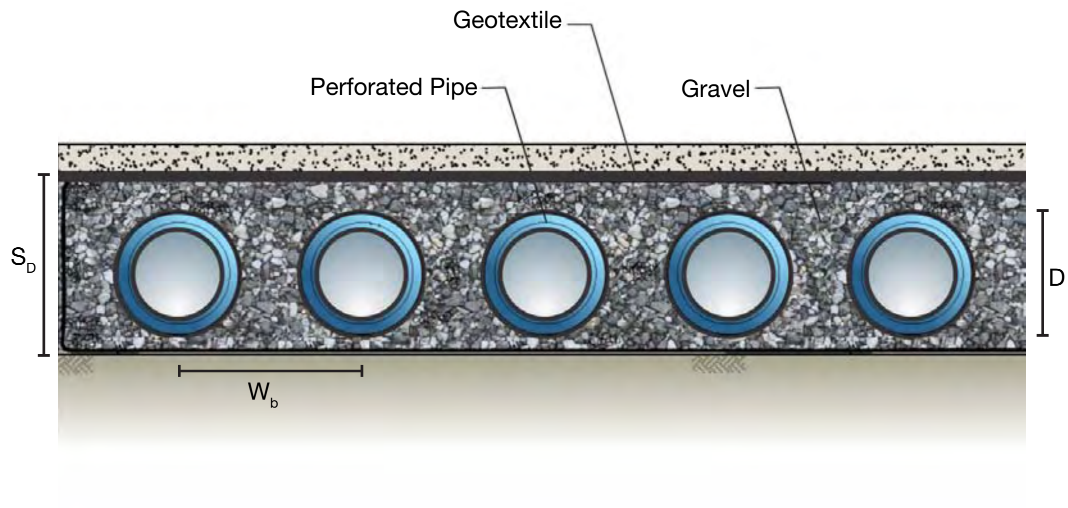


Figure 2-2: The minimum spacing between pipes, center to center (W_b), nominal pipe diameter (D) and maximum storage depth (S_D) are used to calculate the unit volume per length of perforated pipe.

$$V_L = \frac{W_b S_D}{3} + 0.524D^2$$

Where:

V_L = the unit volume, ft³/ft

W_b = the minimum spacing between pipes, center to center, as per manufacturers' specifications, ft

S_D = the maximum storage depth, ft (see Section 2.2)

D = the nominal diameter of the perforated pipe, ft

This methodology assumes that the system is being designed for the maximum storage depth. If the system is being designed for less than the maximum storage depth, the actual storage depth should be used.

The total length of pipe necessary to achieve the required storage volume, V_R, is then calculated as:

$$P_{SL} = \frac{V_R}{V_L}$$

Where:

P_{SL} = the required length of perforated pipe, ft

V_R = the required storage volume, ft³ (see Section 2.2)

V_L = the unit volume, ft³/ft (calculated above)

Calculate System Footprint Area

This section provides the calculation methodology used to determine the minimum required footprint area for a perforated pipe system and the dimensions of a typical layout.

The minimum footprint area required for a perforated pipe system can be calculated as:

$$FA_{min} = P_{SL} W_b$$

Where:

FA_{min} = the minimum footprint area, ft²

P_{SL} = the required length of perforated pipe, ft

W_b = the minimum spacing between pipes, center to center, as per manufacturers' specifications, ft

The layout of perforated pipe systems can be a variety of shapes (i.e. rectangular, L-shaped, etc.) and can depend on the configuration of the site and building foundation. However, for a perforated pipe system with a rectangular layout and 2:1 length to width ratio, the number of rows of pipe, N_P, can be calculated as:

$$N_P = \sqrt{\frac{P_{SL}}{2W_b}}$$

Where:

N_P = the number of rows of perforated pipe required

P_{SL} = the required length of perforated pipe, ft

W_b = the minimum spacing between pipes, center to center, as per manufacturers' specifications, ft

The perforated pipe system dimensions can then be calculated as:

$$L_P = \frac{P_{SL}}{N_P}$$

$$W_P = N_P W_b$$

Where:

L_p = total length of the perforated pipe system, ft

W_p = total width of the perforated pipe system, ft

P_{SL} = the required length of perforated pipe, ft

N_P = the number of rows of perforated pipe required

W_b = the minimum spacing between pipes, center to center, as per manufacturers' specifications, ft

A site specific analysis is required to determine the number of rows and dimensions of perforated pipe system configurations other than a rectangular layout with a 2:1 length to width ratio.

2.3.4 Sizing Stormwater Chamber Systems

Stormwater chambers consist of parallel rows of open-bottom, perforated plastic chambers (half pipes), surrounded by stone aggregate.

Chambers are available in a range of sizes depending on the manufacturer and depth required **(Figure 2-3)**. The length of an individual chamber varies widely depending on the manufacturer, and most manufactured systems are modular in nature, allowing the system designer to choose the number of modules to achieve a desired length for each chamber row.

The system designer should select a system with a depth as close as possible to the maximum storage depth, S_D, calculated in Section 2.2. Selecting a system with depth significantly greater than S_D will result in unused storage volume under design conditions. Selecting a system with depth less than S_D may require a larger footprint to meet the required storage volume, V_R, calculated in Section 2.2.

Stormwater chambers are installed on a foundation layer of gravel, which typically has a minimum depth of six inches. The gravel helps to provide the necessary bearing capacity to support the chambers, fill material and anticipated surface loads. The required depth of gravel will depend on existing soil conditions in the subgrade. System manufacturers typically provide guidance on the required depth of gravel based on the bearing capacity of existing soils.

Gravel is also placed in the space between and around the individual chambers, and a minimum depth of six inches of additional gravel is placed above the chambers in most

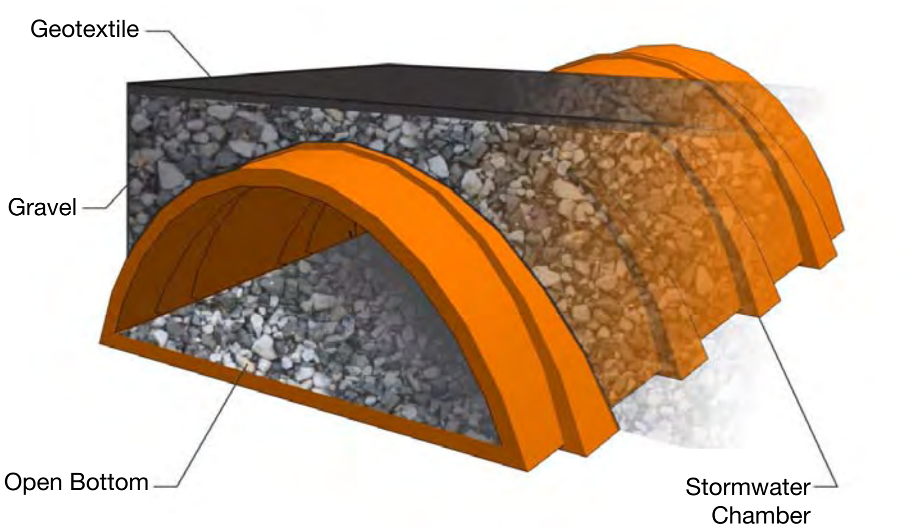


Figure 2-3:
Cross-section of a typical stormwater chamber. Chambers are available in a variety of sizes for different site conditions and stormwater release rates.

manufactured systems. Manufacturers publish tables of values for the available storage volume for an individual stormwater chamber unit as a function of water depth in the system. These published volumes account for the water stored in: (1) the chamber itself; (2) the gravel surrounding the chamber; and (3) the layer of gravel above the chamber. Unless the manufacturer provides the gravel, a void ratio, "e", of 33% should be used.

Most manufactured stormwater chamber systems are modular by design and allow the system designer to choose the number of chambers to achieve a desired length for each chamber row. To minimize the footprint area required, the system should be installed flat or with minimum pitch.

Detailed below is the methodology used to calculate the required number of stormwater chambers to meet the required storage volume, and to determine whether the stormwater chambers will fit in the proposed lot area.

Determine Total Number of Stormwater Chambers

The number of stormwater chambers required for the system is calculated based on the required storage volume, V_R, and the maximum storage depth, S_D. The maximum storage depth, S_D, is used to determine the available storage volume per chamber at that depth, V_C, (including the volume in the surrounding gravel, with a void ratio, "e", of 33%) based on tables published by the manufacturer. The number of chambers, N_C, is then calculated using the following equation:

$$N_C = \frac{V_R}{V_C}$$

Where:

N_C = the required number of stormwater chambers for the system

V_R = the required storage volume, ft^3 (calculated in Section 2.2)

V_C = the available storage volume per stormwater chamber at maximum storage depth, S_D, as per manufacturers' specifications, ft^3

The volume of storage allowed is only to the depth of S_D (see Section 2.2). Therefore, the vendor supplied unit storage volume per chamber, V_C, or per linear foot, must first be adjusted accordingly.

Determine Number of Stormwater Chambers

The maximum number of rows of stormwater chambers, N_{RMAX}, and stormwater chambers per row, N_{CRMAX}, are determined based on manufacturers' specifications and the length, AL_L, and width, AL_W, of the available lot area (**Figure 2-4**). The maximum number of chambers per row is calculated as follows:

$$N_{CRMAX} = \frac{AL_L - W_M - 2B_W}{L_C}$$

Where:

- N_{CRMAX} = the maximum number of chambers per row (round down to nearest whole number)
- L_C = the length of an individual stormwater chamber, as per manufacturers' specifications, ft
- AL_L = the length of the available lot area, ft
- W_M = the width of the manifold, ft
- B_W = the width of the buffer area, ft

Note: Manufacturers typically recommend allowing a one-foot wide buffer area around the perimeter of a stormwater chamber system to allow for adequate work area. The Construction Codes must also be referenced for required buffers and setbacks.

The maximum number of rows which will fit in the available area, is then calculated as:

$$N_{RMAX} = \frac{AL_W - 2B_W + W_S}{W_C + W_S}$$

Where:

- N_{RMAX} = the maximum number of rows, round down to the nearest whole number
- W_C = the width of an individual stormwater chamber, as per manufacturers' specifications, ft
- W_S = the space between rows of stormwater chambers, as per manufacturers' specifications, ft
- A_{LW} = the width of the available lot area, ft
- B_W = the width of the buffer area, ft

The above results should be used to verify that the required number of chambers can be placed in the available lot area. The maximum number of stormwater chambers that will fit in the available lot area, N_{CMAX}, is calculated as:

$$N_{CMAX} = N_{CRMAX} N_{RMAX}$$

Where:

- N_{CMAX} = the maximum number of chambers that will fit in the available lot area
- N_{CRMAX} = the maximum number of chambers per row based on available lot area
- N_{RMAX} = the maximum number of rows based on available lot area

If $N_C > N_{CMAX}$ → Available lot space is insufficient for required number of chambers.

If N_C < or = N_{CMAX} → Available lot space is sufficient for required number of chambers.

Select Final Chamber Configuration

It is recommended that chambers be installed with an equal number in each row to simplify construction.

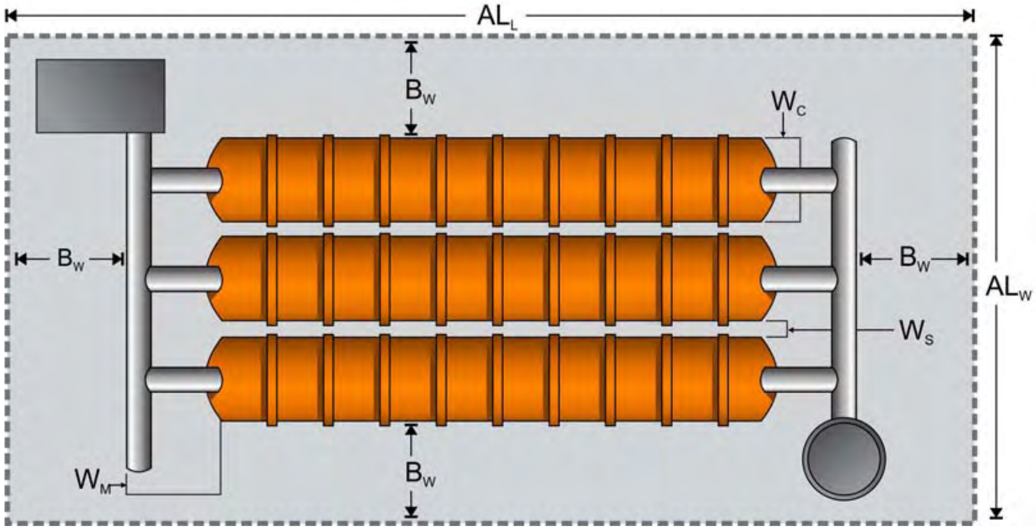


Figure 2-4:
A plan view of a typical stormwater chamber layout.

The designer should choose the number of rows, N_R, and the number of chambers per row, N_{CR}, such that:

$$FA_{\min} = [N_R(W_S + W_C) + 2B_W][N_{CR}L_C + 2B_W + W_M]$$

Where:

N_R = the chose number of rows

N_{RMAX} = the maximum number of rows

N_{CR} = the chosen number of stormwater chambers per row

N_{CRMAX} = the maximum number of stormwater chambers per row

N_C = the required number of stormwater chambers for the system

Where enhanced pretreatment is used, the pretreatment chambers may be installed in a single row or in multiple rows depending on the number of chambers required. The remaining chambers are installed in rows adjacent to the pretreatment chambers to achieve the total storage volume.

Calculate System Footprint Area

The minimum footprint area, FA_{MIN}, for the stormwater chamber system (including buffer and manifold areas) is equal to:

$$N_R \le N_{RMAX}$$

$$N_{CR} \le N_{CRMAX}$$

$$N_R N_{CR} \ge N_C$$

Where:

FA_{min} = the minimum footprint area, ft^2

N_R = the number of rows

W_S = the spacing between rows of stormwater chambers, as per manufacturers' specifications, ft

W_C = the width of an individual stormwater chamber, as per manufacturers' specifications, ft

B_W = the width of the buffer area, ft

N_{CR} = the number of stormwater chambers per row

L_C = the length of an individual stormwater chamber, as per manufactuers' specifications, ft

W_M = the width of the manifold, ft

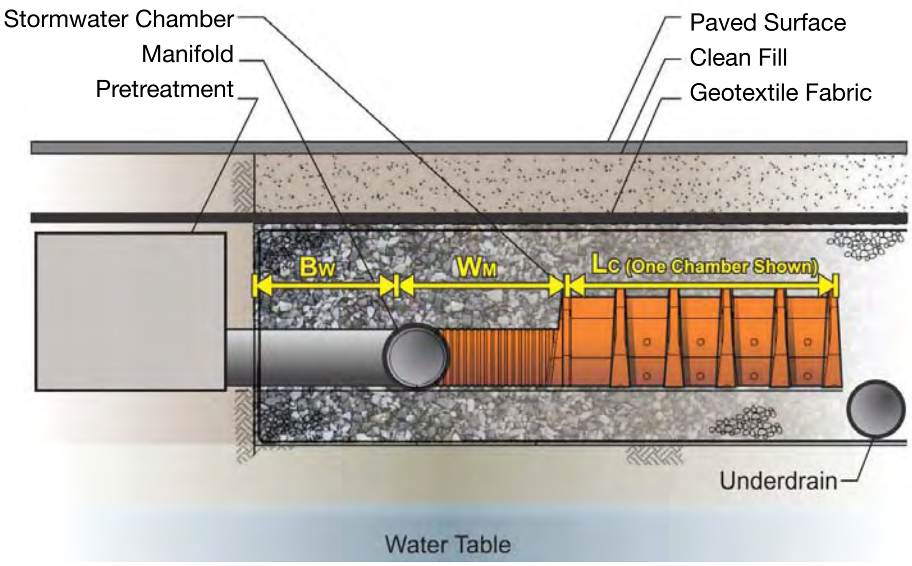


Figure 2-5:
Profile view of a stormwater chamber and distribution system configuration.

Determine Layout of Chambers

The exact size and configuration of the stormwater chambers depends on the manufactured system chosen. This section describes the major components of a stormwater chamber system common among several manufacturers.

Inlet Configuration

The most common stormwater chamber system configuration consists of an inlet catch basin connected to a header pipe and manifold system. Flow from the catch basin enters the header pipe, which is sized in accordance with the Construction Codes. The manifold is used to distribute flows from the header pipe to several parallel rows of stormwater chambers.

Internal Distribution Network

The exact nature of the stormwater chamber system internal distribution network is part of the overall product design and will depend on the manufactured system chosen. While some systems employ HDPE or PVC pipes to directly connect the individual stormwater chambers, others rely on flow through the perforated chamber walls and embedded gravel media for distribution of flow throughout the system.

Outlet Configuration

While several outlet configurations may be available depending on the manufactured system selected, a recommended method is to install a perforated underdrain pipe placed within the crushed gravel foundation layer at the end of the chamber rows, opposite the inlet header pipe. This underdrain pipe should be oriented perpendicular to the orientation of the chambers **(Figure 2-5)**.

Underdrain System

The minimum size underdrain perforated pipe, if included, is three inches in diameter.

2.4 Rooftop System Sizing Calculations

For sites with large roof areas, storing stormwater on the rooftop may be preferable or even necessary. For a rooftop system to meet the DEP stormwater performance standard, the available volume provided by the system must be greater than or equal to the required storage volume, V_R, as calculated in Section 2.2. The design process may be iterative, and the following steps may be repeated for several drainage configurations on a given roof until the requirements of the stormwater performance standard are satisfied.

The procedures in this section can be used to compute the storage volume provided by rooftop systems to handle storm flow generated on the rooftop. The steps below should be used in combination with the DEP Criteria described in Section 2.2. When calculating the onsite developed flow, a runoff coefficient credit may be applied to the portion of a roof that is vegetated. Application of this green roof credit is described in Section 2.4.2. A blue or green roof can be combined with a subsurface storage system to reduce the size of the subsurface system. Combination systems are described in detail in Section 2.6.

2.4.1 Sizing Blue Roof Systems

Determine Number of Drains

The first step in sizing blue roof systems is to determine the number of drains required. According to the Construction Codes, when using controlled flow roof drains, there must be at least two roof drains on roofs up to 10,000 square feet, and at least four roof drains on roofs larger than 10,000 square feet.

Determine Release Rate per Drain

Once the number of drains and drainage configuration have been selected, the release rate from each drain is calculated using the following equation:

$$Q_i = \frac{Q_{ROOF}}{N_{RD}}$$

Where:

Q_i = the maximum release rate from each drain, cfs

Q_{ROOF} = the release rate from rooftop detention, cfs (usually Q_{RR}, calculated in Section 2.2)

N_{RD} = the number of roof drains

Calculate Depth of Flow at Drains

The depth of flow at each roof drain, d_R, is determined based on the relationship between the release rate and the ponding depth, as specified by the roof drain manufacturer. Controlled flow roof drains contain weirs, with defined relationships between ponding depth and release rate **(Figure 2-6)**. For a given roof design, the roof drain manufacturer may have an off-the-shelf drain or may need to customize the weir depending on the release rate and number of drains required.

Manufacturers generally provide a sizing chart with the relationship between the release rate and the ponding depth. For most controlled flow roof drains, the relationship is nearly linear and may be approximated as a line having a defined slope, Q_n, in gallons per minute per inch. Units currently available in the market provide a flow of 9.1 gallons per minute per inch of ponding as standard. If a non-standard drain is used, it should be from a manufacturer approved by DEP, and a licensed professional should provide the manufacturer specifications and rating curve with the site connection proposal. Plans must include the manufacturer make and model information along with a note that no substitution is allowed. In addition, a licensed professional must certify the installa-

Controlled Flow Roof Drain

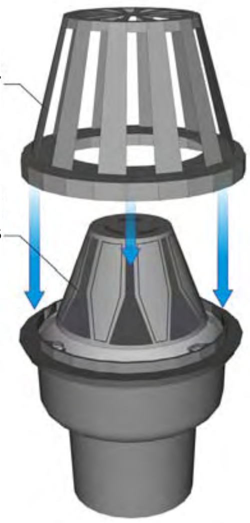


Figure 2-6:
Weirs with predetermined flow rates at various ponding depths control the release rate from a controlled flow roof drain.

tion of the specified non-standard drain following the Technical Report 1 (TR1) inspection.

As described above, the release rate from each controlled flow drain, Q_i, is first calculated in cubic feet per second. To determine the appropriate depth of flow, this release rate is converted to gallons per minute and divided by the release rate per inch of depth, Q_n, as specified by the controlled flow drain manufacturer. This flow depth must be less than or equal to the maximum ponding depth, d_{max}, as determined based on the structural analysis and the Construction Codes.

$$d_R = \frac{449Q_i}{Q_n} \leq d_{max}$$

Where:

d_R = the roof drain depth of flow, in

Q_n = the release rate per inch of ponding, as per manufacturer specifications, gpm/in

Q_i = the release rate from each drain, cfs (calculated above)

d_{max} = the maximum ponding depth, per the Construction Codes, in

Once controlled flow drains have been selected, the release rate from the roof drain specifications should be checked to verify that the design release rate from the blue roof is achieved. The licensed professional is responsible for checking to make sure that the controlled flow roof drain manufacturer provides the proper number of weirs for each roof drain, so that the total flow from all roof drains is equal to or less than the release rate from the rooftop system, Q_{ROOF}.

Controlled flow roof drains should be tamperproof to prevent unauthorized modifications, which would change the release rate and alter system performance. To ensure drains are tamperproof and flow is not increased beyond the calculated design, the manufacturer should provide controlled flows with the weirs welded in place.

Calculate the Available Storage Volume

The slope of the roof and controlled flow drain locations can significantly impact the available storage area on the rooftop **(Figure 2-7)**. On a flat roof with no slope, the available storage volume is calculated as:

$$V_A = A_R \frac{d_R}{12}$$

Where:

V_A = the available storage volume, ft^3

A_R = the available roof area, ft^2

d_R = the depth of flow, in (calculated above)

Note: Equipment or structures on the roof may interfere with rooftop storage. Those areas must not be included in the total available roof area when calculating available storage volume.

Depending on the roof configuration, even a 0.5% slope can reduce the available storage volume by 50% of the flat storage volume. Therefore, it is highly important to consider slope and controlled flow drain configuration as soon as possible in the design process.

For a sloped roof, the available storage volume needs to be calculated based on the geometry of each drainage area. Three factors are most important in determining the available storage capacity on a sloped roof: (1) the slope of the roof; (2) the number of slope directions (i.e., uni-directional will result in triangular volumes where multi-directional slope will result in pyramidal volumes); and (3) distance from the controlled flow drain to the edge of the drainage area (high point of the roof).

Calculations of the total available storage volume must be included in the connection proposal application. Steps to calculate available storage volume on a uni-directionally sloped roof are outlined below:

- Determine if the high point will be inundated when ponding the design storage volume;
- Calculate the volume of the triangular prisms around the drain;
- Calculate the volume of the rectangular prism above the triangles if the high-point is inundated; and
- Calculate the total available storage volume for all drainage areas.

See **Table 4-1** for available storage volumes of a typical uni-directional roof with a 0.5% slope.

Steps to calculate available storage volume on a multi-directionally sloped roof, which is generally more common than a uni-directionally sloped roof and stores less volume, are outlined below:

- Determine if the high point will be inundated when ponding the design storage volume;
- Calculate the volume of the pyramid around the drain;
- Calculate the volume of the rectangular prism above the pyramid;
- Calculate the volume of triangular prisms (if drainage areas are rectangular, not square);
- Calculate the volume of rectangular prisms above triangular prisms; and
- Calculate the total available storage volume for all drainage areas.

2.4.2 Sizing Green Roof Systems

This section explains when to apply reduced runoff coefficients for green roofs, and how to calculate the required storage volume and available storage for the system. The growing media that forms the substrate of the green roof provides a runoff reduction benefit. If the grow-

Roof Slope and Storage Volume

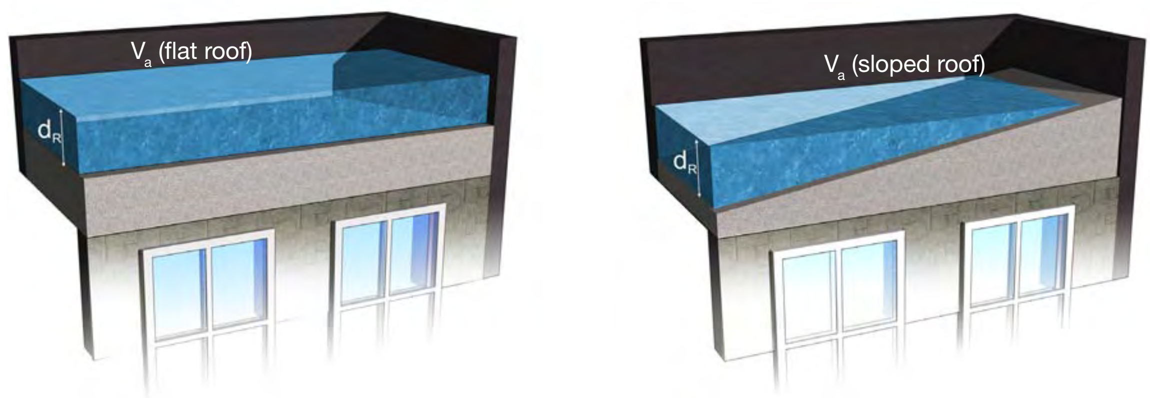


Figure 2-7:
For a given depth of flow, d_R, the storage volume on a relatively flat roof is greater than that of a sloped roof.

ing media is four inches or greater in depth, a C-value of 0.70 can be used to calculate the developed flow as per Section 2.1. Connection proposal applications with a proposed C-value of less than 0.70 for a green roof will be reviewed by DEP on a case-by-case basis.

The amount of storage provided by green roofs is limited by the drainage layers and the controlling weir elevation of the roof drain. The depth of growing media that is designed to be unsaturated (the depth that drains between storms) provides additional storage volume, and green roofs may also be designed to temporarily pond water at the surface. However, in almost all cases, green roofs need to be combined with a controlled flow roof drain or another onsite source control to comply with DEP's stormwater performance standard. The required storage volume can be accommodated through the use of separate storage reservoirs, such as drainage layers under the soil that store water and subsurface systems that receive flow from the green roof.

Calculate Depth of Flow at Roof Drains

After the release rate and required storage volumes are calculated as described in Section 2.2, the full set of calculations outlined in Section 2.4.1, Sizing Blue Roof Systems, should be completed. The following information provides the procedures that apply to green roofs only.

Calculate Available Storage Volume

See Section 2.4.1, Sizing Blue Roof Systems. Green roofs with drainage layers, when used in combination with blue roofs to ensure compliance with the stormwater performance standard, can provide storage volume within the assembly. However, if the roof slope is 1% or less, the slope does not need to be included in the available volume calculations and the roof can be considered flat. For all green roofs, slope must be accounted for when greater than 1%, or if storage is designed to pond on top of the green roof.

The Construction Codes limits stormwater storage on a roof to a maximum of 24 hours during a 10-year design storm.

The storage volume in green roofs is taken as the pore space in the growing media and drainage layer, and must be calculated as per manufacturers' specifications for the green roof design as part of the storage volume calculations submitted to DEP. Storage volume provided by moisture retention mats or other detention devices in the drainage layer, if part of the green roof, should also be included in these calculations. If there is not enough storage volume within the green roof assembly, storage can be designed to pond on top of the green roof.

2.5 Storage Volume Reduction Calculations

2.5.1 Determining Volume Reduction from Infiltration

Reductions in the required storage volume for proposed infiltration practices may be applied based on results from soil boring logs and permeability tests as per Appendix H. Where determined feasible, infiltration will effectively serve as a secondary outflow mechanism from the infiltration practice (**Figure 2.8**). Therefore, the infiltration loss can be combined with the stormwater release rate to determine an effective release rate and to decrease the required storage volume.

Calculate the Effective Release Rate (Q_{ERR})

The approach for combining the stormwater release rate with the infiltration loss to determine the effective release rate includes the following steps:

1. Calculate the required storage volume and maximum storage depth according to DEP's Criteria.

2. Size the open-bottom subsurface system based on the initial required detention volume and depth according to Section 2.2 of these guidelines. This will provide the minimum footprint area.

3. Use the footprint area from initial sizing to calculate infiltration loss according to the equation:

$$Q_{\inf} = \frac{FA_{\min} i_{soil}}{43{,}200} = \frac{(1{,}748)(1.0)}{43{,}200} = 0.04 cfs$$

$$Q_{ERR} = Q_{RR} + Q_{\inf} = 0.25 + 0.04 = 0.29 cfs$$

Where:

Q_{inf} = the infiltration loss, cfs

FA_{min} = the minimum footprint area, ft^2

i_{soil} = the soil infiltration rate (see Appendix H), in/hr

4. Add infiltration loss (Qinf) to the required release rate to compute the effective release rate:

$$Q_{ERR} = Q_{RR} + Q_{\inf}$$

Where:

Q_{ERR} = the effective release rate, cfs

Q_{RR} = the required release rate, calculated in section 2.2, cfs

Q_{inf} = the infiltration loss, cfs

Calculate Modified Required Storage Volume

Re-calculate the required storage volume utilizing DEP's Criteria and the effective release rate.

For example, given:

- stormwater release rate (Q_{RR}) = 0.25 cfs
- required storage volume (V_R) = 865 ft^3

Infiltration Practices

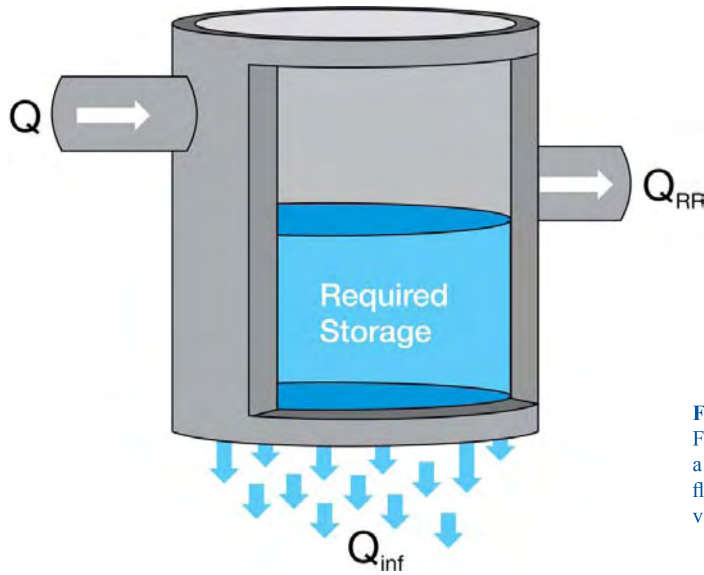


Figure 2-8:
For infiltration practices, a portion of the developed flow is retained on site via infiltration.

- minimum footprint area (FA_{min}) = 1,748 ft^2
- soil infiltration rate (i_{soil}) = 1.0 in/hr

Calculations:

$$Q_{inf} = \frac{FA_{min} i_{soil}}{43,200}$$

Use the effective release rate, Q_{ERR}, in conjunction with DEP's Criteria to determine the new required storage volume for the infiltration practice.

2.5.2 Determining Volume Reduction from Recycling

Applicants proposing a dedicated stormwater recycling system may specify a minimum continuous and constant use rate to reduce the size and footprint of subsurface or rooftop system. To receive volume credits for onsite stormwater management systems, the following criteria for recycling systems should be demonstrated on the connection proposal application submitted for DEP review:

1. The required release rate for the entire site cannot be exceeded at any time;
2. A minimum rate of continuous and constant water use from the recycling system should be specified, along with evidence that this water use will be consistent throughout the year and will be supplied by the stormwater recycling system at all times stored stormwater is available, even during the design storm specified in DEP's Criteria (i.e. 10-year storm). If the minimum constant and continuous water usage rate from the stormwater recycling system is less than the required release rate, an acceptable stormwater management system must be designed to manage the flow before discharging to the sewer system;
3. Any stormwater management systems required downstream of the stormwater recycling system shall be sized according to the guidance presented in Section 2, adding the continuous and constant water usage rate from the stormwater recycling system to the required release rate;
4. If a secondary or backup water supply is necessary to achieve a desired usage rate onsite, this supply should not reduce the

available storage volume within the stormwater recycling system and should not contribute any water to the stormwater management system;

5. Any connection to the city's water supply system should have a backflow prevention device per the Construction Codes;

6. Only the onsite drainage area connected to the recycling system can be considered for volume credit; and

7. Stormwater management systems incorporated into the same structure as the stormwater recycling system will be considered on a case-by-case basis provided the dedicated storage volume and outlet orifice are equivalent to those provided by a downstream stormwater management system.

If all of the above conditions are achieved, the minimum continuous and constant rate of water use effectively serves as a secondary outflow mechanism from the stormwater management system. Therefore, this rate can be combined with the stormwater release rate to decrease the stormwater management system size as follows:

1. Add minimum continuous and constant rate of water use, Q_{use}, to the stormwater release rate, Q_{RR}. This will provide the effective release rate:

$$Q_{ERR} = Q_{RR} + Q_{USE}$$

Where:

Q_{ERR} = the effective release rate, cfs

Q_{RR} = the required release rate, calculated in section 2.2, cfs

Q_{USE} = the continuous water use rate for rainwater recycling, cfs

2. Calculate the required storage volume using DEP's Criteria and the effective release rate as the new stormwater release rate.

For example, given:

- stormwater release rate (Q_{RR}) = 0.25 cfs
- minimum continuous and constant Rate of Water Use (Q_{use}) = 0.02 cfs

Calculation:

$$Q_{ERR} = Q_{RR} + Q_{USE} = 0.25 + 0.02 = 0.27cfs$$

Use Q_{ERR} in conjunction with DEP's Criteria to determine the new required storage volume.

2.6 Sizing Combination Systems

This section provides guidance on different types of combination stormwater management systems and related sizing calculations for compliance with DEP's stormwater performance standard. Based on DEP's Criteria, the sizing calculations above, and additional information provided in these guidelines, a number of combination systems are recommended including:

- Subsurface or rooftop systems with rain gardens, vegetated swales and other surface green infrastructure practices to decrease developed site flows and provide required storage volumes and release rates;
- Infiltration practices and rooftop systems or surface green infrastructure practices; and
- Stormwater recycling systems and subsurface or rooftop systems.

The calculations below specifically describe the recommended steps for sizing and configuring rooftop systems for discharge to a subsurface system requiring only one connection to the fronting sewer. The following steps should be used to calculate the required storage volumes for the "in-series systems" described above. Alternate configurations, such as "parallel systems," should follow similar procedures with modifications made specific to the type of subsurface or rooftop system upstream per the respective section of these guidelines. The total flow from the combination system and the site must comply with DEP's stormwater performance standard.

2.6.1 Calculate the Release Rate

See DEP's Criteria referenced in Section 2.2 of these guidelines to calculate the release rate, Q_{RR}, for the entire site.

2.6.2 Determine Available Storage Volume on Roof

Follow the procedures outlined in Section 2.4.1, Sizing Blue Roof Systems, to calculate the available storage on the rooftop. The maximum ponding depth should then be compared to the structural loading capacity of the roof and requirements of the Construction Codes. Verify that the release rate of the controlled flow drains matches the release rate used to calculate the available storage volume on the roof (this may be an iterative process). The only modification to the steps outlined in Section 2.4.1 is that the release rate from the rooftop system, Q_{ROOF}, can exceed the required release rate, Q_{RR}, so additional drains and weirs can be used to accommodate the slope and storage area available.

2.6.3 Calculate Effective Runoff Coefficient

When rooftop flow is restricted by controlled flow roof drains and discharged to a subsurface system, the effective runoff coefficient for the roof, C_{ER}, is computed by means of the following procedure.

Compute the ten-year rainfall intensity, i_{10}, for the duration of the storm, t_V, which requires the maximum detention volume and is used in the storage volume calculation in Section 2.2 above, by means of the equation:

$$i_{10} = \frac{140}{t_V + 15}$$

Where:

i_{10} = the ten-year rainfall intensity, in/hr

t_v = the duration of rainfall event requiring maximum detention volume with a variable outflow, as calculated according to DEP's Criteria, minutes

Compute the effective runoff coefficient for the roof with runoff restricted by controlled flow roof drains, C_{ER}, by the means of the equation:

$$C_{ER} = \frac{311 Q_{RR}(t_V + 15)}{A_T}$$

Where:

C_{ER} = the effective runoff coefficient for the roof with runoff restricted by controlled flow roof drains

Q_{RR} = the maximum release rate from roof, cfs

t_V = the duration of rain event requiring maximum detention volume with a variable outflow, min

A_T = the roof area tributary to the roof detention, ft^2

2.6.4 Calculate the Required Volume for the Subsurface System

See DEP's Criteria referenced in Section 2.2 of these guidelines to calculate the required storage volume, V_R, using the effective runoff coefficient for the restricted roof, C_{ER}, for the roof when calculating the weighted runoff coefficient for the site, C_W. The resulting storage volume can be used to size the subsurface system per the guidelines in Section 2.3, Subsurface Systems.

SECTION 3

SUBSURFACE SYSTEMS

Subsurface systems provide temporary storage of stormwater runoff underground, slow release to the sewer system, and retention where infiltration into soils below is feasible. This section describes typical subsurface systems that comply with the stormwater performance standard. Selection of the appropriate subsurface system will depend on a number of factors, including siting, design and construction considerations specific to each development. In addition to these considerations, general operations and maintenance recommendations are provided in this section.

Perforated pipe system installed at Nehemiah Spring Creek Homes at Gateway Estates Phase 2 in Brooklyn, a project sponsored by HPD and the Nehemiah Housing Development Company.

Figure 3-1:
Subsurface storage vaults installed at Nehemiah Spring Creek Homes at Gateway Estates Phase 2 in Brooklyn, an affordable housing development sponsored by HPD and the Nehemiah Housing Development Company.

3.1 Types of Subsurface Systems

Subsurface detention is an effective practice for controlling runoff on a wide variety of sites. Choosing and designing the best subsurface system for each site requires a careful review of the site's characteristics in early planning and design phases. Four types of subsurface systems—storage vault/tank, gravel bed, perforated pipe and stormwater chamber—are described below.

All types of subsurface systems are open-bottom except for vaults or tanks, which can be designed as either open or closed-bottom systems. Where site conditions allow, open-bottom systems facilitate infiltration, reducing stormwater volumes entering the sewer system and providing water quality treatment. Under these conditions, open-bottom systems are referred to as infiltration practices and include drywells that are designed and constructed in accordance with these guidelines.

Providing infiltration through open-bottom systems may allow property owners to request a detention volume reduction on the connection proposal application, based on the results of soil borings and permeability tests. In addition, the bottom of all infiltration practices must be located a minimum of three feet above the groundwater table to prevent possible groundwater infiltration into the sewer system, and boring logs must be submitted to establish groundwater table levels. In addition, all open-bottom systems must comply with setback and buffer distances from structures and lotlines, per the Construction Codes.

A pretreatment structure at the inlet of the subsurface system may also be implemented to trap coarse sediment, oil and grease, and debris, and provide an accessible cleanout location. Pretreatment structures must be properly maintained to remain effective over time.

Finally, an overflow is required for all subsurface systems to minimize the risk of damage to the system and upstream property during large rainstorms.

3.1.1 Storage Vaults and Tanks

Vaults and tanks provide open space for water storage and, as a result, require less space to detain a given volume compared to other subsur-

Advantages and Limitations of Subsurface Systems

Advantages:

- Do not take up area above the surface
- Easy to implement below paved areas and open spaces
- Can be covered with vegetation, grass, asphalt, concrete or pavers
- Able to withstand substantial surface loading, such as HS-20 loading requirements
- Flexible in design layout, allowing them to be configured within irregular spaces
- Long life cycles
- Multi-chamber systems reduce potential for clogging
- Allow for infiltration (if open-bottom system)
- Readily available materials or proprietary technologies

Limitations:

- Can clog if pretreatment and maintenance are inadequate
- Footprint of system is dependent on void ratio
- Setbacks from building foundation and property lines may apply (if open-bottom system)
- Only closed-bottom systems can be used on sites with lotline-to-lotline buildings
- The bottom of the detention facility must be located a minimum of three feet above groundwater (if open-bottom system)

face systems. Where existing soil and groundwater conditions allow, storage vaults and tanks can be designed as open-bottom systems that promote infiltration. Closed concrete systems are useful at sites where infiltration is either not possible or undesirable, space is constrained, or for systems located inside buildings. Storage vaults and tanks are typically constructed from either pre-cast concrete or corrugated metal pipe (CMP). Other options include cast-in-place concrete or proprietary modular systems, some of which are made from high-strength plastics.

3.1.2 Gravel Beds

Gravel bed systems consist of a clean-washed, uniformly graded stone aggregate storage bed. Gravel beds have the lowest void ratio compared to other subsurface systems (typically 33%) and, as a result, require more space to detain a given volume of stormwater. However, the larger footprint area provides greater potential for infiltration. Gravel beds are intended to be used as infiltration practices where site conditions allow and often contain an underdrain system.

3.1.3 Perforated Pipes

Perforated pipe systems consist of a set of parallel perforated pipes embedded in gravel. In many ways, perforated pipe systems work in a similar manner as oversized underdrains or French drains (a gravel filled trench with perforated pipe used to convey water). While underdrains and French drains are typically designed for conveyance, a perforated pipe system is

Figure 3-2: Construction of a perforated pipe system at NYCHA's Bronx River Houses in the Bronx.

designed for storage. Stormwater is stored in pipes between four and 48 inches in diameter, and is released into the ground from the stone-filled trench. Perforated pipes function as infiltration practices where site conditions allow.

3.1.4 Stormwater Chambers

Stormwater chamber systems consist of parallel rows of open-bottom, perforated plastic chambers (half pipes) surrounded by stone aggregate. The void ratio is maximized in the storage chambers and, when full, the void space in the gravel also provides stormwater storage. As proprietary technologies, stormwater chamber designs are developed and modified on a regular basis, and should be installed according to manufacturers' specifications. Stormwater chambers are intended to be used as infiltration practices where site conditions allow.

3.2 Siting Considerations for Subsurface Systems

Subsurface systems are suitable for different land uses in urban environments. Subsurface systems can be installed below a variety of generally flat areas, such as lawns, gardens, parking spaces or lots, carports, driveways, walkways, patios, and public plazas. All subsurface systems should be designed to meet the load-bearing requirements of the surface cover, and should not be constructed below building foundations. This section outlines key siting considerations for selecting the appropriate subsurface system during site planning and building design.

Sustainable Urban Site Design Manual

The New York City Department of Design and Construction's (DDC) June 2008 *Sustainable Urban Site Design Manual* serves as a resource for environmentally and socially responsible urban site design practices for agencies and licensed professionals. The manual features case studies of city projects that incorporate sustainable site design strategies including: maximizing vegetative applications; limiting site disturbance; implementing stormwater source controls; and using recycled materials.

Table 3-1: Footprint areas (sq ft) of subsurface systems for different lot sizes and C-Values (for planning purposes only)

Lot Size (sq ft)	System Depth (ft)	$C_w = 0.9$				$C_w = 0.7$			
		Vault	Storm-water Chamber	Perforated Pipe	Gravel Bed	Vault	Storm-water Chamber	Perforated Pipe	Gravel Bed
5,000	1.5	217	335	355	591	169	260	276	460
6,000	1.5	291	449	475	792	226	349	370	616
7,000	1.5	368	569	602	1,003	286	442	468	780
8,000	1.5	448	692	733	1,222	348	539	570	950
9,000	1.5	530	820	868	1,447	413	638	675	1,125
10,000	1.5	615	950	1,006	1,678	478	739	782	1,304
15,000	1.5	1,058	1,635	1731	2,885	823	1,272	1,346	2,244
20,000	1.5	1,524	2,355	2,494	4,157	1,185	1,832	1,940	3,233
30,000	1.5	2,496	3,859	4,086	6,810	1,942	3,001	3,179	5,297
43,560	1.5	3,860	5,965	6,316	10,527	3,002	4,640	4,913	8,188
65,340	2.5	2,687	4,153	4,397	7,329	2,090	3,230	3,420	5,700
87,120	4.5	2,052	3,172	3,358	5,597	1,596	2,467	2,612	4,353

* Infiltration is not accounted for in these sizing values.

3.2.1 Soil, Bedrock, and the Water Table

Open-bottom systems can be used in areas with or without permeable soil. In areas with permeable soil, a detention volume reduction for the infiltration practice may be permitted consistent with the guidelines discussed in Section 2. Open-bottom systems should be located at least three feet above the seasonally high water table elevation.

In areas where existing soil has low load-bearing capacity, it may be necessary to provide a thicker stone bed layer beneath the subsurface system for structural support.

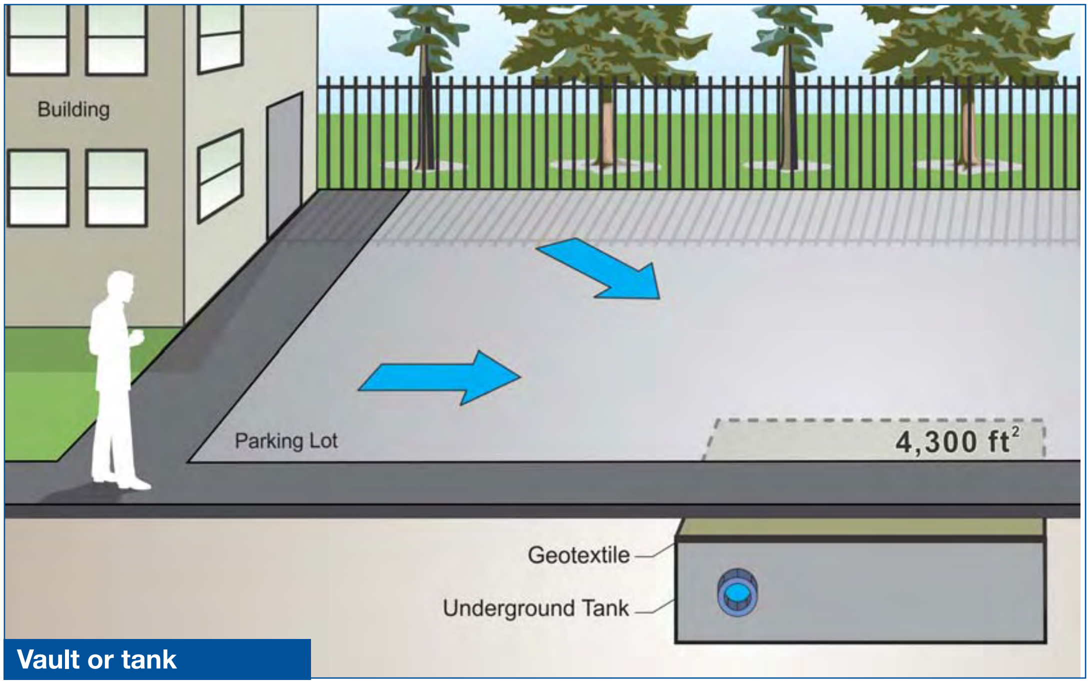
Depending on the elevation of bedrock, site designers and licensed professionals should ensure that any subsurface lateral movement can be accommodated and will not impact adjacent buildings or neighboring properties.

3.2.2 Buffers and Setbacks

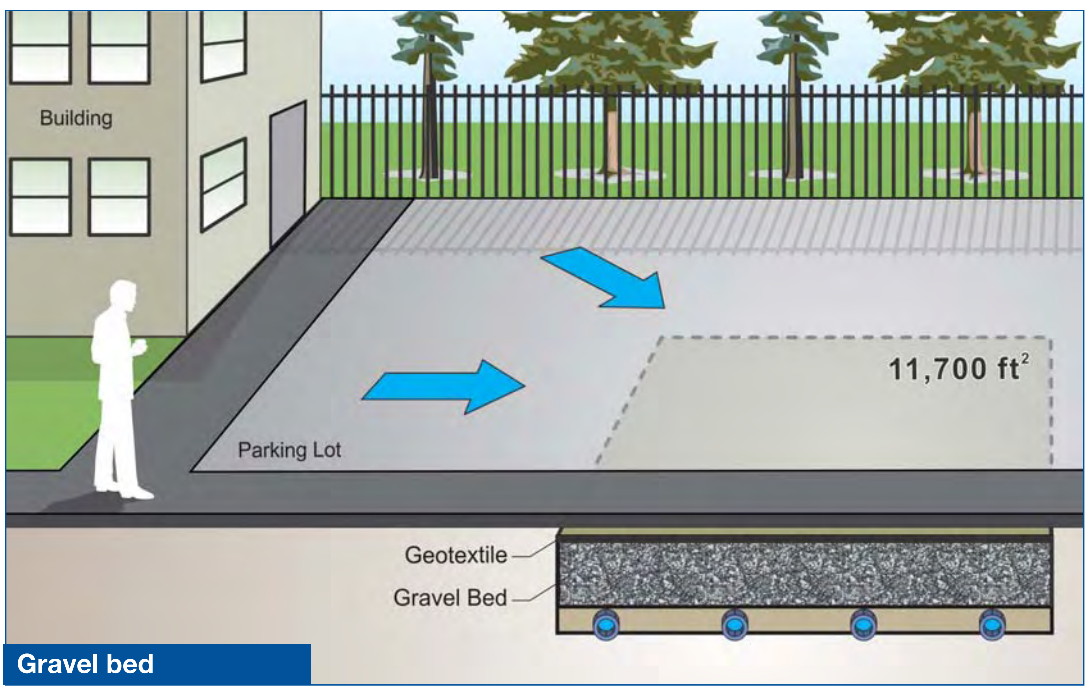
If an open-bottom system is to be installed, requirements for setbacks or buffers apply, per the Construction Codes. Specifically, open-bottom subsurface systems must be located at least five feet from all lotlines (except lotline abutting a street) and ten feet from all foundations or walls. In addition, specific zoning regulations for setbacks, yard spaces and floor area ratio (FAR) may also impact the siting of building footprints, non-building uses, and the configuration of a subsurface system.

3.2.3 Utility Considerations

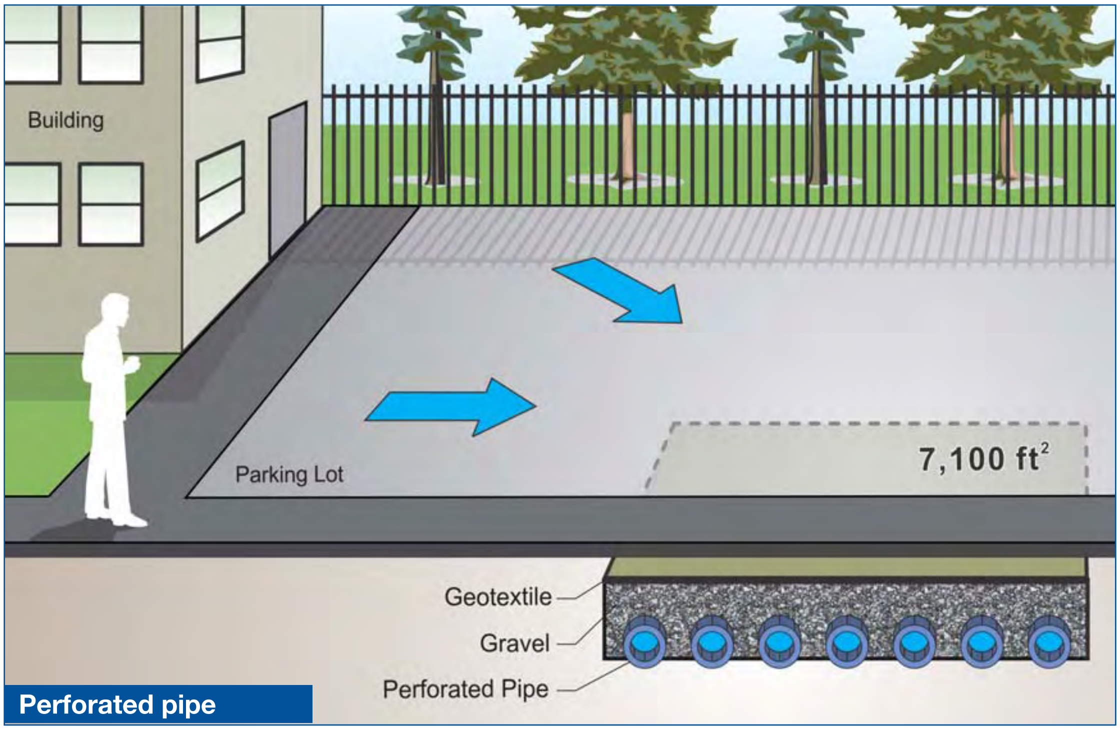
The locations of existing underground utilities should be established before a subsurface system is selected. Utilities, such as existing water mains, telecommunications, and steam and gas lines, can be costly and difficult to relocate. In



Vault or tank



Gravel bed



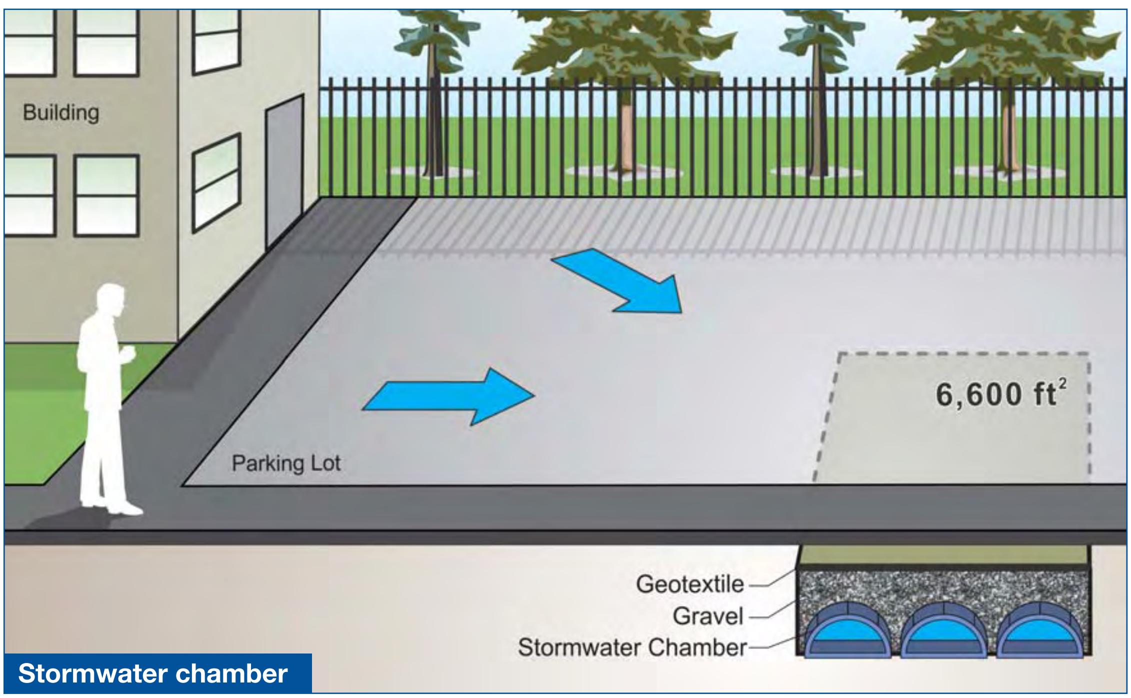


Figure 3-3:
Schematics of four different subsurface systems showing relative footprint areas on a typical one-acre lot

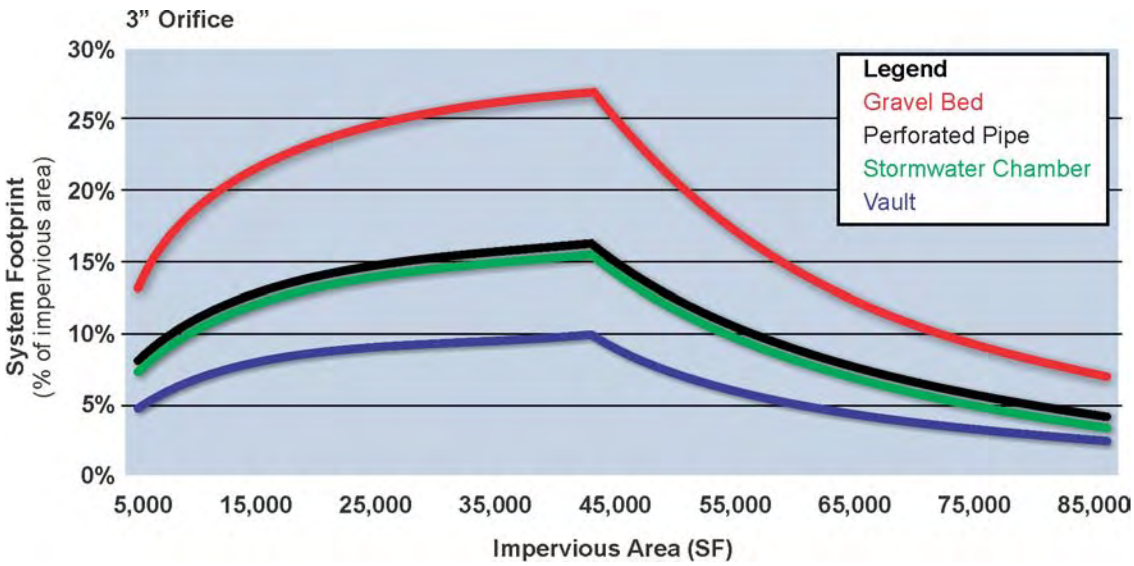


Figure 3-4a: Relationship between impervious area and relative footprint of a subsurface system using a 3-inch orifice to control the release rate (assumes no infiltration).

addition, access to such utilities, including sufficient sheeting distances, should be maintained and may affect the layout and siting of a subsurface system. State law requires that excavators and contractors contact DigNet - a nonprofit organization that serves as the liaison between utility companies and excavators or homeowners - between two and 10 days before any mechanized digging or excavation work to mark underground lines.

3.2.4 System Configuration

Subsurface systems must be sized to control the required storage volume, as calculated in Section 2.1. **Table 3-1** illustrates the effect of lot size and runoff coefficients on the footprint areas of subsurface systems for planning purposes only. For a given amount of impervious area, gravel bed systems require the greatest footprint area relative to the site impervious area, whereas vaults and tanks have the smallest space requirements**.** The footprint area of a subsurface system also depends on the amount of storage provided in void space, which varies by system type. Increasing the system depth can reduce the system footprint area as long as the stormwater performance standard is met, the subsurface conditions are adequate, and the elevation of the sewer connection is below the outlet of the subsurface system.

Figure 3-4a and **Figure 3-4b** illustrate the relationship between impervious area and the footprint area of the subsurface system, which is shown as a percentage of the total impervious area of the lot. As the total impervious area increases, the size of the subsurface system relative to the impervious area increases to a maximum value, then decreases. The peaked shape of the curves is a result of the stormwater performance standard, which holds the release rate constant at 0.25 cubic feet per second for sites up to one acre in size, but allows a higher release rate (proportional to lot size) for sites larger than one acre.

The primary determinants of stormwater outlet flow from a subsurface system are the head or pressure on the outlet orifice and the diameter of the orifice. The greater the system depth and orifice diameter, the greater the outlet flow.

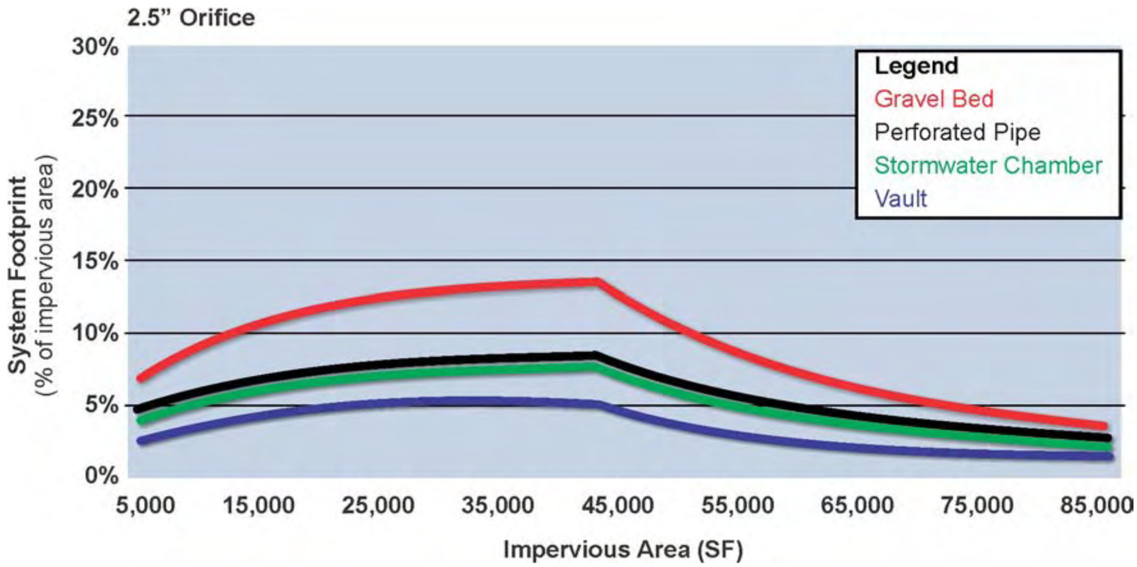


Figure 3-4b: Relationship between impervious area and relative footprint of subsurface system using a 2.5-inch orifice to control the release rate (assumes no infiltration).

Per DEP's stormwater performance standard and given a certain orifice size, maximum system depths are held constant until the area threshold of one acre is exceeded and a higher release rate is permitted. With the higher required release rate, the maximum depth of the system (i.e. the head on the orifice) can increase. The increase in system depth allows the footprint area to become smaller as a percentage of the total impervious area. The trends illustrated in the figures apply as long as the system depth is not limited by site constraints.

Licensed professionals are allowed to vary the size and type of orifice if a greater system depth is feasible and a smaller footprint area is desired to maximize building uses. For example, a one-acre lot controlled by a vault with a 2.5-inch diameter orifice **(Figure 3-4b)** has half the footprint area of a vault controlled by a three-inch diameter orifice **(Figure 3-4a)**. Given the same release rate, the head above a 2.5-inch orifice can be greater than the head above a three-inch orifce. Therefore, the decreased orifice size increases the maximum system depth and allows for a smaller system footprint area. The DEP stormwater performance standard allows orifices with a minimum diameter of two inches.

If dictated by space constraints, subsurface systems can be installed adjacent to each other in linear or differently shaped configurations. A stacked or terraced configuration may be possible for all systems except for gravel beds, provided that the stormwater performance standard is met, the sewer is located below the depth of the outlet orifice, and access to all units is provided for inspection and maintenance. To maintain efficient flow in the system, separate storage units should be properly connected to each other with pipe or, if applicable, gravel. Disconnected units with separate inflow and pretreatment structures may also be installed in different parts of the site, provided that all units can be connected to a common outflow point.

The actual sizing of subsurface systems may also differ based on topography, the presence of utilities, and the location of other ancillary structures required for sewer connections. Depending on these factors, the sewer connection, pretreatment structures, drains, inlets, and outlet

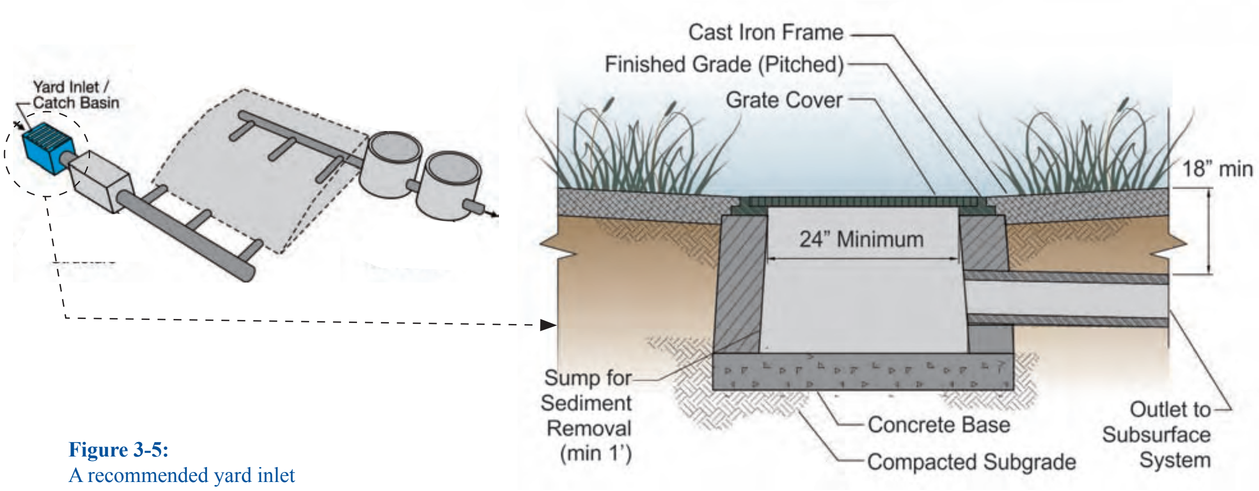


Figure 3-5:
A recommended yard inlet (situated at the low point of the site) with pretreatment sump.

control structures may also be some distance from the subsurface system. Access to these features should be provided on the surface for regular system maintenance and inspections.

The outlet control structure for subsurface systems should be located at the most downstream point in the system to ensure proper system function. The outlet control structure should generally be situated at the lowest elevation on the site that still allows adequate depth and flow to the sewer connection.

Bioretention in Parking Lots

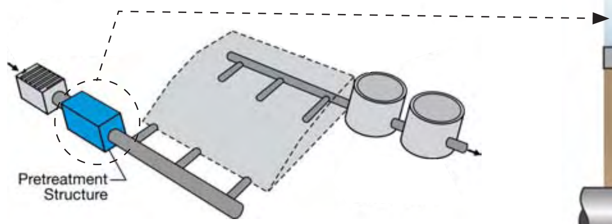
In accordance with the New York City Zoning Resolution, most new construction of commercial and community facility parking lots require perimeter and interior landscaped areas to control stormwater runoff. The New York City Zoning Resolution also requires a minimum percentage of planting in front yards in R1 – R5 Districts based upon street frontage. Adding perimeter and interior landscaping will effectively reduce the weighted runoff coefficient and developed flow for the site. Parking lot pavement should also be graded to allow sheet flow into these landscaped areas. DEP will reveiw graded parking lot designs for reduced storage volume requirements and overall compliance with the stormwater performance standard.

3.3 Subsurface System Design

Proper design will help to ensure that the subsurface system is built to provide adequate storage, support the desired use at the surface, conform to existing rules and regulations, and allow for appropriate operation and maintenance over time, as needed. The following guidelines, along with manufacturer-provided specifications, will assist the licensed professional in designing subsurface systems to comply with DEP's stormwater performance standard.

3.3.1 Inlets and Drains

Inlets and drains capture and convey surface runoff into a subsurface system. Yard inlets should be situated at low points of the site **(Figure 3-5).** Yard inlets should be connected



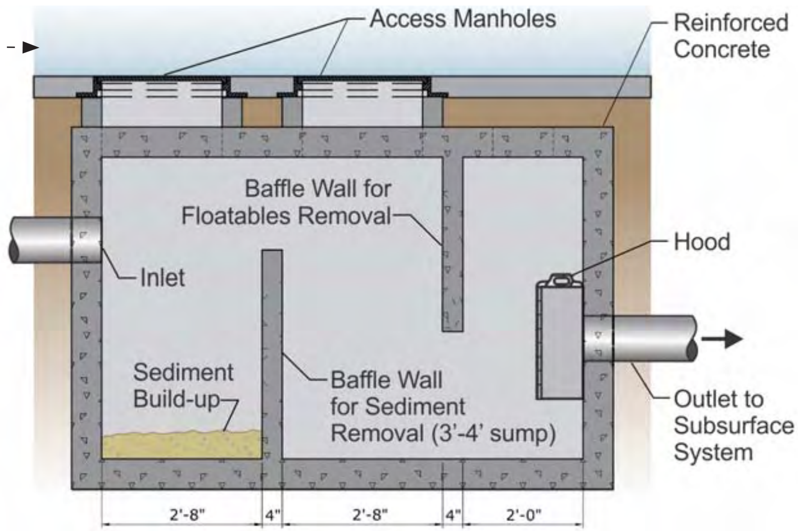


Figure 3-6:
A three-chamber pretreatment structure provides a section for sediment removal and a section for floatables removal (trash and hydrocarbons).

to sumps or hoods, which may also be fitted with pretreatment filter bag inserts to capture sediment, leaves and other debris (see following section for additional pretreatment information). Rooftop runoff can be conveyed to the pretreatment sump of the inlets and drains using direct downspout connections.

For larger impervious areas (such as parking lots), catch basins with grates, sumps and hoods are recommended. The inlet grates prevent large pieces of trash from entering the inlet and sumps collect sediment and grit. Hoods and baffles prevent floatable debris from entering the subsurface systems. Catch basins may also be fitted with pretreatment filter bag inserts to capture sediment as long as they are not located in the current or proposed public right-of-way. Depending on the size and condition of the site, the following catch basins are recommended:

- A rectangular catch basin of concrete, commonly installed within the street bed or in parking lots, which includes a 48-inch deep sump and a plan view width and length of 42 inches;
- A cylindrical basin with a diameter approximately four times greater than the diameter of the outlet to the system. The minimum diameter is three feet, in order to provide adequate access for maintenance; or
- A vendor-supplied catch basin.

In open-bottom systems, the inlet velocity should be limited through the selection of the header pipe diameter and slope in order to protect the stone bedding from scour or disturbance. Manufacturers of proprietary systems may provide a recommended upper limit for the inlet velocity.

3.3.2 Pretreatment

Although not required, subsurface systems should include a pretreatment structure, when feasible, to ensure continuous system performance and provide an accessible location for cleaning sediment and debris from the system **(Figure 3-6)**. Pretreatment structures remove sediment, floatable debris, hydrocarbons and other pollutants commonly found in stormwater runoff. Without pretreatment, these pollutants may settle or coalesce within the sub-

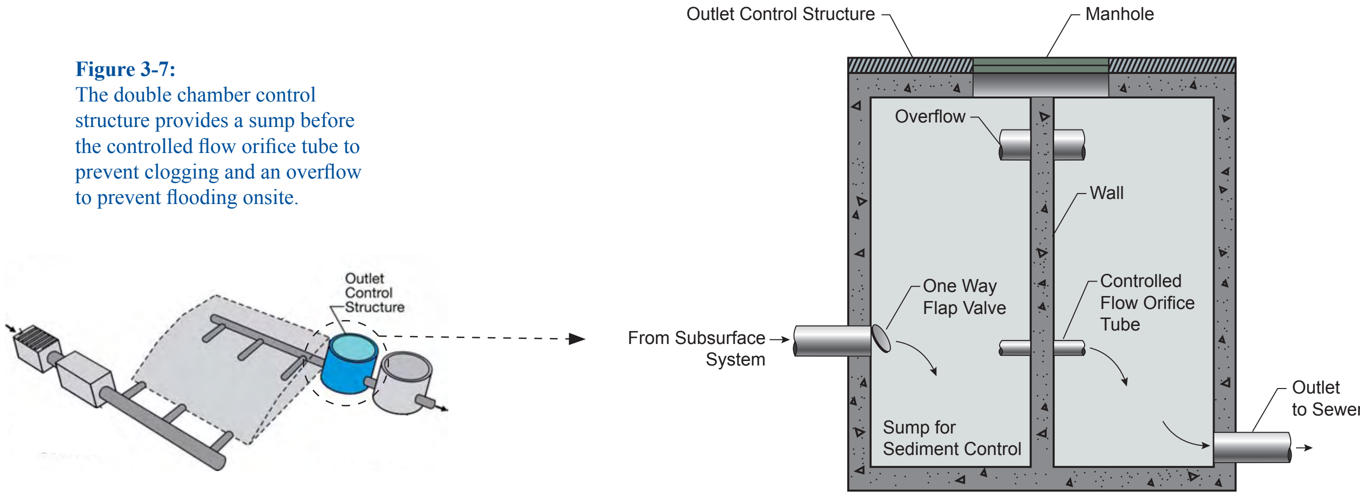


Figure 3-7: The double chamber control structure provides a sump before the controlled flow orifice tube to prevent clogging and an overflow to prevent flooding onsite.

surface system, and over time, could reduce storage capacity, clog the distribution system, and prevent infiltration. As a result, the system may fail and water may back-up onto the surface of the site at the inlets or drains.

Pretreatment structures should be placed downstream of all inlets and just upstream of the subsurface system. The outlet from the pretreatment structure is directly connected to the subsurface system using a distribution or header pipe.

Pretreatment structures typically consist of a sump, filter, floatables baffle, and debris hood. The sump allows for adequate settling of sediment and grit carried by surface runoff. Sump depth should be based on the size of the drainage area and type of inlet. The baffle and debris hood help to separate floatable debris and liquids. The baffle should extend at least four inches below the inflow invert elevation.

Filter bag inserts are woven or nonwoven fabrics that are placed under or attached to the inlet grate to capture litter and debris passing through the grate. These fabric bags should be accessible from the surface to enable inspections, debris removal, cleanings and replacement, as necessary. Filters are generally sized based on the length and width or diameter of the inlet grate.

An alternative pretreatment approach is available for stormwater chambers. In this configuration, an additional stormwater chamber substitutes for a header pipe. This header chamber receives flows from the inlet structure, serves as a pretreatment chamber, and distributes flows into the stormwater chamber system. Raised outlet pipes in the header chamber allow it to fill to the design height before overflowing into the other chambers in the system. This configuration is possible only with stormwater chambers that provide pipe perforations laterally on the main chamber units. Manufacturers may specify other pretreatment structures for proprietary systems that should be constructed as part of the subsurface system.

Pretreatment may be of particular importance for industrial maintenance facilities where pollutants of concern include, salt, oils, and grease. In addition to the structures described above, pretreatment devices such as media filters, catch

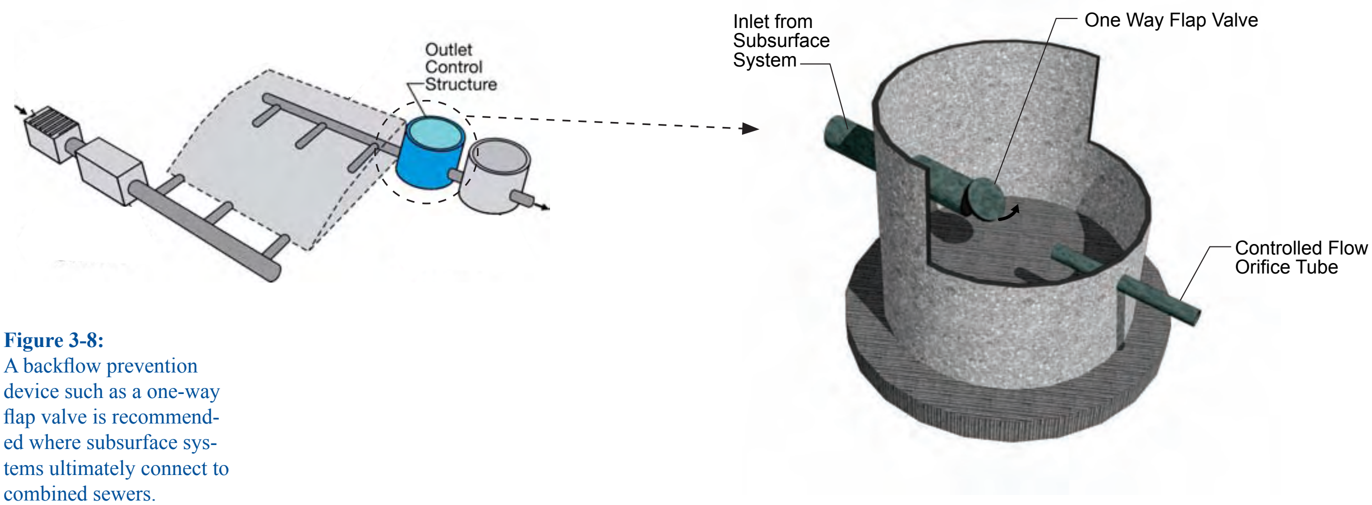


Figure 3-8:
A backflow prevention device such as a one-way flap valve is recommended where subsurface systems ultimately connect to combined sewers.

basin inserts, and sorbents have been shown to be effective at removing oils and grease (CWP 2007, Pitt et al. 1999). Salt, however, is highly soluble and is not readily removed by structural management practices, including media filters. Pollution prevention, such as covering salt storage areas or placing impermeable barriers around salt piles is the most effective method of reducing salt transport via stormwater runoff (WDNR 1994, MPCA 2000).

3.3.3 Outlet Control Structure

The outlet control structure should include a sump, manhole, overflow or bypass, controlled flow orifice tube and a backflow prevention device. The orifice size, combined with the depth of head acting on the orifice, restricts the developed site flow to the release rate determined by DEP's stormwater performance standard. To prevent clogging and maximize the subsurface detention depth, the smallest orifice tube allowed by DEP is two inches in diameter.

The outlet control structure, as shown in **Figure 3-7,** is located between the collector pipes from the subsurface system and the connection to the sewer. The outlet control structure should also be designed with a sump at least 12 inches in depth to collect any particles that are conveyed through the subsurface system. A manhole or riser should be located above the outlet control structure to provide access for inspections and cleanings.

The collector pipe from the subsurface system connected to the outlet control structure should have a method of preventing backflow into the system according to the Construction Codes **(Figure 3-8)**. One method of backflow prevention is a check valve installed on the downstream side of the collector pipe (e.g., duckbill check valve or one-way flap valve).

The outlet pipe leading to the sewer should allow a velocity of at least three feet per second. The diameter of the outlet pipe is determined by the minimum required velocity of three feet per second and the available slope between the outlet control structure and the sewer connection. The outlet sump depth should be modified as appropriate to keep the outlet pipe slopes within 10%. The minimum outlet pipe diameter is one pipe size larger than the orifice size of the outlet con-

Figure 3-9: Observation wells allow property owners to observe water levels and flush the subsurface system should it become clogged.

trol structure, and it must increase to that size within three feet of the orifice.

3.3.4 Observation Well

In order to monitor the function of the subsurface system, an observation well is recommended. The well should be located near the longitudinal center of the system, and as identified in the engineering design documents. When clogging occurs, the observation well can be used as a cleanout in order to flush the system.

Observation wells should be flush with ground surfaces to avoid a tripping hazard. They should consist of a minimum four-inch diameter polyvinyl chloride (PVC) pipe, extending from the reinforced circular port on the top of the subsurface system to the surface grade. The pipe should be anchored to the subsurface system, secured and capped during the backfill process, and equipped with a lockable, flush-mounted top lid. The area around the observation well should be graded to divert drainage and debris away from the well. Observation wells should be clearly marked on the site plan and as-built plans for the subsurface system.

3.3.5 Materials

General regulations for building and plumbing materials are outlined throughout the Construction Codes. The listed materials and related specifications included in **Table 3-2** should not be considered exhaustive or inclusive of all applicable specifications. The licensed professional is responsible for meeting all applicable criteria related to building and plumbing materials. Alternatives may be proposed subject to approval by DOB. For proprietary systems, materials will vary depending on manufacturers' specifications.

3.3.6 Surface Loading

The licensed professional is responsible for meeting all applicable surface loading criteria. Surface loading may vary for proprietary systems. Accordingly, installation of proprietary systems and allowable surface uses should conform to manufacturer specifications and warranties. For drivable surfaces and subsurface systems at least 18 inches below the ground surface, it is generally acceptable to assume an AASHTO HS-20 loading (32 kips/axle or approximately 80 psi). In some cases where trucks are

Figure 3-10:
Permeable pavers installed outside a DOT maintenance facility in Queens.

fully loaded or for other allowable uses above subsurface systems such as lawns, gardens, parking spaces or lots, carports, driveways, walkways, patios, and public plazas, loading requirements should be based on geotechnical and structural surveys by licensed professionals. No permanent structures that would prevent access to subsurface systems for repair and replacement should be constructed.

Fill should be well-compacted and filling procedures should follow industry standards. The contractor should compact each lift of backfill to 90% Standard Proctor Density, as verified by AASHTO T99, with a vibratory roller (max gross weight of 12,000 lbs; max dynamic force of 20,000 lbs) and at least four passes. The maximum lift thickness should be six inches.

The allowable width and length of any free span concrete structure should be reviewed by a licensed professional for necessary support columns or walls within the subsurface system.

3.3.7 Climate Considerations

Due to cold weather conditions in the city, protective measures should be included in the design of subsurface systems to prevent adverse impacts during freezing temperatures and snow accumulations. Certain parts of subsurface systems, such as sumps, should be located beneath the frost line (considered to be about four feet below-grade) so the system functions as intended throughout the year. Whenever possible, snow should not be stored on top of a subsurface system, such as on parking lots, unless the system was designed to handle such surface loads.

In addition, measures should be implemented to prevent snow melt containing deicing materials such as sand or sodium chloride from entering and clogging the system. Sand and salt passage into subsurface systems can be reduced in numerous ways, including implementing operational modifications, utilizing alternative deicing materials, and installing physical barriers around stormwater inlets. Operational modifications include sweeping and vacuuming streets and paths in between melt events, adjusting the rate and timing of sand and salt application, providing employee training, establishing “no salt or sand” zones, and using surface overlay (self-deicing) systems. Alternate treatment materials include calcium chloride, magnesium chloride, potassium chloride, urea, calcium magnesium

Table 3-2: Materials and specifications for subsurface systems (to be used in conjunction with manufacturers' specifications)

Material	Specification
Stone	Three-quarters to two-inch well-graded, clean-washed, angular crushed stone aggregate with the following properties: • Wash loss of no more than 0.5%. Minimum 33% voids as measured by ASTM C29 • Hardness as measured by the LA Abrasion Test (AASHTO T96 or ASTM C535) after 500 revolution should be less than 40% loss • Recycled materials should not be used instead of stone aggregate • Refer to ASTM D448 No. 57 or AASHTO M 43-88
Concrete	Concrete used in the construction of subsurface systems, including but not limited to storage vaults and pretreatment structures should meet the following: • Minimum 3,000 psi structural reinforced concrete • All construction joints should include waterstops • Cast-in-place wall sections should be designed as retaining walls
Stormwater Chambers	• Chamber units should be made of a typical polypropylene material • Specifications vary by manufacturer
Header Pipe, Collector Pipe, Observation Well Pipe	Pipe and fittings should meet one of the following requirements: • Four inch diameter or greater Schedule 40 non-perforated PVC meeting the requirements of ASTM D1785, ASTM D2466, or ASTM D2665 • Four inch diameter or greater Schedule 80 non-perforated PVC meeting the requirements of ASTM D1785, ASTM D2464, or ASTM D2467 • Four inch diameter or greater perforated PVC meeting the requirements of ASTM F858 or ASTM D2729 • Twelve inch diameter or greater corrugated high density polyethylene (HDPE) meeting the requirements of AASHTO M294 Type S. If perforated, perforations should meet AASHTO Class II specifications • Port openings should be three-quarters inch diameter PVC • Pipe fittings should meet one of the following requirements: ASTM F1866, CSA B137.2, CSA B182.2
Backfill	From the top of the embedment stone to 18 inches above the top of the system: • Backfill should be granular, well-graded soil/aggregate mixture, with <35% fines • Most pavement sub-base materials can be used in lieu of this layer • Pavement sub-base may be a part of this layer
Topsoil Backfill	From the top of the backfill layer to the bottom of the pavement or unpaved finish grade above: • Any soil/rock materials or native soil free of clay lumps, brush litter, roots, stones two inches and larger, and other foreign material • Testing of soil may be required to ensure compliance with these criteria • Whenever feasible, topsoil should be salvaged onsite and amended as necessary to meet the criteria above • Pavement sub-base may be a part of this layer

Table 3-2: (Continued) Materials and specifications for subsurface systems (to be used in conjunction with manufacturer's specifications)

Material	Specification
Geotextile	Geotextile for separation between stone and backfill/native soil should have the following properties: • Nonwoven polypropylene • Flow rate > 110 gal/min/sq.ft • Percent Elongation per ASTM D4632 < 50% • Minimum Permittivity per ASTM D4491 (sec -1): 0.2/sec • Minimum Tensile Strength ASTM D4632: 100 lbs • Grab Strength per ASTM D4632: 1100 N • Tear Strength per ASTM D4533: 400 N • Puncture Strength per ASTM D4833: 2200 N • Refer to AASHTO M288 and NYSDOT Standard Specifications, Section 737 – Geosynthetics Table 737-01B, Class 2, Type I Geotextile for stabilization and scour protection at each inlet pipe: • Woven polypropylene • Refer to AASHTO M288 Class 1 Woven Geotextile
Impermeable Liner	Impermeable liners should meet the following requirements when used for separation between the subsurface system and embedment stone in areas where infiltration is not permitted: • ASTM D751 (30 mm thickness) • ASTM D412 (tensile strength 1,100 lb, elongation 200%) • ASTM D624 (tear resistance 150 lb/in) • ASTM D471 (water absorption +8 to -2% mass) • A geotextile fabric should be used to protect the impermeable liner from wear and tear.
Filter Bag Insert	If filter bags are required, they should have the following properties: • Woven or nonwoven geotextile with flow rate greater than 150 gallons per minute per square foot • Insert should be self-draining within 24 hours

Figure 3-11: Manifolds can be used in subsurface systems to evenly distribute flow through the system.

acetate, and corn or beet byproducts (Keating 2004; USEPA, 2006). It should be noted, however, that alternate treatment materials vary in cost and may pose other environmental concerns (such as increased nutrient release from urea).

Physical barriers to clogging include pretreatment sumps and temporary berms or barriers around stormwater inlets which settle out sand and salt prior to overflow into the inlet to the subsurface system. Accumulated sand and salt can be removed from these barriers in between adverse weather events. For further details, please refer to Section 3.3.2, Pretreatment.

3.4 Subsurface System Construction

The following construction techniques are recommended to ensure proper installation of the system, protect any onsite structures and adjacent properties, and ensure the subsurface system functions safely and effectively as a means of controlling site runoff. In addition, other activities suggested or required by the manufacturer of proprietary systems should be followed to avoid nullifying warranties.

3.4.1 Pre-Construction Meeting

A pre-construction meeting should be conducted prior to the installation of any subsurface system. The recommended attendees include the property owner, general contractor, subcontractors, licensed professional of record, and supplier of the system (if proprietary). At this meeting, plans for the subsurface system as well as site plans that include information about building footprint, locations of utilities, topography and subsurface conditions should be reviewed and any site-specific concerns should be discussed. No work should begin until all parties are in agreement that the materials and methods used will not compromise onsite structures or adjacent properties.

3.4.2 Soil Excavation, Field Testing, and Disposal Excavation

In areas of past manufacturing, commercial, industrial, or institutional use, or in other areas

Recommended Construction Sequencing

1. Prior to designing the subsurface system, locate and/or design all utility lines and connections.
2. Test soil and groundwater (where applicable) and dispose excavated soil in accordance with all applicable federal, state, and local regulations. Develop and follow a Health and Safety Plan (HASP) during testing and installation.
3. For new development projects, install subsurface systems toward the end of the construction process, if possible.
4. Install and maintain adequate tree protections and erosion and sediment controls to divert runoff around the disturbed area, prevent migration of excavated materials, and filter runoff leaving the disturbed area during construction. Do NOT use subsurface systems as temporary sediment basins or traps during construction.
5. In open-bottom systems, do NOT compact the existing subgrade under the system's footprint or subject it to excessive construction equipment traffic prior to installation.
6. Where erosion of the subgrade has caused accumulation of fine materials or surface ponding, remove this material with light equipment and scarify the underlying soil to a minimum depth of six inches to promote infiltration (only where infiltration is appropriate and specified). All fine grading should be done by hand.
7. Excavate the foundation of the subsurface system to a uniform, level, compacted subgrade free from rocks and soft material such as muck.
8. For perforated pipe systems, place nonwoven geotextile along the bottom and sides of the bed and wrap around all perforated pipes.
9. Place geotextile, bedding stone and impermeable liner (if required) immediately after the approval of subgrade preparation by the licensed professsional. Geotextile is to be placed in accordance with the manufacturer's standards and recommendations, if applicable.
10. Install bedding stone at a minimum depth of six inches. Compaction of the bedding stone should be minimal with heavy construction equipment kept off the bed bottom as much as possible.
11. Install inlet, pretreatment, and outlet control structures; subsurface systems; observation wells, manholes and clean-outs; piping to sewer connections; and all other necessary system components as specified in the engineering design documents.
12. Place embedment stone in maximum six-inch lifts around the subsurface system to a minimum of six inches above the system. Do not compact the embedment stone. Cover the embedment stone with geotextile.
13. Place approved backfill over the subsurface system in maximum six-inch lifts. Each lift should be compacted as specified in Table 3-3.
14. Install surface cover as specified by the engineering design documents. Seed and stabilize topsoil if surface is to be vegetated.
15. Do not remove inlet protection or other erosion and sediment control measures until site is fully stabilized.

Figure 3-12: Test pits may be necesary to determine subsurface conditions, including potential soil contamination.

where site reconnaissance indicates any signs of contamination, soil borings or test pits located within the footprint area of the subsurface system are necessary.

The required number of soil borings should be based on the size of the excavation. A general guideline is to perform one soil boring for all subsurface systems (including pretreatment and outlet control structures) with a footprint area of less than 1,000 square feet. For larger systems, perform one soil boring for every 2,500 square feet of subsurface system footprint area or two borings per subsurface system, whichever is greater. Borings should be taken to the anticipated excavation depth, at a minimum.

Portable meters including a combustible gas indicator (CGI) and either a photoionization detector (PID) or an organic vapor analyzer (OVA) should be used during the completion of the soil borings. A Health and Safety Plan (HASP) should be developed and followed during the digging of test pits. All excavated soil must be disposed of in accordance with all applicable federal, state, and city regulations.

3.4.3 Installation of Subsurface Systems

Key components of installation include the foundation, subsurface system including pretreatment and outlet control structures, header and collector pipes, embedment stone, and backfill. General guidelines for the installation of each of these components are further described below. **Table 3-3** lists typical installation methods and specifications for subsurface systems. These specifications may vary by manufacturer. Some proprietary subsurface systems have specific installation instructions that should be followed to attain the manufacturer's warranty.

Foundation

Installation begins with the excavation of the area to the depth for which the subsurface system was designed. The excavated area should be free of standing water. If soft or unsuitable soil is present during the preparation of the subgrade soil, over-excavate the bed bottom and attain the required grade with appropriate fill material, as approved by the licensed professional. Alternatively, use a geotextile stabilization fabric or

Figure 3-13: Catch basins installed to convey runoff to subsurface systems at Nehemiah Spring Creek Homes at Gateway Estates Phase 2 in Brooklyn.

grid system to meet the design loading capacity, as specified by the licensed professional. Grade the foundation subgrade to be uniform and level. Minimize the use of heavy equipment on the subgrade and scarify the bed bottom after all work involving heavy equipment has been completed. Geotextile should be placed along the excavation sidewalls to help prevent soil migration into the system. Geotextile should only be installed on the bed bottom as a soil stabilization technique, as indicated by the licensed professional, and should not be installed on the bed bottom if infiltration is specified.

A six-inch minimum thickness is required for the subsurface bedding. Bedding stone is to be compacted as specified in **Table 3-3**. Heavy equipment should not be allowed on bedding stone to avoid excessive soil compaction.

Subsurface Systems

Storage Vaults and Tanks

For prefabricated concrete structures, corrugated metal pipe systems, or proprietary modular systems, follow all manufacturer guidance for proper installation. Place the storage vault(s) on the stone bedding layer according to the engineering design documents. Spacing between storage vaults should follow the manufacturers' specifications. Proprietary modular systems may need a geotextile liner surrounding the vault. In areas of high groundwater or where infiltration is not permitted, an impermeable liner may be required to separate corrugated metal pipe or modular systems from the embedment stone. The impermeable liner should be wrapped around the vault systems and protected by geotextile to prevent tearing.

Gravel Beds

Place the collector pipes as specified in the engineering design documents. Provide a minimum of three inches of gravel below the collector pipes. Underdrains should be placed within the bottom width of the gravel bed with a slope of 0.5% to 2%. When included in the design, header pipes should be placed during the final lift of gravel. At least six inches of gravel should be placed on top of the header pipes.

Table 3-3: Typical installation specifications for subsurface systems

Category	Item	Specification
Depth of Stone	Beneath Stormwater Source Control System	• 6" minimum
	Above Stormwater Source Control System	• 6" minimum
Backfill Cover	With Pavement	• 12" minimum (excluding pavement) • 96" maximum
	Without Pavement	• 12" minimum • 96" maximum
Compaction Requirements	Bedding Stone	• Compact with vibratory roller (max gross weight of 12,000 lbs; max dynamic force of 20,000 lbs) with its full dynamic force applied to achieve a flat surface
	Embedment Stone	• No compaction
	Backfill Material	• 90% Standard Proctor Density, as verified by AASHTO T99 • Compact with vibratory roller (max gross weight of 12,000 lbs; max dynamic force of 20,000 lbs)
Spacing	Perforated Pipes (if applicable)	• If internal diameter is less than 24", minimum spacing of 12" • If internal diameter is greater than 24", minimum spacing is equal to half the diameter
	Stormwater Chambers (if applicable)	• 6" minimum between chambers or per manufacturer recommendations
Soil Stabilization	Geotextile Fabric	• On sides of excavation • On bottom only for systems that do not infiltrate • Immediately below backfill • Scour protection beneath inflow pipes • Around perforated pipes (if applicable) • Adjacent panels of geotextile should overlap a minimum of 16" or be sewn with a double-locked stitch such as Federal Standard No. 751a Type 401

Figure 3-14: Mechanical tampers were used to install the gravel bed below permeable pavers at DPR's Olmsted Center in Queens.

Perforated Pipes

The contractor should follow the engineering design documents and manufacturer's installation instructions when installing perforated pipes. At minimum, three inches of clean-washed gravel should be placed beneath the perforated pipes. The spacing between parallel pipes should be at least 12 inches for pipes with internal diameters less than 24 inches, and at least equal to half of the internal pipe diameter for pipes larger than 24 inches. Pipes should be completely lined in geotextile to prevent clogging of perforations.

Stormwater Chambers

Each proprietary stormwater chamber system has specific installation instructions that should be followed to obtain the manufacturer's warranty. The construction guidance provided herein is not intended to supersede any manufacturer's installation instructions. Stormwater chambers should be placed on the stone bedding layer according to the engineering design documents. Spacing between stormwater chambers should be a minimum of six inches, or as indicated by the manufacturer. Use a reciprocating saw or an air saw to cut holes for the pipes in the required chambers at the elevations indicated in the engineering design documents. Geotextile, or other appropriate netting or fabric as specified by the licensed professional, should be installed beneath the inflow pipes in all chambers for scour protection to ensure that the bedding stone is not disrupted as flows enter the system. Fabric should be installed so that it extends beyond the width of the stormwater chamber and is effectively anchored in place by the chamber. The length of fabric installation should be in accordance with the engineering design documents.

Header and Collector System

The header and collector pipes are recommended components of all subsurface systems to ensure even distribution of detained stormwater throughout the system. Certain designs, including multi-cell systems, may need additional header and collector pipes. Insert the header and collector pipes into the assembled subsurface system as indicated by the engineering design documents or manufacturer's installation instructions.

Figure 3-15: Pretreatment structures are typically installed after the geotextile and bedding stone is placed.

Embedment Stone

After proper installation of the subsurface system and all associated pipe, embedment stone should be installed in six-inch maximum lifts over the source control system. Do not compact the embedment stone. Stone can be placed with an excavator or telescoping conveyor boom, or pushed with a bulldozer. Applicable manufacturer installation instructions regarding loading and cover requirements for heavy construction equipment should be reviewed.

Stone should be placed in no more than a two-inch lift differential between any point on the subsurface system, excluding the inlet, pretreatment, and outlet control structures during the backfilling process. Advance the backfill along the length and width of the subsurface system at the same rate to avoid differential loading on the system. Backfilling at different heights from one side of the subsurface system to the other in excess of 12 inches can cause distortion of the system or potential collapse. After minimum cover for construction loading across the entire width of the subsurface system has been reached, advance the equipment to the end of the recently placed fill and begin the sequence again, until the system is completely backfilled with embedment stone.

Backfill

Backfill materials, such as excavated fill or structural backfill, should be installed above geotextile in lifts that do not exceed six inches. Geotextile prevents the downward migration of backfill materials into the subsurface system. The fill should be distributed with a construction vehicle that meets the maximum wheel load or ground pressure limits specified in manufacturer instructions, if applicable. Backfill should be a minimum of 12 inches in depth if the surface cover is pavement. Backfill can be reduced to a minimum of six inches if a vegetative cover is used. If vehicle traffic is allowed on the vegetative cover, however, the soil backfill depth should be increased to a minimum of 18 inches

During the construction process, a licensed professional should be retained by the owner to assume responsibility for special or progress inspections, as required by the Construction Codes.

Figure 3-16: Embedment stone was placed over stormwater chambers at NYCHA's Bronx River Houses to provide structural support and additional storage volume.

to prevent vehicle rutting. The maximum depth of backfill (including stone) over subsurface systems is 96 inches. Backfill material should be compacted as specified in **Table 3-3**.

3.4.4 Construction Inspections and As-Built Certification

During the construction process, a certified licensed professional should be identified to assume responsibility for special or progress inspections, as required by the Construction Codes. In addition, it is recommended that the following inspections be performed for subsurface systems under the supervision of the construction manager and a licensed professional:

- Stabilization of site to begin rough grading of subsurface system;
- Installation of primary and secondary erosion and sediment control measures in active construction area(s);
- Completion of excavation;
- Inspection/testing of bedding, embedment, and drainage stone, as applicable, to ensure compliance with stone specifications;
- Installation of inlet, pretreatment, and outlet control structures;
- Excavation and installation of subsurface system and all associated pipe;
- Placement of geotextile and, if applicable, impermeable liner;
- Placement and compaction of aggregate;
- Connection of inflow to pretreatment, pretreatment to source control system, source control system to outflow, and outflow to sewer system;
- Inspection, testing, and placement of structural backfill;
- Placement of soil mix (applicable for designs with vegetated cover);
- Completion of final grading and establishment of permanent stabilization; and
- Planting, restoration, and completion.

Once construction is complete, the licensed professional must submit a Technical Report 1 (TR1) certification to DOB along with as-built drawings to ensure that the constructed subsurface system complies with the approved drawings. Departures from the permit documents should be noted, along with shop drawings or notes that describe special conditions or supplemental features of the installation that are not part of the permit documents. It is the owner's responsibility to ensure that documented inspections are conducted during construction in accordance with the Construction Codes. In many cases, contractors will provide construction quality assurance services and furnish close-out documents to the owner at the point of substantial completion.

3.5 Operations and Maintenance for Subsurface Systems

Subsurface systems must be inspected and maintained in order to function as designed, ensure required release rates and storage volumes over time, and comply with *Chapter 31*. DEP and DOB are not responsible for any onsite or offsite injuries or damage to persons or property resulting from improper design, construction, operation, or maintenance.

3.5.1 Post-Construction Monitoring

Post-construction monitoring during the first year after installation is important for gauging the effectiveness of subsurface systems during operation and determining whether any system modifications are necessary. Monitoring inflow and outflow within pretreatment structures and control structures along with weather conditions can provide useful information about system performance during and after rain events. In addition, regular and frequent inspections during the first year would help to determine the appropriate activities and schedule for future maintenance.

Prior to inspections, a measuring device such as a ruler can be inserted in observation wells at the risers, clean-outs or manholes of pretreatment, and inlet and outlet control structures to provide a point of reference for future measurements of sediment build-up.

3.5.2 Inspections

Routine post-construction inspections of subsurface systems are recommended to ensure continued performance and compliance with city codes and regulations. Licensed professionals and contractors can conduct inspection activities as can site maintenance staff, landscapers, septic professionals and other trained professionals. In addition, property owners can inspect debris and sediment deposits at drains and inlets, draindown of the water in the system at the observation well(s) and record general observations on the surface in the area of the subsurface system.

Back-ups at inlets and drains, standing water, or prolonged soggy ground cover during regular rain events (less than one-inch) are all signs of poor performance, possibly as a result of inadequate maintenance. Impervious surfaces over subsurface systems should be checked for signs of deterioration and pervious surfaces should be checked for erosion and proper vegetative cover.

The frequency of inspection and maintenance activities vary by location. A routine inspection schedule should be established for each individual location based on the first year of post-construction monitoring and site-specific variables, including tree cover, land use (i.e., industrial, commercial, residential), percent imperviousness, and anticipated pollutant load.

To ensure adequate system performance, annual inspections and inspections within 24 hours of significant rain events are highly recommended. The inlet, pretreatment structure, outlet control structure, and observation well(s) should be inspected for proper system loading and draindown time, as well as for debris accumulation. Depending on type of subsurface

Table 3-4: Recommended inspection activities for subsurface systems

Schedule	Activity
Seasonally/quarterly for the first year; bi-annually thereafter	• Inspect inlet, pretreatment structure, and outlet control structure to ensure good condition • Inspect surface of subsurface system, if impervious, for signs of deterioration, rutting, or spalling • Inspect pervious surfaces above the system for signs of erosion or improper vegetative cover • Inspect all risers and clean-outs of the perforated pipes in perforated pipe systems
Semi-annually for the first year; annually thereafter.	• Inspect pretreatment, inlet and outlet control structures, and observation well(s) for accumulated sediment • Inspect header pipe for accumulated sediment
Monthly and after large rain/snow storms	• Inspect yard drains, catch basin grates, roof gutters and leaders, and filter bags for blockage, debris, and ice formation • Inspect observation well(s) and outlet control structure for proper draindown between storms

system, header pipes should also be inspected at the inlet. The above components should also be inspected annually during dry weather to check for obvious signs of damage.

Table 3-4 outlines recommended inspection activities and their frequency. The suggested frequencies for different activities in the table should be modified based on the first year of post-construction monitoring results and site specific variables as mentioned above. The troubleshooting section below may be used to address issues found during inspections.

3.5.3 Maintenance

Chapter 31 requires property owners and their successors to file a deed restriction to ensure operation and maintenance of stormwater management systems throughout the life of the system or until replacement is approved by DEP. In addition, the property owner must retain records and furnish proof of maintenance in the form of a certification by a liscenced professional submitted to DEP every three years.

Property owners may enter into annual or bi-annual maintenance contracts with commercial vendors that are able to provide the range of maintenance activities described in these guidelines and manufacturer specifications. All maintenance activities should occur during dry weather unless an emergency situation necessitates maintenance or repairs during rain events.

Maintenance activities for subsurface systems typically focus on regular sediment and debris removal at inlets, yard drains, catch basin grates and roof gutters and leaders. Depending on source control type, other loca-

Table 3-5: Recommended maintenance activities for subsurface systems

Schedule	Activity	Equipment
Seasonally or as needed	• Remove and clean filter bag • Immediately clean up spills on the pavement draining to the green infrastructure • Sweep impervious surfaces that drain to the green infrastructure • Maintain paved cover so that it drains properly to subsurface system • Maintain vegetation cover in good condition with complete coverage (if applicable) • Clean debris from pervious surface over subsurface system, if applicable • Clean perforated pipes (if applicable)	• Broom • Shovel • Replacement filter bags • Jet vacuum
When 25% of the pipe volume has been filled	• Jet-vacuum sediment and debris from the header pipe. Use a high-pressure nozzle with rear-facing jets to wash the sediment and debris into the inlet or pretreatment sump	• Jet vacuum
When sediment buildup reaches half the sump capacity (e.g., six inches)	• Vactor sediment and debris from the pretreatment sump. • Apply multiple passes of jet vacuum until backflush water is clean	• Vactor truck • Jet vacuum
Semi-annually the first year; annually thereafter	• Remove sediment and debris from sumps in pretreatment and outlet control structures using a vacuum truck or similar device, after other system components such as pipes and vaults have been maintained • Replace filter bag	• Shovel • Jet vacuum • Replacement filter bags
Every five to ten years	• Jet-vacuum pipes clear of debris for perforated pipe and gravel bed systems, if scour protection has been installed below the pipes	• Jet vacuum
Winter considerations	• Break up ice formation around inlet hood	• Ice pick, or equivalent tool • Manhole bar

Note: The jet-vacuuming process uses a high-pressure water nozzle to propel itself while scouring and suspending sediment. As such, this process should not be performed in any portions of a subsurface system where scour protection has not been installed.

tions for sediment and debris removal may include manholes, risers, header pipes, collector pipes, and outlet control structures.

Sediment buildup in pretreatment and inlet sumps will naturally occur over time and, if left unaddressed, will lead to poor performance or system failure. If sumps are properly maintained, pipes, chambers, and gravel beds internal to the system would likely remain free of sediment build-up. The extent of sediment buildup in sumps and pipes should be used as a guide for determining the need for system cleaning. If sediment buildup is between 5% and 25% of the pipe diameter or 50% of sump capacity, cleaning should be performed. If sediment buildup exceeds 25% of the pipe diameter or more than 75% of sump capacity, the capacity of the system to convey stormwater during high flows may be significantly compromised, and cleaning must be performed immediately.

Figure 3-17: Sediment build-up in sumps should be removed using a vacuum or vactor truck depending on the size of the system.

Maintenance of pretreatment and inlet sumps and outlet control structures should be performed outside the sediment sumps. The sumps are not intended for human entry during regular maintenance. Vector trucks, Jet-vacuums or other appropriate means of cleaning out sediment and floatable debris should be used from above grade **(Figure 3-17)**.

Good housekeeping and pollution prevention activities above subsurface systems should be employed to improve the operation and lifespan of subsurface systems. These activities include regular sweeping of impervious surfaces that drain to pretreatment or system inlets, maintaining landscaping and vegetative cover in good condition, storing household or workplace chemicals securely and safely, and cleaning up spills immediately and before contaminated runoff can enter the subsurface system.

Additionally, vehicular access over subsurface systems with vegetated surfaces should be prohibited to prevent system compaction, unless specifically designed for vehicle loads. Care should also be taken to avoid excessive compaction by mowers.

Table 3-5 outlines recommended maintenance activities and their frequency. The suggested frequencies for different activities in the table should be modified based on the first year of post-construction monitoring results and site specific variables as mentioned above.

3.5.4 Developing an Inspection and Maintenance Plan

Developing a site stormwater inspection and maintenance plan is crucial to the success of the subsurface system, and should be based on the results of the first-year post-construction monitoring program. Property owners should ask the contractor or licensed professional to document the appropriate inspection and maintenance activities after the post-construction monitoring period is complete. The maintenance plan should identify a maintenance manager who is responsible for operating and maintaining the subsurface system.

The plan should also include a maintenance schedule developed for the life of the subsurface system. The schedule should outline the specific maintenance activities that are required to be completed, the frequency and timing, and the person or entity responsible for completing the activity. The property owner must keep all records of inspections and maintenance activities and regularly update the plan based on actual system requirements, the results of maintenance activities, and compliance with DEP's stormwater performance standard.

3.5.5 Troubleshooting

If problems are identified during routine maintenance and inspection, the property owner should take time to troubleshoot the problem. **Table 3-6** outlines common problems and potential solutions. If problems persist, a licensed professional should be consulted.

Table 3-6: Troubleshooting guide for subsurface systems

Problem	Analysis				Diagnosis	Solution
Overflow at inlet or pretreatment structure	Check observation well or pretreatment structure	Water not present			Possible clog in the connection between pretreatment structure and header system	• Dewater pretreatment sump • Check baffle and header pipe for obstructions • Check connection between pretreatment structure and header system for obstructions
		Water present	Dewater pretreatment structure	Successful dewatering	Possible clog in header system	• Check header pipe for obstructions • Check perforated pipes (if present) for obstructions Clean affected pipes
				Unsuccessful dewatering	Possible clog in collector, outflow, or (if present) perforated pipes	• Check pipes for obstructions • Clear affected pipes
	Check outlet control structure	Water not present			Possible clog in collector or (if present) perforated pipes	• Check pipes for obstructions • Clear affected pipes
		Water present	Dewater outlet control structure	Successful dewatering	Possible clog in outflow pipe	• Check outflow pipe to sewer for obstructions • Clear outflow pipe as necessary
				Unsuccessful dewatering	Possible backup in sewer	• Call 311 to report a problem
Ponding water over subsurface system (if pervious cover present)	Check outlet control structure	Water not present			Possible clog in header, collector, or (if present) perforated pipes	• Check pipes for obstructions • Clear affected pipes
		Water present	Dewater outlet control structure	Successful dewatering	Possible clog in outflow pipe	• Check outflow pipe to sewer for obstructions • Clear outflow pipe as necessary
				Unsuccessful dewatering	Possible backup in sewer	• Call 311 to report a problem
Overflow at outlet control structure	Check observation well or outlet control structure	Water not present			Possible backup in sewer	• Dewater outlet control structure • Check outlet pipes for damage • Call 311 to report a problem
		Water present	Dewater outlet control structure	Successful dewatering	Possible clog in outflow pipe	• Check outflow pipe to sewer for obstructions • Clear outflow pipe as necessary
				Unsuccessful dewatering	Possible backup in sewer	• Call 311 to report a problem
Smells/ odors	Check outlet control structure	Odor present			Possible backup in sewer	• Call 311 to report a problem
		Odor not present	Check inlet and pretreatment structure	Odor not present	Possible clog in collector or (if present) perforated pipes	• Dewater outlet control structure • Check outflow pipe to sewer for obstructions • Clean outflow pipe or (if present) perforated pipes
				Odor present	Possible contamination in runoff	• Dewater pretreatment structure • Remove sediment and debris from sump

SECTION 4

ROOFTOP SYSTEMS

Rooftop systems provide temporary storage of stormwater runoff on roof surfaces, slow release to the sewer system and retention where evaporation or vegetative uptake is feasible. This section describes typical rooftop systems that comply with DEP's stormwater performance standard. Selection of the appropriate rooftop system will depend on a number of factors, including siting, design and construction considerations specific to each development. In addition to these considerations, general operations and maintenance recommendations are provided in this section.

A green roof at DEP's Paerdegat CSO Facility.

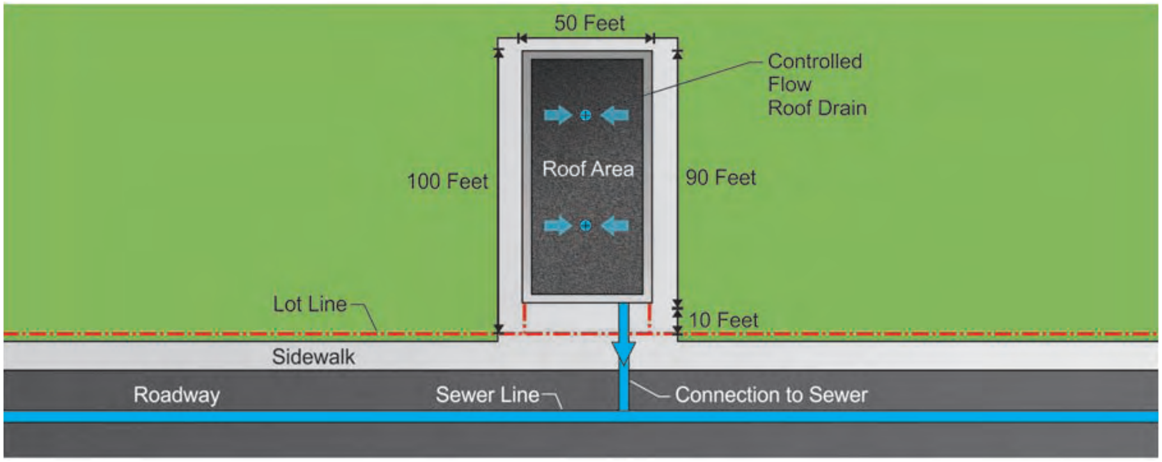


Figure 4-1: Example development lot where a blue roof may adequately control site runoff given a large building footprint.

4.1 Types of Rooftop Systems

Rooftop systems are an effective practice for controlling runoff on a wide variety of sites. Choosing and designing a rooftop system for a specific site requires a careful review of the building and site characteristics early during planning and design phases. Two types of rooftop systems — blue roofs and green roofs — are described below.

Typically, if rooftop systems are used as standalone practices or in a parallel configuration, they require a controlled flow roof drain to comply with DEP's stormwater performance standard.

For some sites, rooftop systems may be connected to subsurface systems to adequately manage total site runoff. Rooftop systems may also be incorporated into rainwater recycling systems, where flows routed from rooftop systems to cisterns or other harvesting features are captured and used for onsite purposes such as site irrigation, thus, permanently retaining the water. (See Section 5, Combination Systems, for further information.)

4.1.1 Blue Roofs

Blue roofs consist of controlled flow roof drains to regulate the rate of runoff from the roof. Weirs or orifices attached to the roof drains slow flow into the building's storm drains or roof leaders. Water will pond on the roof surface for a short period after a rain event as the runoff is slowly released through controlled flow roof drains.

Roof drains that integrate volumetric weirs within the drain assembly are commercially available. Alternatively, a manufacturer can customize an orifice size for a specific development. The number and sizing of weirs and orifices are based on a pre-determined relationship between the water depth approaching the drain and the flow rate entering the drain. A waterproofing membrane must be installed as part of the roofing system if the roof is designed to detain stormwater.

4.1.2 Green Roofs

Green roofs consist of layers of growing media and plants on top of the roofing system. Green roofs detain rooftop stormwater runoff and reduce the rate of runoff entering the city sewer system during rainfall events. Green roofs can also

Advantages and Limitations of Rooftop Systems

Advantages:

- Well suited for lotline-to-lotline buildings.
- Requires no additional land area.
- No excavation required.
- Easy to install.
- Extends the life of the roof by protecting roofing membranes from ultraviolet radiation.
- Commercially available products.
- Readily coupled with other storage techniques, such as subsurface storage or cisterns.
- Compatible with other rooftop uses.
- Green roofs add economic value to developments when used as passive recreational features or rooftop farms.
- Green roofs provide co-benefits, such as heat island reductions, energy conservation and climate change offsets, air quality improvements and increased wildlife habitat value.

Limitations:

- Roofs with steep slopes (greater than 2% slopes for blue roofs and greater than 5% for green roofs) will provide limited storage.
- Regular inspection and maintenance of roof surface and roof drains are required.
- Limited benefit on sites where roof area makes up only a small portion of the total impervious area.
- Additional loading on roof may add to the cost of the building structure.

retain stormwater and permanently remove runoff from the sewer system, as the growing media absorbs stormwater and the vegetation evapotranspires water into the atmosphere. Green roof systems in these guidelines are grouped into two categories: single-course and multi-course systems. The primary distinction between the two systems is that multi-course systems have a separate drainage layer, while single-course systems do not. The type of system that is selected may influence calculations of required storage volumes.

Single-course systems, as shown in **Figure 4-2**, rely on the growing media alone to provide sufficient drainage, without using a separate drainage layer. Accordingly, the media used is designed to have a higher porosity and permeability than that used in other assembly types. Typical single-course assemblies are a minimum of four inches thick and include a waterproofing membrane, root barrier, sheet drain, insulation, filter fabric, growing media and vegetation layers.

Multi-course systems incorporate a drainage or reservoir layer consisting of plastic or geocomposite sheets. The drainage layer captures water on top in troughs or cups and allows for flow to drain freely below the troughs **(Figure 4-3)**. Alternatively, a capillary layer can be composed of granular mineral media to minimize the shock to the root system of the vegetation under wet conditions **(Figure 4-4)**. Given the multiple layers, the total height of the system is typically greater than four inches. In addition to the components of the single-course system and the separate drainage layer, multi-course systems may also include a filter layer to trap soil and sediment.

4.2 Siting Considerations for Rooftop Systems

Rooftop systems are appropriate for different land uses in urban environments. Rooftop systems are particularly suitable for buildings with footprints that cover all or most of the lot and relatively flat roofs. This section outlines key siting considerations for selecting the appropriate rooftop system during site planning and building design.

4.2.1 Site and Building Characterization

The first step in designing an effective rooftop system is to understand how rooftop runoff contributes to the total developed flow from the site. If non-roof area is small (i.e., less than 10% of total site area), the site's total developed flow may be equivalent or nearly equivalent to the rooftop runoff, and rooftop systems would be a cost-effective option to consider. On certain sites, it may be possible to detain the entire required storage volume with a rooftop system. On sites where the non-roof area is significant, additional analysis of site conditions is required to determine whether a subsurface system or combination of rooftop and subsurface systems would be most effective. (See Section 5, Combination Systems.) Rooftop systems may be used to compensate for non-roof areas and reduce the size of a subsurface system. At sites that use combination systems, the total combined flow from rooftop and subsurface systems exiting the site should not exceed the required release rate for the total lot area per DEP's stormwater performance standard.

Blue roofs are considered a low cost detention option. Coupled with light colored roofing material, they can also help to minimize the urban heat island effect and provide rooftop cooling.

In addition to considering non-roof areas, the desired physical characteristics of the roof surface, including roof slope, roofing materials, and deflection/loading capacity must be considered when selecting a rooftop system. Slope should be a major consideration during building and rooftop design if a rooftop system is the selected method of detention. Large slopes may reduce stormwater storage capacity on roofs below required storage volumes and cause greater depths of ponding and loading at the drains.

Blue roofs utilizing controlled flow roof drains generally require flat or nearly flat roofs (e.g., less than 2% slope). Blue roofs with modifications approved by DOB and DEP that mitigate slope and more evenly distribute the ponded water may be considered for roofs with slopes greater than 2%. Green roofs being used as stormwater management systems are recommended only on roofs with relatively shallow slopes (e.g., less than 5% slope). See additional information about the impact of slopes on rooftop systems in Section 4.3.5, Roof Slope, Ponding Depth and Drainage Configurations, and Section 4.3.7, Loadings and Structural Capacity.

In addition, both green and blue roof drains should be located away from trees, if possible, to prevent leaf litter that would result in the clogging of the drains and additional ponding on the rooftop.

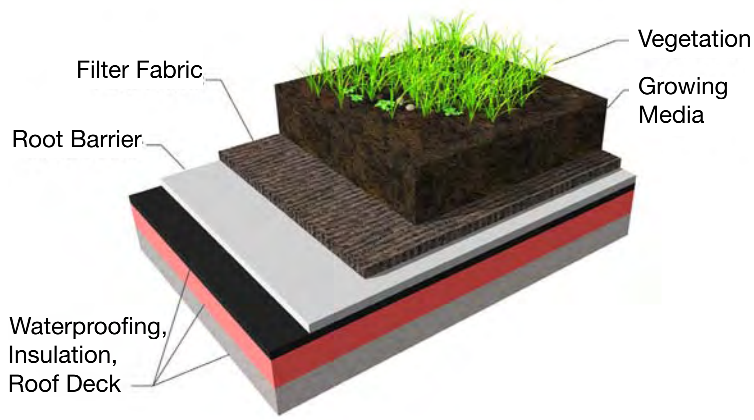


Figure 4-2: Typical layers of a single-course roof system.

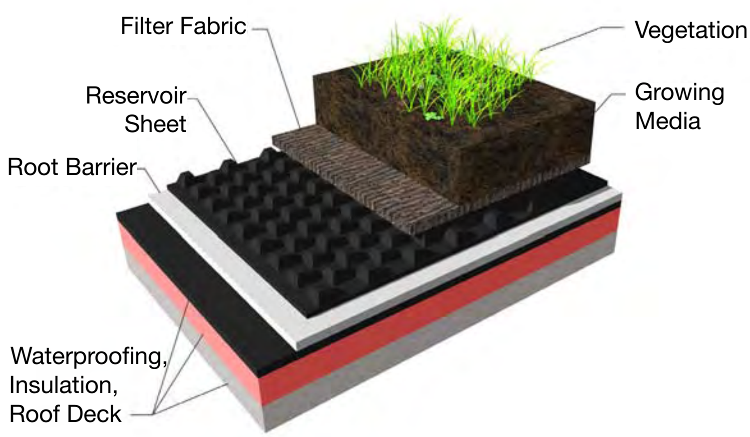


Figure 4-3: Typical layers of a multi-course roof system with synthetic drainage layer.

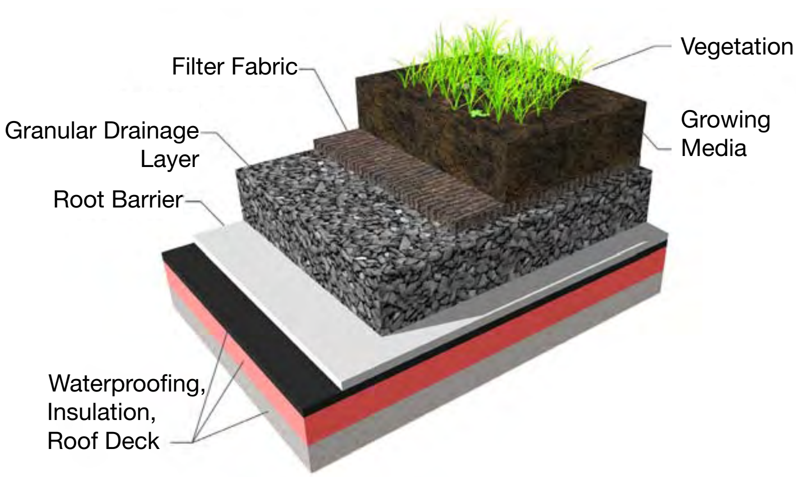


Figure 4-4: Typical layers of a multi-course roof system with granular drainage layer.

Different Types of Green Roofs

The single-course and multi-course green roof assemblies discussed in the guidelines are both variations on extensive green roofs, the difference being that multi-course green roofs incorporate a drainage layer in their design.

Common extensive green roof features include:

- Four to five inches of growing media;
- Lightweight growing media designed for water retention;
- Shallow rooted, drought tolerant vegetation; and
- Typically irrigation free after the establishment period.

Common intensive green roof features include:

- Greater than five inches of growing media;
- Heavier, more nutrient laden growing media;
- Deeper rooted vegetation, often including trees or shrubs;
- Require irrigation past the first year; and
- Much heavier green roof assembly overall.

Intensive green roofs provide stormwater control equal to or greater than extensive green roofs do, but are not discussed specifically in these guidelines because designs are much less universal. Credit for intensive roofs beyond that provided for extensive green roofs may be discussed on a case-by-case basis with DEP for compliance with the stormwater performance standard.

4.2.2 Complementary Uses

Rooftop systems generally do not restrict the roof from being used for other functions or purposes such as siting mechanical equipment, providing passive recreation, or serving as a means of egress or a point of rescue for fire safety. Possible uses for the building's roof structure should be considered in the design of a rooftop system and can be designed to be compatible with uses proposed in the current development plan or in the future. Rooftop systems are designed to hold only a few inches of ponded water on the roof for short periods, ranging from a few minutes to a few hours after a rain event, at times when the rooftop is unlikely to be used by residents or visitors.

If such water ponding is determined to be incompatible with current or future uses, the rooftop system may be designed to occupy a portion of the roof area, leaving additional roof space available for the other uses. For passive recreational uses, decking over a blue roof could provide space above the ponded area. Passive recreational features such as picnic areas should be relegated to paved or decked areas, and not be placed on a green roof. Green roofs are not designed to have foot traffic which could cause damage to plants, soil compaction, and erosion. Walkways or pavers should be incorporated into the design of the green roof if needed for resident or visitor access to different parts of the roof. Americans with Disability Act (ADA) requirements for walkway pitches, railing heights, and threshold offsets should be observed for roofs intended for public access. In general, green roofs do not require pathways specifically for maintenance activities, as these activities usually involve a comprehensive sweep of the entire green roof surface to weed, fertilize, and infill bare spots.

The use of solar panels on top of green roofs can also be implemented, as long as the panels allow sunlight and stormwater to reach the green roof. Otherwise, solar panels should be installed on non-green portions of the roof. Photovoltaic panel stands that have been specifically designed to be ballasted by green roofs are now available from several manufacturers.

Mechanical equipment and other rooftop structures should be installed on raised pads above the roof deck. The pads should be appropriately flashed with waterproofing material. Locating equipment on raised pads will reduce the extent of roof penetrations and flashing required. If structures and equipment are mounted directly on the roof within the area intended for ponding water, it may be necessary to provide additional waterproofing around the structure or equipment or to elevate the equipment above the anticipated maximum water depth to prevent damage and provide access for maintenance.

It is recommended that pads also be constructed for potential structural or mechanical uses that may be constructed in the future. In addition, access should be provided for façade rigging equipment including the use of temporary equipment (beams and weights) that may be needed in the future. If appropriate staging areas for façade maintenance are not provided, damage to the rooftop system may result.

Sufficient structural loading analysis that considers cumulative loads where multiple uses are proposed and incorporated into the design should be conducted by licensed professionals, in accordance with the Construction Codes. Section 4.3.7 provides additional detail on loading considerations.

4.2.3 Considerations for Multiple Roof Levels

For buildings with multiple roof levels, rooftop systems can be applied on each level where drains control runoff. Alternatively, a roof at a higher elevation can drain directly onto a lower roof with a regulated discharge. In this case, the storage volume on the lower roof would be calculated based on the combined runoff from all contributing roof levels. This storage volume would then be used to determine the maximum water depth on the lower roof.

Other Benefits of Green Roofs

- Green roofs can help a project applying for Leadership in Energy and Environment Design (LEED) certification achieve a number of Sustainable Sites credits.
- Green roofs are eligible for a property tax abatement from New York City.
- When maintained appropriately, green roofs improve runoff water quality by filtering out particles, nutrients and heavy metals.
- Evapotranspiration from the roof helps to lower temperatures, helping to address the heat island effect that leads to higher temperatures in the City.
- Green roof vegetation improves air quality by intaking carbon dioxide (and other harmful volatiles) and producing oxygen through photosynthesis. Airborne particles and heavy metals are also trapped by the plants and growing media, reducing particulate loading in the air.
- Green roofs can provide a habitat for flora and fauna, enhancing biodiversity in the city.
- Green roofs used for agricultural production can contribute fresh food to communities and additional revenue for building owners.

Figure 4-5:
Multiple level green roof on DPR's Five Borough Building on Randall's Island.

For green roofs, draining a roof at a higher elevation directly onto a lower roof is recommended only if the lower roof is designed with a multi-course green roof. Draining the upper roof can cause erosion on the lower roof if the lower roof is a single course system. With the multi-course system, the upper roof leader can discharge directly to the drainage layer, thereby avoiding damage to the growing media and vegetation.

4.3 Rooftop System Design

Proper design will help to ensure that the rooftop system is built to provide adequate storage, support the desired use on the roof, conform to existing rules and regulations, and allow for appropriate operation and maintenance over time, as needed. The following guidelines, along with manufacturer-provided specifications, will assist the licensed professional in designing rooftop systems to comply with DEP's stormwater performance standard.

4.3.1 Roof Assemblies and Materials

Durability of the roof assembly is important for maximizing the operating life of a rooftop system. Materials selected should have a long life expectancy and be accompanied by a manufacturer-provided quality control program. All roofing systems generally consist of roofing materials that provide insulation and waterproofing on top of the roof deck and structural support members. Therefore, while many types of insulation and waterproofing are available and can work as part of a rooftop system, the intended use of the roof for storage of water should be confirmed with the manufacturer to ensure the warranty covers such use.

New York City Fire Codes

Similar to conventional roofs, green and blue rooftop systems are subject to the New York City Fire Department's (FDNY) Fire Code (2008). The Fire Code should be consulted during the design and construction process for compliance with fire operations features, fire resistance rated construction, means of egress and other regulations. Additionally, rooftop systems must provide appropriate access and means of ventilation to FDNY for emergency conditions, and ensure structural loading consistent with the Construction Codes.

Unprotected Roof Assembly

Unprotected roof assemblies are roof systems where the insulation lies between the roof deck and the membrane, as shown in **Figure 4-6**. Unprotected roof assemblies may require ballast where the waterproofing membrane is loose-laid rather than adhered to the insulation and roof deck. Depending on the dry weight of the green roof, it may provide the ballast needed to weigh down the membrane, avoiding the need for another type of ballast or adhesive. Caution should be used with thinner green roofs, as their weight may not be substantial enough to be used as ballast, especially if erosion of soil media occurs.

Green roofs help protect the roof assembly from the elements, providing the benefits of a protected roof assembly and extending the roof life.

Although the insulation lies below the waterproof membrane in unprotected roof assemblies, it is still advisable to use water-resistant insulation materials to avoid harm to the insulation, which could lead to roof repair or complete replacement. Rooftop systems require insulation with a relatively high compressive strength to handle the additional weight. Therefore, it is essential that the designer calculates the total weight of the rooftop system so that the insulation can be strengthened accordingly.

Protected Roof Assembly

Also known as a protected membrane roof (PMR) assembly or an inverted roof membrane assembly (IRMA), a protected roof assembly consists of an insulation layer that covers the waterproofing membrane on top of the roof structure **(Figure 4-7)**. The insulation layer tends to have stronger compressive strength than the insulation layer in unprotected roof assemblies, and fewer modifications to standard roof design may be required for rooftop systems.

Protected roof assemblies often use ballast, rather than adhesives, to hold the insulation in place. When creating blue roofs on roofs with ballast, the depth and porosity of the ballast will be part of the design criteria and may require additional ponding depth or surface area to achieve the same storage volume. As with unprotected roof assemblies, the dry weight of the green roof may be able to provide the ballast needed to weigh down the insulation, avoiding the need for adhesives or another type of ballast. Caution should be used with thinner green roofs, as their weight may not be substantial enough to be used as ballast, especially if erosion of soil media occurs or large rainfall events result in flotation.

4.3.2 Waterproofing Membrane

Rooftop detention systems are considered wet systems and, thus, require waterproofing. In general, the waterproofing membrane should withstand the temporary ponding of water on a regular basis. Common waterproofing membrane systems include modified bitumen roofing (MBR), waterproof types of single-ply roofing, metal roof panels, spray polyurethane foam (SPF) roofing, and liquid-applied (including polyurethane-based and polymer-modified bituminous products) roofing. The first four are typically found in unprotected roof assemblies, though they can also be used for protected assemblies. SPF membranes are not classified as either a protected or unprotected roof assembly because they incorporate the insulation into the membrane. Liquid-applied membranes tend to be used in protected roof assemblies.

High quality MBR sheet roofing products are suitable for use with rooftop systems. These systems involve two or more layers of MBR sheets tiled to minimize seam vulnerability. These are generally not resistant to root attack and should

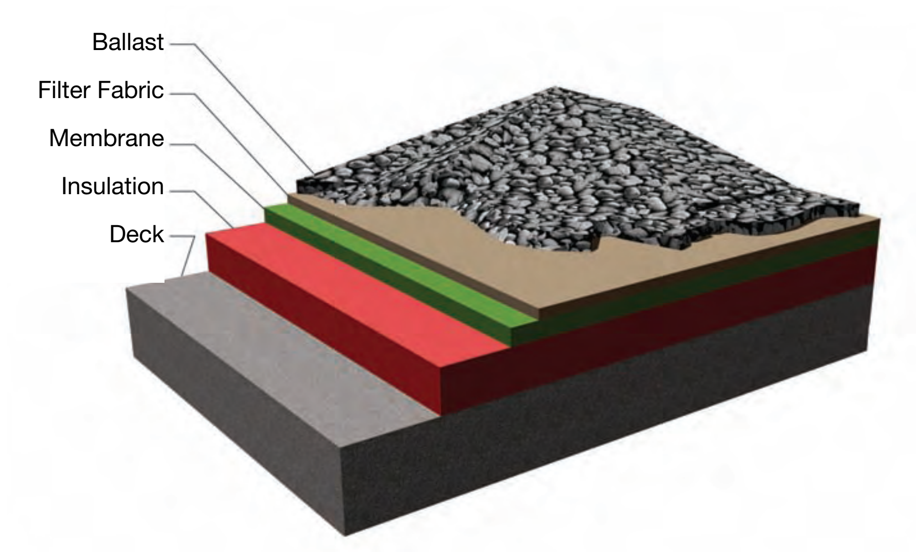


Figure 4-6:
Unprotected roof assembly (with geotextile and ballast if required by design).

be installed in conjunction with a supplemental root barrier layer.

Lower quality MBR roof systems are not recommended for use below rooftop systems because they contain many layers of asphaltic sheets with fiber reinforcement that can wick moisture and many seams where water can penetrate the system. These systems are also fairly thin and less durable than other types of roof assemblies, requiring regular maintenance and more frequent replacement. Metal roof panels are also not recommended for blue roofs due to their required 2% minimum slope, per the Construction Codes.

Many single-ply systems are designed specifically for green roof applications, and thus are capable of holding water during a storm. Single-ply membranes come in large sheets of thermoplastic, or thermoset (i.e., rubber), and therefore have fewer seams. The sheets come in variable thicknesses, and their thick, durable layers with few seams make these membranes particularly well-suited for rooftop detention systems. Thermoplastic membranes can be seamed using hot-air welding methods that can result in seams that are as strong and durable as the field membrane itself.

SPF membranes incorporate insulation into the membrane and do not need a stand-alone insulation layer. These roofing systems are considered to be more stable than others and, therefore, tend to be used in areas where hurricanes or high wind speeds are a concern and on roofs with atypical configurations. SPF roof systems are not common in the city because of high associated costs. However, because the system has no seams and is durable, this membrane is suitable for rooftop systems.

Fluid-applied membranes are similar to SPF systems in that they are applied onsite as a coating. However, fluid applied membranes require a separate insulation layer. The liquid is poured onto the roof and spread with a squeegee until the desired thickness is reached. The liquid-applied membrane is self-healing and very durable, making the use of these membranes a viable option for blue roofs. Liquid-applied membranes tend to last the longest of any roof system with little maintenance required, but the initial cost of these membranes tends to be more expensive

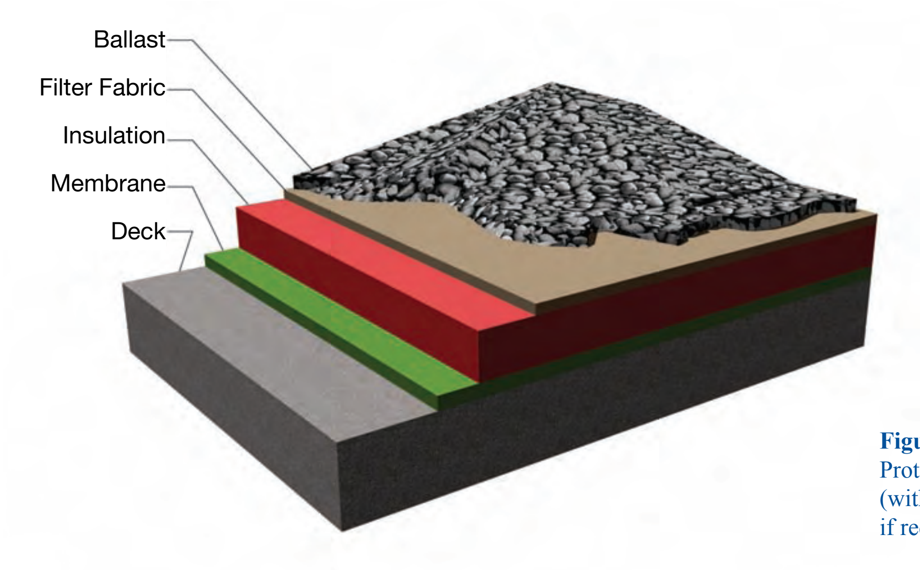


Figure 4-7:
Protected roof assembly (with geotextile and ballast if required by design).

than other membrane types. These membranes are available in both hot and cold fluid-applied versions.

The New York City School Construction Authority (2007) recommends use of a "hot fluid applied, rubberized asphalt, fabric reinforced roofing system in a protected membrane configuration" for new construction that includes blue and green roof systems. The durability and lack of seams makes this membrane suitable for use with rooftop systems. Cold liquid-applied systems are equally effective and may be comparable in cost due to strict regulations on the use of the propane-fired devices for hot fluid systems. For green roofs, polymer-modified bituminous products require a supplemental root barrier layer.

4.3.3 Leak Detection Systems

Leak detection is an important element in the design and construction of rooftop systems. Some systems involve installation of a network of sensors as part of the initial roof design, while other options include low and high voltage surveying. Leak detection should be conducted during construction (after the installation of the waterproofing membrane), and on a regular basis after installation of the rooftop system. Both passive and active electrical methods are available for locating leaks.

The most common passive technique is low-voltage leak surveying. This method does not require the permanent installation of any components, provided the waterproofing is installed over a cast-in-place structural concrete, steel, or composite steel-concrete deck. The survey should be conducted by a trained technician. High voltage methods, while effective for evaluating watertightness during the construction phase, are not useful after a blue or green roof is installed because the waterproofing must remain in a dry condition.

Active systems involve the installation of a network of electrical sensors beneath the waterproofing membrane. These systems can be designed to continually check for leaks and to set off an alarm when a leak is detected. Active systems are not compatible with liquid-applied and most other adhered waterproofing systems.

Figure 4-8: Installation of fiberboard and first ply of waterproofing membrane during construction of a blue roof at PS118 in Queens.

It is recommended that some type of long-term leak detection system is employed. It is up to the licensed professional and property owner to decide which system provides adequate protection, balancing the cost with the associated risk of leakage.

4.3.4 Roof Drains and Scuppers

Roof drains and leaders for blue and green roofs should be sized in the same manner as conventional roof drain systems and in accordance with the Construction Codes. If a site's stormwater runoff is to be controlled on the rooftop, controlled flow roof drains are required for blue roofs and green roofs to comply with DEP's stormwater performance standard. These drains are commercially available and typically incorporate volumetric weirs into the drain assembly to control the flow rate entering the drain.

Depending on the roof design and required release rate, off-the-shelf or custom drain designs may be used. Designers are advised to use the storage volume and release rate calculations in the DEP Criteria and Section 2 of these guidelines, rather than rely solely on manufacturer-provided sizing charts. Weir-style controlled flow roof drains must be tamper-proof to prevent unauthorized modifications, which could alter system performance.

As with conventional roof systems, blue and green roof installations should include secondary (emergency) scuppers or roof drains to comply with the Construction Codes. Secondary drains and scuppers should be located at the desired ponding depth of the blue roof. Green roof installations will almost always be four inches thick or greater, which will require setting the secondary drain higher than four inches over the low point of the roof and the scuppers higher than four inches from the surface of the roof assembly. If the green roof is designed to allow ponding on the surface of the green roof, the scuppers may need to be raised accordingly. The structural design of the building should account for the maximum ponding depths at the secondary drains and scuppers.

In addition to the secondary drains or scuppers, excess flows may enter the controlled flow roof drain at an uncontrolled rate by flowing over the top of the drain.

Figure 4-9: Installation of waterproofing membrane during construction of a green roof at PS118 in Queens.

Clogging of roof drains through accumulation of debris can significantly alter the relationship between water depth and flow rate, and diminish system performance. To ensure that the system performs as designed and to avoid overburdening maintenance personnel, strainers should be placed around the drain inlets to catch debris before it enters the drains. Such strainers, commonly found on standard roof drains, are commercially available in various diameters to fit common drain sizes.

4.3.5 Roof Slope, Ponding Depth, and Drainage Configurations

To function as an effective stormwater control, a blue roof should provide adequate storage volume to control release rates in accordance with DEP's stormwater performance standard. For this reason, application of blue roof systems is most effective on roofs with slopes of up to about one-quarter-inch per foot (or 2% slope).

The slope of a roof has a significant impact on the volume of water that can be detained on the roof while maintaining shallow ponding depths around the roof drains. For a given roof configuration, the available storage volume depends on a number of variables including roof size, drainage configuration, direction of slope and maximum allowable ponding depth.

For ponding depths greater than four inches, additional structural analyses are required according to the Construction Codes. Section 4.3.7 provides additional detail on loading considerations. For a given ponding depth, the drainage configuration should be designed to achieve the maximum possible storage volume. One way to increase the available storage volume on a sloped roof is to increase the number of drainage areas. The optimal number of drainage areas for a given roof size depends on the slope of the roof and the maximum ponding depth.

Regardless of how the roof area is divided into drainage areas, one potential problem with this approach is that as sloped roofs become larger, more drainage areas and drains are required to maximize the available storage volume. Given a fixed total roof area, as the number of drains increases, the required release rate per drain may become too small to achieve using commercially available controlled flow roof drains.

Figure 4-10:
The orifice in this controlled flow drain sets the ponding depth and controls the outflow from the roof on DEP's Storage Facility in Brooklyn.

For alterations to existing buildings, rooftop storage may be maximized by installing check dams or weirs at intermediate locations along the roof surface or ponding trays throughout the roof surface. Check dams or weirs may be constructed of any material that can temporarily detain water and withstand environmental conditions on rooftops. Appropriate materials include angle iron, fiberglass, roof tiles, and pavers with roof flashing. These modifications should be appropriately weather sealed and secured to the roof structure. Spacing of a series of check dams or weirs on sloped surfaces should ensure that one does not cause backwater against another at maximum water surface storage.

Table 4-1 is included for planning purposes only to show available storage volumes for a range of alternate roof drain configurations with a uni-directional slope of 0.5%. While the uni-directional slope configuration is not the most restrictive configuration, it is used to provide guidance for sloped roof applications.

Storage volumes are calculated assuming three inches of ponding depth with controlled flow roof drains rated at 9.1 gallons per minute per inch (0.02 cfs per inch). To determine the available storage volume on such a roof using this table, the total roof area and the length-to-width ratio of the individual drainage areas must be known. By selecting the roof area and length-to-width ratio from the appropriate row and column in the table, the available storage volume for the roof configurations illustrated in **Figures 4-11a**, **4-11b**, and **4-11c** can be estimated. Uni-directional roof slopes result in more storage volume than multi-directional sloped roofs, and most roofs have slopes steeper than 0.5%. Therefore, **Table 4-1** illustrates the high range of available storage. Design calculations for available storage volumes are needed for all roofs intended to be used as rooftop detention.

4.3.6 Growing Media and Vegetation

The engineered soil used in green roof construction is referred to as growing media. In order to satisfy a range of physical and horticultural requirements, media for green roofs is usually based on lightweight aggregates. These materials, lighter than most soil, have high surface area and porosity and moderate to high permeability.

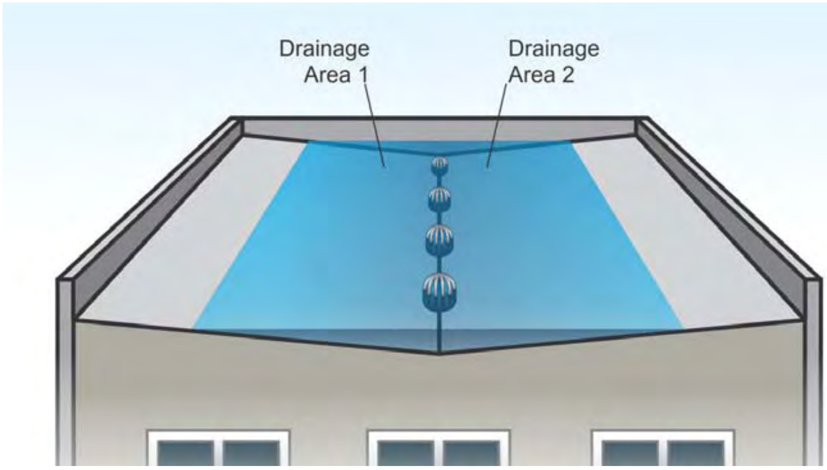


Figure 4-11a:
Uni-directional sloped roof with four drains and two drainage areas.

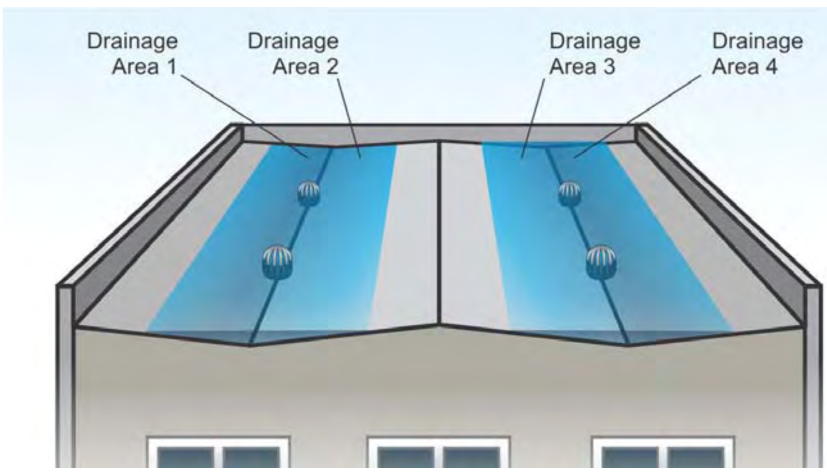


Figure 4-11b:
Uni-directional sloped roof with four drains and four drainage areas.

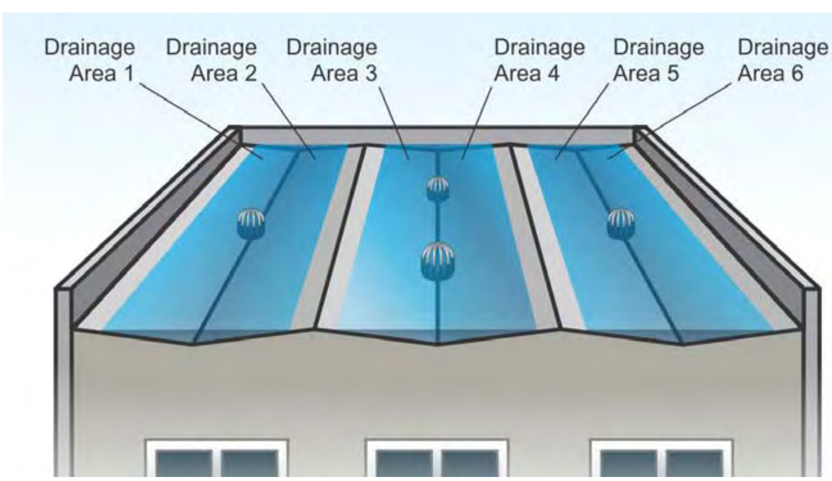


Figure 4-11c:
Uni-directional sloped roof with four drains and six drainage areas.

Table 4-1: Available storage volume (cu ft) for uni-directional sloped roofs of different sizes and length-to-width (L/W) ratios (for planning purposes only)

Roof Area (sq ft)	2,000	4,000	6,000	8,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000
Number of Drainage Areas (N) = 2												
L/W = 1	388	684	919	1,106	1,250							
L/W = 2	342	553	678									
L/W = 3	306	452	494									
L/W = 4	276	368										
Number of Drainage Areas (N) = 4												
L/W = 1	444	842	1,210	1,553	1,875	2,602	3,232	3,779				
L/W = 2	421	776	1089	1,368	1,616	2,126						
L/W = 3	403	726	997	1,225	1,417							
L/W = 4	388	684	919	1,106	1,250							
Number of Drainage Areas (N) = 6												
L/W = 1	463	895	1,306	1,702	2,083	2,985	3,821	4,603	4,335	6,022	6,667	7,273
L/W = 2	447	851	1,226	1,578	1,911	2,667	3,333	3,921	4,438			
L/W = 3	435	817	1,165	1,484	1,778	2,424	2,959					
L/W = 4	425	789	1,113	1,404	1,667	2,219						

*Assumes ponding depth of three inches and slope of 0.5%

Plant species should be carefully selected to achieve a vigorous plant cover over the green roof. Despite the relatively shallow media depth of many green roofs, plants with long roots, such as Panicum and Andropogon grass, can adapt to the thin veneers of green roofs. Plants that do not have a documented record of success over a period of at least three years under similar conditions should be used sparingly and with caution. Plants that require irrigation past the establishment period should not be included in green roofs unless the roof is designed as a rooftop farm. Species having deep tap roots should be avoided. Several additional planting recommendations are summarized below:

- The selected plant community should be able to accommodate brief periodic saturated soil conditions;
- Plants with differing growing media requirements should not be mixed or located in the same area of a roof;
- Ground covering plants should always be included in the design. Measures that promote the rapid development of this groundcover should be introduced early during construction;
- Typically, evergreen perennials dominate in green roof design, as it is often desirable to maintain a continuous foliage ground cover for aesthetic purposes. For extensive green roofs with thin layers of media and without irrigation, consider also sowing annual or biennial plants in the fall. This can add color and interest and will also provide dense spring foliage to help in suppressing weeds.

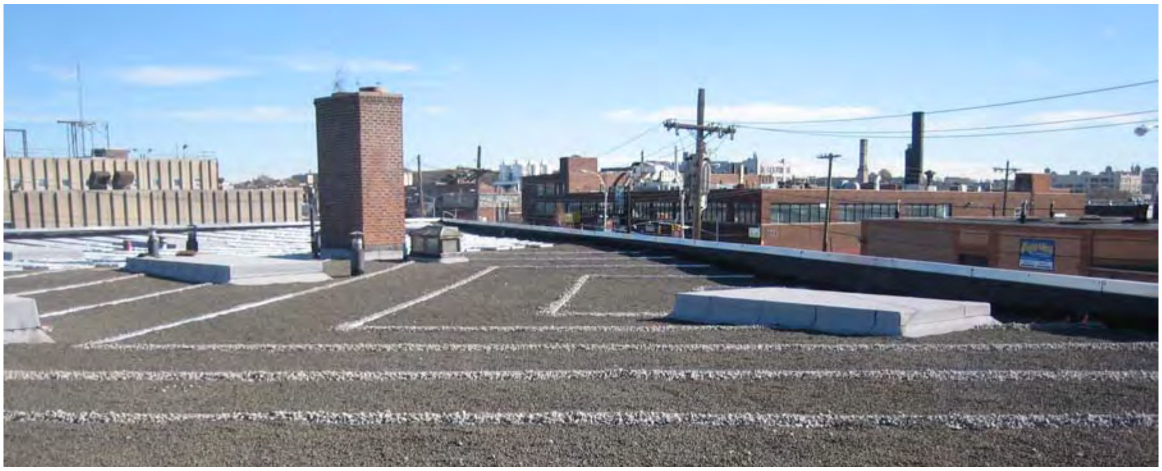


Figure 4-12: Intermediate check dams were installed on DEP's Storage Facility in Brooklyn to control flow on sloped portions of the roof.

Self-sowing annuals are another way to enhance the green roof. Regardless of the use of evergreen or other green roof appropriate species, establishment of a dense, perennial root mass is important for green roof function;

- Many Sedum varieties, the most common vegetation used on green roofs, are deciduous and distinctly seasonal. Sedums can survive in the windy and sun exposed conditions found on most green roofs, and are very good at establishing the necessary initial plant cover. Once the plant cover is established, other non-Sedum varieties can be established a few years into the life of the green roof; and
- Plants with particularly aggressive rhizome roots should be avoided. In particular, bamboo species and Miscanthus should not be used on extensive green roofs. Some native plants that are suitable for shallow soil (less than five inches) without irrigation are Allium and Rudbeckia.

All selected species should be appropriate for the specific green roof design, and a landscape or green roof specialist should be consulted. The project goals (ecological, horticultural, or other) will dictate the appropriate combination of native and non-native species. The Greenbelt Native Plant Center, a division of DPR, has compiled a list of native species appropriate for green roofs in the northeast. This information is provided in Appendix F of these guidelines. The species recommended by the Greenbelt Native Plant Center have not been fully tested to-date for viability on green roofs in the northeast; however, the species were carefully selected based on a number of criteria and will be updated as studies progress.

The number of drains and sizing of each drainage area on the rooftop can help mitigate slope impacts when designing a blue roof. For green roofs, quality and quantity benefits can be enhanced by maximizing the flow path length from roof high points to drains.

Figure 4-13: Native plants such as Allium (left) and Rudbeckia (right) have shallow root systems suitable for green roofs. (Source: Harry Cliffe and Joseph Marcus, Lady Bird Johnson Wildflower Center).

4.3.7 Loadings and Structural Capacity

Where a blue or green roof is employed, the building needs to be designed and built to have adequate structural capacity to support the weight of the stormwater storage volume and rooftop system components. The roof and building structural systems should be designed by a licensed professional to comply with the Construction Codes and requirements for rain and snow loads, controlled drainage, and deflection due to ponding. At a minimum, rooftops in the city are designed for a live load of 30 pounds per square foot.

One inch of ponded stormwater on a rooftop adds approximately five pounds per square foot of loading. The weight associated with one inch of saturated green roof media is generally in the range of seven to eight pounds per square foot, but will vary widely based on the particular assembly. The maximum dead load associated with a green roof includes the weight of the waterproofing system and insulation, all media and synthetic materials in a wet condition, and mature plants. To demonstrate compliance with the allowable dead loads for a particular project, use the procedure outlined in ASTM Standard Procedure E2397, Determination of Dead Loads and Live Loads associated with Green Roof Systems.

During the construction process, a licensed professional should be retained by the owner to assume responsibility for special or progress inspections, as required by the Construction Codes.

Analysis for deflection, which describes the degree to which a structural element is displaced under a load, is particularly important for roofs where ponding instability may occur near the drain. Per the Construction Codes, roofs with a slope of less than 2% must be analyzed to ensure that the roof provides adequate stiffness to prevent progressive deflection as rain falls or snow melts on the roof surface. As slopes between one-half and 2% are optimal to maximize the storage volume available for blue roofs and many green roofs, these designs generally require a deflection analysis by a licensed professional to ensure compliance with this requirement.

Figure 4-14:
Blue roof system during winter installed at DEP's Storage Facility in Brooklyn. Prior to rain events, it may be necessary to clear ice and snow from around roof drains to allow for blue roofs to function properly during the winter.

4.3.8 Climate Considerations

Significant freezing of standing water from a rainfall event is unlikely because roofs with controlled flow roof drains have short drain times, ranging from a few minutes to a few hours, and the stormwater is constantly flowing toward and down the drain. Similarly, green roofs should be designed to have positive drainage, and storage of water within the drainage layer should not last for more than a few hours. Rooftop systems should be designed to drain down within 24 hours to ensure storage volume is available for subsequent rainfall events.

Clogging of drains by snow and ice accumulated on a roof prior to a rain event is a potential problem. As with conventional shallow sloped roofs, maintenance procedures for blue roof systems include the removal of accumulated snow prior to an anticipated rain event to prevent possible overloading and damage to the roof. Homeowners or building maintenance staff should remove snow from the blue roof using the same removal methods used for conventional roofs. Snow removal on green roofs (except around the roof drains) is not recommended as the snow acts as a protective layer for the vegetation. This extra load should be accounted for in the structural design.

Wind is also a concern for green roofs, as the wind can scour vegetation and growing media, damaging the system. The eroded soil can also impair stormwater flow off the roof by clogging the roof drains, which could lead to excessive ponding of water on the roof. Generally, wind-stabilized margins consisting of course stone or pavers should be considered at roof perimeters where the parapet height is less than three feet high, and on regions of the roof where the estimated design wind uplift will exceed 25 pounds per square foot.

The potential for disruption or damage by wind may vary with building height, building geometry, geographic location, and local topography. As a result, green roofs are best suited for low buildings, but can be installed on tall buildings or buildings with higher wind loads when designed properly. The probability of wind damage is greatest immediately after installation and diminishes as the green roof system matures. With many green roof systems, temporar-

Figure 4-15: Application of tar and waterproofing membrane during installation of a green roof at PS118 in Queens.

ily protecting the media prior to establishment of a mature plant ground cover is advisable. This can be accomplished with wind scour erosion blankets fabricated from organic fibers, tackifying agents, or pre-grown modules and mats.

Due to the constant movement of water and short drain down time, mosquitoes are not a nuisance associated with rooftop systems, as mosquito larva need 72 hours of stagnant water to survive.

4.4 Rooftop System Construction

The following construction techniques are recommended to ensure proper installation of the system, protect the roof structure and equipment, allow access to the roof, and ensure the roof functions safely and effectively over time as a means of controlling site runoff. Other activities suggested or required by the roof membrane manufacturer or the green roof supplier should be followed in order to avoid nullifying respective warranties.

Before any construction for the rooftop system begins, construction of all major components of the building's structural system should be completed and a construction inspection by a licensed professional should be conducted to verify that the building, as constructed, has the capacity to support roof loads from the rooftop system. Specific construction sequence guidelines along with manufacturer-provided installation instructions will assist in constructing rooftop systems that comply with DEP's stormwater performance standard.

Urban Agriculture

Rooftop gardens and farms offer opportunities for local food productionand are an additional means of providing residents with additional access to healthy, affordable and local produce. Mayor Bloomberg's PlaNYC Update 2011 includes initiatives to facilitate agricultural projects throughout the city and through partnerships with public schools and high density residential complexes.

4.4.1 Pre-Construction Meeting

A pre-construction meeting should be conducted prior to the installation of any rooftop system. The recommended attendees include property owner, general contractor, subcontrac-

Figure 4-16: Roof drain screens and covers help prevent leaves and other debris from entering and clogging roof drains.

tors, licensed professional of record, and supplier of the system (if proprietary). At this meeting, design specifications for the roof assembly and rooftop system should be reviewed and any site-specific concerns should be discussed. No work should begin until all parties are in agreement that the materials and methods used will not compromise warranties for the installation.

4.4.2 Waterproofing System

Roof membranes should be installed in accordance with manufacturer specifications to provide proper waterproofing. The system should have a waterproof seal along all seams in the roof membrane and in areas where mechanical devices, equipment, or other structures are affixed to the roof surface. The waterproofing system should be attached to the roof surface using adhesives or other methods approved by the system manufacturer. Adhesives that may corrode or otherwise compromise the performance of the membrane or roof system should be avoided. If a green roof is to be used as ballast for the membrane, temporary ballast should be used until the green roof is installed.

Waterproofing and associated flashing should also be protected from damage due to abrasion, puncture, and ultraviolet light. Flashing should be designed with the same expectation for longevity as the field membrane that is protected by the green roof. In most cases, this involves installing protective counter-flashing or adhering a protective sacrificial membrane to the flashing. Geotextile can be used to protect the field membrane from punctures associated with normal use, including maintenance. Depending on the assembly type, a geocomposite drainage layer may serve this purpose.

4.4.3 Installation of Controlled Flow Drains

Controlled flow roof drains should be included in both blue and green roof designs to ensure compliance with DEP's stormwater performance standard. Specifications for the required water level and flow rate for a given roof should be determined by a licensed professional. This information is then supplied to the drain manufacturer as part of the design process, and the drain openings are sized to achieve these values. These specialized drains are then installed in place of conventional roof drains. The set-

Figure 4-17: The green roof on The Verdesian, a residential building in lower Manhattan, provides dedicated space for access, passive recreation and the building's mechanical equipment.

tings on these drains are set prior to installation, and any adjustable components of the drainage assembly must be fixed to prevent future modification. Flood tests should be conducted after installation of the controlled flow drains.

To prevent leaves and other debris from entering the drain, each drainage inlet should be equipped with a screen or strainer that completely encloses the inlet. Such screens consist of a mesh surface with sufficient surface area to catch debris while allowing unrestricted passage of water to the drain. Screens should be attached securely to the roof with screws or bolts and must be tamperproof to prevent unauthorized modifications to the drain inlets.

4.4.4 Installation of Green Roof Systems

Outlined below are the different components of typical green roof systems. Depending on the building and roofing system specifications, different combinations of the below components may be used. At a minimum, green roofs should consist of vegetation, growing media, a protection course (fabric layer, insulation, and sheet drain) and a root barrier.

Membrane

Prior to installing the green roof system, the roof assembly should be carefully inspected and tested for watertightness using a method agreeable to all parties (i.e., flood testing or leak detection). Flood testing involves closing the roof drains off and filling the roof with water to determine if there are any leaks apparent during the membrane installation process. All leaks should be fixed before the green roof system is installed on top of the membrane which would make further leak detection and membrane repair more difficult.

Protection Courses and Root Barriers

All green roofs require the same level of protection against root penetration. Over an extended time period and without attentive maintenance, annual grass and perennials are likely to estab-

As with conventional roof systems, the type of insulation selected needs to comply with thermal resistance (R-value) requirements based on the building type, per New York City Energy Conservation Code requirements.

Recommended Construction Sequencing

1. For new development projects, install rooftop systems toward the end of the construction process, if possible. The rooftop system should be installed only after the waterproofing system, all rooftop equipment, and architectural features (e.g., parapets, hatchways, thresholds, fixed lighting, and plumbing) have been completed.
2. Install leak detection systems (if applicable) after the rooftop structural capacity is approved by a licensed professional.
3. Construct and install all necessary downspouts, scuppers, and controlled flow roof drains in accordance with the manufacturers' standards and recommendations, if applicable.
4. After the installation of the controlled flow roof drains, a flow test should be conducted at the roof drains to ensure the proper conveyance of water off the roof and that each drain is flashed appropriately to prevent leaks.
5. For green roof systems, install all protective courses, root barriers (if required), and drainage layers according to the specifications of the licensed professional.
6. For green roof systems, install a filter layer followed by the growing media. The filter layer should be placed to prevent migration of the growing media into the drainage layers.
7. For green roof systems, plant or seed directly into the growing media at an appropriate season for plant establishment. Generally this is in the spring or fall.

lish in Sedum-based green roofs. The waterproofing system should be able to resist attack from the rhizomes of aggressive annual plants. Only plastic or rubber membranes are acceptable as root barriers. When waterproofing is used without a supplemental root barrier, the waterproofing materials should be tested for root resistance. Seams should provide the same level of root resistance as the root barrier membrane. Acceptable seaming methods are hot-air welding (thermoplastic membranes) or overlaps of at least five feet combined with an adhered seam. Sealing the root barrier seams also provides additional waterproofing for the system and, potentially, extends the life of the roof.

Drainage Layers

For multi-course systems, the functions of the drainage layer are to: (1) maintain the overlying growth media in a drained and aerated condition, (2) promote the flow of percolated water toward controlled flow roof drains, and (3) prevent surface flow. Important properties of drainage layers are thickness and in-plane flow capacity, also known as transmissivity. Transmissivity of the drainage layer and the location of drains on the roof have a direct influence on the time of concentration (the time it takes for a pulse of rainfall to reach the roof drains).

The controlled flow roof drains create backwater into the green roof assembly, so the green roof should be explicitly designed to be compatible with this condition. This may involve increasing the thickness of the drainage layer by adding granular drainage, introducing a thick geocomposite drainage component, or some combination of both.

In single-course roofs the protective layer may provide some water retention. However, those assemblies do not have an independent drain-

Figure 4-18: Fence installed on St. Simon Stock School in the Bronx to allow student access to the green roof.

age layer. Instead, they depend on the transmissivity of the growing media to drain and aerate the media.

Geocomposites

Care should be exercised to select a drainage product that is appropriate for the design conditions and does not compromise meeting DEP's stormwater performance standard. Geocomposite drainage layers may have moderate to high transmissivity (typically greater than 2.5 gal/min/ft where i=1, based on ASTM D4716). In addition to transmissivity, important properties of green roofs include compressive strength, resistance to biological activity, and permeability to vertical flow or percolation. Over-draining or under-draining a green roof can adversely affect the plant foliage. Geocomposite drainage layers should not be confused with protection layers (though they may be combined), which generally feature lower transmissivity.

Reservoir sheets are a special class of geocomposite drainage layers that have indentations on their upper surface to capture and retain water. There are two types: (1) sheets that are transmissive on both sides, and (2) sheets that are transmissive on the underside only. Granular mineral drainage media is frequently used in combination with reservoir sheets for sheet stabilization, reducing shock to plant roots and improving transmissivity.

Granular Drainage Layers

Granular mineral drainage media can be used to provide a drainage layer that moderates flow toward drains and increase the time of concentration. Granular drainage layers may be as thin as one inch, but are typically two to four inches in thickness. This type of drainage layer can be used to supplement assemblies that include reservoir sheets and fill in some void space to reduce shock to the root system. Layers that incorporate drainage media become part of the root zone of the plants and the materials should be chosen accordingly.

Granular drainage layers should contain as little silt and clay as possible, and should have high permeability and porosity. Green roof installers should consider the minimum granular drainage layer recommendations indicated in **Table 4-2**.

Figure 4-19: Drip irrigation on a constructed green roof at Fordham Bedford Housing in the Bronx.

Water Retention Mats

Water retention mats are not necessary for green roof assemblies, but are sometimes incorporated to store an additional amount of water and keep water distributed across the extent of the roof assembly. Storage ability of the mats (typically fleece or mineral wool) vary based on the thickness of the material. This functionality is sometimes integrated into the protection layer that lies on top of the root protection barrier. Water retained in the mats can be included in the volume of water detained on the roof.

Filter Layers

Filter layers are used to keep the growing media from migrating into the drainage layer and to keep the growing media in place. On green roofs, geotextiles are used for filtration, either in the form of fleece or woven fabric. The geotextile either lies between the drainage layer and the growing media, or is built into the drainage mat. The fabric should allow root penetration, be resistant to microbial attacks and chemicals, and need not be weather resistant. Green roof installers should consider the geotextile recommendations in **Table 4-3.**

Growing Media

The growing media should not be vulnerable to degradation caused by freeze-thaw cycles, perennially moist conditions, compression, or biodegradation. To prevent long-term hazard of fabric clogging or loss of permeability, media used in green roofs should not contain more than 15% particles in the silt-size fraction, nor should it contain more than 3% in the clay-size fraction.

For single-course green roofs where no efficient drainage layer is present, the combined clay and silt content should not exceed 10% by mass, and the total organic content should be less than 2.5 pounds per cubic foot of media based on the mass lost upon combustion. A maximum of 50% of the growing media should pass through the No. 10 sieve (2 mm).

For multi-course green roofs where an efficient drainage layer is present, the combined clay and silt content should not exceed 15% by mass, and the total organic content should be less than four pounds per cubic foot of media, based on the mass lost upon combustion. Between 30% and 80% of the growing media should pass through a No. 10 sieve (2 mm).

Table 4-2: Granular drainage layer recommendations (Source: FLL)

Property	Reference Value	Unit
Proportion Silt[1] Proportion Clay[1]	≤ 10 ≤ 2	Percent by mass Percent by mass
Water Permeability[2]	≥ 15	in/min
Air-filled Permeability[3]	≥ 20	Percent by volume
pH Value	6.0-8.5	N/A
Salt Content (water extract)[1]	≤ 0.22	lb/cu ft
Salt Content (gypsum extract)[4]	≤ 0.16	lb/cu ft

Notes:

1. The value should be as low as possible
2. Based on ASTM E2396 (Note: This exceeds FLL recommended minimum of seven inches per minute)
3. Based on ASTM E2399 (Applies where backwater or extended water storage in the drainage layer is anticipated)
4. Where needed

Table 4-3: Geotextile recommendations

Property	Reference Value	Unit	ASTM Test
Density	≥ 8	oz/sq yd	D3776
Apparent Opening Size	≥ 0.06 ≤ 0.2	mm	D4751
Permittivity	≥ 1.5	1/sec	D4491
Puncture Resistance	130	lbs	D4833
Mullen Burst Strength[1]	≥ 300	psi	D3726

Notes:

1. For filter fabrics covering dimpled sheets

Recommendations for optimal growing media choices for both single and multi-course green roofs are provided in **Table 4-4.**

Vegetation

Early fall is the preferred season to plant green roofs, so that plants can take advantage of the fall and spring growing seasons to develop a more substantial root structure prior to the first summer. This is true whether starting from seed or cuttings. Spring planting is also acceptable, though more irrigation may be required during the first summer. Factors that are essential to a healthy, comprehensive root cover include using the correct growing media with proper porosity and nutrient levels for the type of green roof system, and planning for irrigation needs if the roof is planted in the spring or summer.

A complication associated with green roofs is that weeds may start to take hold in the growing media, forcing out the desired vegetation. Strategies to minimize weed 'pressure' include:

- Introducing measures that promote the rapid development of groundcover in the first growing season;
- Not installing a thicker media layer than needed to support the plants;
- Not mixing plants with differing growing media requirements in the same area of a roof; and
- Planning for appropriate O&M in terms of irrigation and weeding.

Pre-grown mats or modules can be used to accelerate ground cover. When planted at the

Figure 4-20: Rain gauge at PS118 in Queens.

proper time and using best practices, cuttings and seed can also be used to provide a rapid cover. Plugs should be installed at a minimum density of two plants per square foot. As noted above, temporary irrigation is advised throughout the first full growing season for all projects. At least 80% of the ground should be covered by vegetation by the end of the first full growing season.

Signage

After installing a rooftop system, signs should be posted on bulkhead doors that provide access to the roof and near drainage inlets to inform building owners, maintenance staff, and others that the roof is designed for storing stormwater. Signs should indicate that several inches of water may pond after storm events and that roof drains require specific maintenance procedures and should not be altered. This type of informational signage will help to increase awareness of the rooftop system and prevent future modifications, which may be incompatible with the roof design.

4.4.5 Construction Inspections and As-Built Certification

During the construction process, a certified licensed professional should be identified to assume responsibility for special or progress inspections, as required by the Construction Codes. In addition, it is recommended that the following inspections be performed for rooftop systems under the supervision of a licensed professional:

- Building structural system and roof deck;
- Leak/flood testing of the roof membrane system and drains after installation;
- Verification that the controlled flow roof drains and screens have been properly installed; and
- Testing of the roof drainage system's connection to the sewer.

Once construction is complete, the licensed professional should submit the Technical Report 1 (TR1) certification to DOB along with as-built drawings to ensure that the constructed rooftop system complies with the approved drawings. Departures from the permit documents should

Table 4-4: Growing media recommendations (Source: FLL)

Properties	Single-Course	Multi-Course	Unit
Granular Distribution			
Proportion Silt & Clay	≤ 10	≤ 15	Percent mass
Proportion Gravel	≥ 75	≤ 50	Percent mass
Water and air management			
Maximum Water Capacity	≥ 20 & ≤ 65	≥ 35 & ≤ 65	Percent volume
Air Content at Max. Water Capacity[1]	≥ 10	≥ 6	Percent volume
Air Content at pf 1.8	-	≥ 20	Percent volume
Water Permeability	2.5 - 15.5	0.02 - 2.8	in/min
pH value, salt content			
pH Value (in $CaCl_2$)	6.0-8.5	6.0-8.5	N/A
Salt Content (water extract)[2]	≤ 3.5	≤ 3.5	g/l
Salt Content (gypsum extract)[3]	≤ 2.5	≤ 2.5	g/l
Organic substances			
Organic Content (loss on ignition)	≤ 40	≤ 65	g/l
Nutrients			
Nutrients Available to Plants			
Nitrogen (N) (in $CaCl_2$)	≤ 80	≤ 80	mg/l
Phosphorus (P_2O_5) (in CAL)	≤ 200	≤ 200	mg/l
Potash (K_2O) (in CAL)	≥ 700	≥ 700	mg/l
Magnesium (Mg) (in $CaCl_2$)	≤ 200	≤ 200	mg/l
Nutrients Available to Plants (in CAT)			
Nitrogen (N)	≤ 80	≤ 80	mg/l
Phosphorus (P_2O_5)	≤ 50	≤ 50	mg/l
Potash (K_2O)	≤500	≤500	mg/l
Magnesium (Mg)	≤ 200	≤ 200	mg/l
Foreign Bodies			
Diameter > 6mm			
Tiles, Glass, Ceramics and Similar	≤ 0.3	≤ 0.3	Percent mass
Metal, Plastic	≤ 0.1	≤ 0.1	Percent mass
Total Area for Plastics	**≤ 0.3**	**≤ 0.3**	**sq.ft/cu.ft**

Notes:

1. Recommend using measured actual particle density as basis for computing porosity of lightweight aggregates
2. The value should be as low as possible
3. Where needed
4. Either in CAL(calcium acetate lactate)/calcium chloride or CAT(Calcium chloride Diethylene triamine pentaacetic acid)

Figure 4-21: Green roof drain inspection chamber on St. Simon Stock School in the Bronx.

be noted, along with shop drawings or notes that describe special conditions or supplemental features of the installation that are not part of the permit documents. It is the owner's responsibility to ensure that documented inspections are conducted during construction in accordance with the Construction Codes. In many cases, contractors will provide construction quality assurance services and furnish close-out documents to the owner at the point of substantial completion.

4.5 Operations and Maintenance for Rooftop Systems

Rooftop systems must be inspected and maintained in order to function as designed, ensure required release rates and storage volumes over time, and comply with *Chapter 31.* DEP and DOB are not responsible for any onsite or offsite injuries or damage to persons or property resulting from improper design, construction, operation, or maintenance.

4.5.1 Post-Construction Monitoring

Post-construction monitoring during the first year after installation is important for gauging the effectiveness of rooftop systems during operation and determining whether any system modifications are necessary to ensure systems function as intended. Monitoring debris at roof drains and ponding on the roof surface, along with weather conditions, can provide useful information about system performance during and after rain events. In addition, regular and frequent inspections during the first year would help to determine the appropriate activities and schedule for future maintenance.

4.5.2 Inspections

To ensure proper inspection and maintenance, it is important to inform maintenance staff and other potential users of the roof that a rooftop system has been installed. Posting signs on the roof, as discussed in Section 4.4.4, and clearly communicating expectations for maintenance, are critical to prevent damage and tampering, and to ensure that rooftop systems function properly over time.

Table 4-5: Recommended inspection activities for blue roofs & green roofs

Schedule	Activity
Blue Roofs	
Semi-annually under dry conditions	• Inspect roof drain inlets to ensure in good condition • Inspect drain inlet screens/strainers to ensure in good condition • Inspect roof membrane to check for signs of deterioration
Quarterly and after rain events	• Inspect roof to verify achievement of water depth and drain time requirements • Inspect secondary drainage inlets for blockage or debris
After snow/icing events	• Check roof drain inlets for blockage caused by buildup of snow or ice
Green Roofs	
Monthly during growing season, under dry conditions	• Inspect green roof to identify invasive species, weeds and bare spots • Inspect for signs of drought during extended dry periods
After rain event	• Inspect roof to verify achievement of water depth and drain time requirements • Inspect secondary drainage inlets for blockage or debris
Semi-annually under dry conditions	• Inspect roof drain inlets to ensure in good condition (during irrigation activities, over-watering can be identified by dry weather flow at the drains) • Inspect drain inlet screens/strainers to ensure in good condition • Inspect the condition of exposed waterproofing and flashing • Inspect temporary or permanent wind blankets
Annually under dry conditions	• Soil samples to determine nutritional requirements
After snow/icing events	• Check roof drain inlets for blockage caused by buildup of snow or ice

As with conventional roofs, routine post-construction inspections of green and blue roof systems are necessary to ensure continued performance. Inspections are particularly important within 24 hours of significant rain events to ensure the specified ponding depths and drain times are being achieved, standing water does not persist for more than 24 hours, and there are no leaks as a result of roof conditions. Water depths or drain times exceeding the design values for the system may be indicative of debris clogging the system or improper performance of outlet control structures. Any debris observed around the roof drains should be removed. Extensive ponding of water beyond the design level may be indicative of damage to the green roof, leading to media leakage and clogging of the drains.

Inspections of inlet screens, drainage inlets, and the roof membrane system are recommended every six months during dry weather to check for debris or signs of damage.

Table 4-5 outlines regular inspection activities and their frequency. This list can be modified after the first year of maintenance based on site specific conditions. The troubleshooting section below may be used to address issues found during inspections.

4.5.3 Maintenance

Chapter 31 requires property owners and their successors to file a deed restriction to ensure operation and maintenance of stormwater management systems throughout the life of the system or until replacement is approved by DEP. In

Figure 4-22: Staff performing maintenance on DPR's Five Borough Building green roof.

addition, the property owner must retain records and furnish proof of maintenance in the form of a certification by a licensed professional submitted to DEP every three years.

Property owners may enter into annual or bi-annual maintenance contracts with commercial vendors that are able to provide the range of maintenance activities described in these guidelines and manufacturer specifications. All maintenance activities should occur during dry weather unless an emergency situation necessitates maintenance or repairs during rain events.

Maintenance activities for blue roofs focus on preventing clogging of drainage inlets and preventing deterioration of the roof membrane. Maintenance activities for green roofs focus on ensuring healthy vegetation with minimal weeds or bare patches and preventing clogging of drainage inlets.

After the conclusion of the establishment period for vegetation on green roofs (usually two or three years), ongoing maintenance should be minimal. Nonetheless, without regular annual inspections and maintenance, green roofs may develop problems, including wind erosion, bare spots, infestations of annual weeds that can choke out beneficial cover plants, and nutrient deficiencies.

Factors that are essential to a healthy, comprehensive root cover include using the correct growing media with proper porosity and nutrient levels for the type of green roof system, irrigation if the roof is planted in the spring or summer, and attentive weeding until the desired groundcover is established. Plants should not be over fertilized. Irrigation should be limited to the first full growing season with focus on the establishment period, and then eliminated after plants are established except in times of extreme drought. Timely service visits should be made to catch weeds before they go to seed.

For blue roofs, maintenance activities can generally be performed by individual building owners or site maintenance staff as needed. Contact the contractor responsible for the installation of the rooftop system immediately if it is not performing as designed. For green roofs, building owners may enter into contractual arrange-

Figure 4-23: DCP's Parking lot requirements and impervious surface reductions may allow for smaller required storage volumes.

ments with the green roof designer or installer to perform maintenance activities. Onsite maintenance staff may, in certain instances, be trained to also perform this function.

For all rooftop systems, adequate maintenance of the secondary drainage system is essential to ensure its performance in the event of a failure of the roofing system. In addition, the rooftop system and membrane should be evaluated every 20 years to assess the need for replacement.

Table 4-6 includes recommended maintenance considerations for blue and green roofs.

4.5.4 Developing an Inspection and Maintenance Plan

Developing a site stormwater inspection and maintenance plan is crucial to the success of the rooftop system and should be updated based on the results of the first-year post-construction monitoring program. The maintenance plan should identify a maintenance manager who is responsible for operating and maintaining the rooftop system.

The plan should include a maintenance schedule developed for the life of the rooftop system. The schedule should outline the specific maintenance activities that are required to be completed, the frequency and timing, and the person or entity responsible for completing the activity. The property owner must keep all records of inspections and maintenance activities and regularly update the plan (i.e., every five years) based on actual system requirements, the results of maintenance activities, and compliance with DEP's stormwater performance standard.

4.5.5 Troubleshooting

If problems are identified during routine maintenance and inspection, the property owner should take time to troubleshoot the problem.

Problems with a blue roof system generally fall into two categories: (1) the system drains too slowly, resulting in buildup of excess water on the roof for extended periods of time, bypasses of the controlled flow roof drains, or overflow via secondary drains/scuppers during small rainfall events, or (2) the system drains too quickly, exceeding the design release rate. **Table 4-7** outlines these common problems and offers potential solutions. If problem persists, a licensed professional should be consulted.

Table 4-6: Recommended maintenance activities for blue roofs & green roofs

Schedule	Activity	Equipment
Blue Roofs		
During inspections or as needed to ensure performance	• Remove debris from drainage inlets and inlet screens to prevent clogging • Remove debris from secondary drainage inlets/scuppers	• Shovel
Winter considerations	• Break up ice formation around inlets	• Ice pick, or equivalent tool
Green Roofs		
During inspections or as needed to ensure performance	• Hand weeding • Chemical weed management (e.g., use of pre-emergent preparations to combat the germination of annual weeds) • In-fill planting in bare spots. In most cases this can be accomplished by separating healthy plants and using these cuttings to re-establish areas that have been the victim of weed infestation, wind erosion, etc. • Apply fertilizer, based on nutritional requirements test and roof manufacturer guidelines • Irrigate plants if extended dry period leads to excessive dryness in growing media • Remove debris from drainage inlets and inlet screens to prevent clogging • Remove debris from secondary drainage inlets/scuppers	• Gloves • Hand tools • Water supply and hose • Spray or spread applicators
Winter considerations	• Break up ice formation around inlets	• Ice pick, or equivalent tool

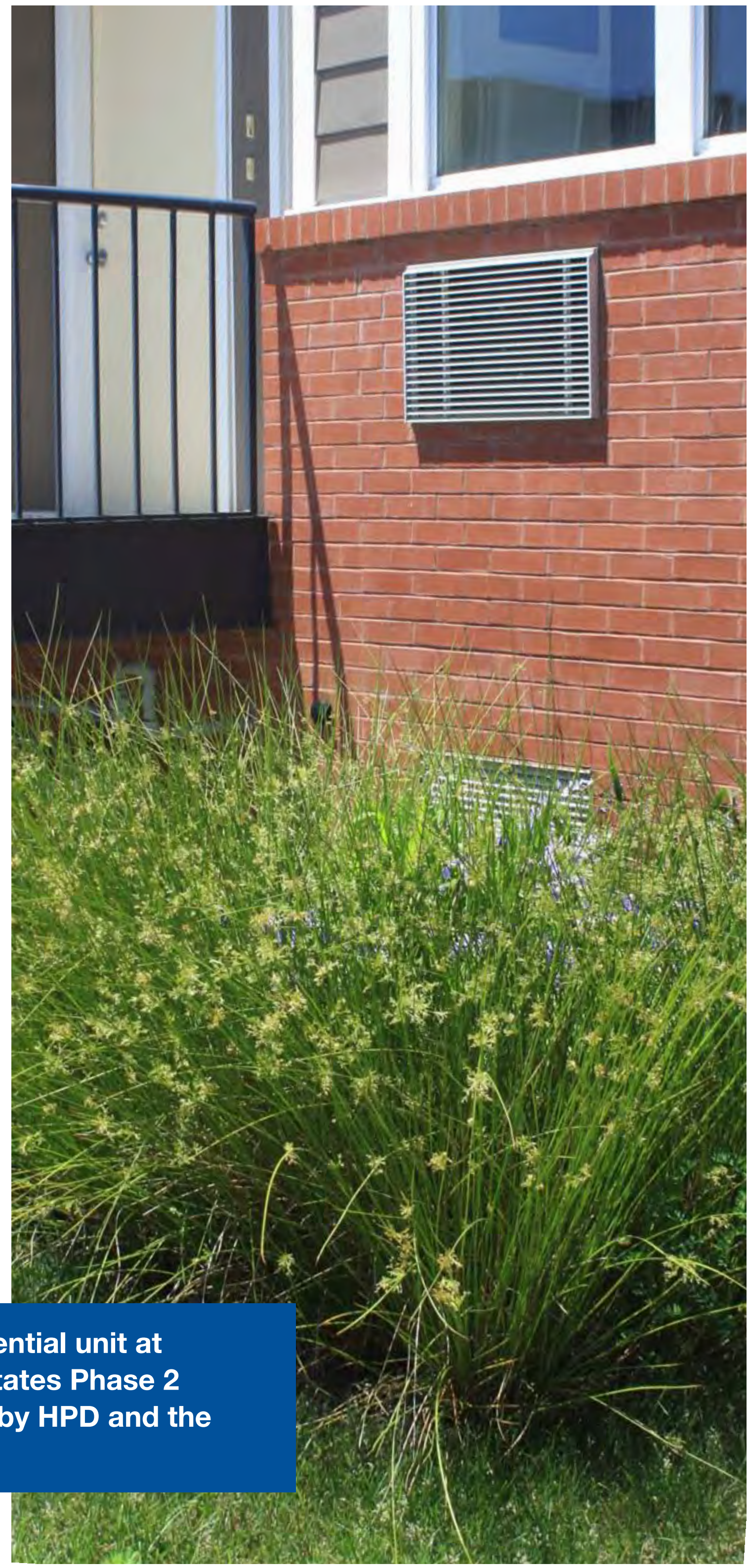
Problems with a green roof system generally fall into three categories: (1) the system drains too slowly, resulting in buildup of excess water in the growing media for extended periods of time, (2) the system drains too quickly, exceeding the design release rate, or (3) the vegetation does not take to the growing media. If the information in these guidelines does not solve these problems, contact a licensed professional or green roof designer for further assistance.

Table 4-7: Troubleshooting guide for rooftop detention systems

Problem	Analysis				Diagnosis	Solution
Ponded water/ saturated growing media several hours after rain event OR Stormwater overtopping drains and overflowing via scuppers during small or light rain events	Check Roof Drain Inlets	Debris present			Clog at drain inlet or inlet screen	Clear debris from drainage inlet and continue to monitor performance
		No debris present	Check flow in downstream pipes	Full flow in downstream pipes	Possible downstream obstruction	Check for flow at downstream connection points to locate obstruction
				Little or no flow in downstream pipes	Possible malfunction of weir-controlled drains	Contact contractor responsible for roof drain installation
No ponding or shallow ponding depth during large rain events					Possible malfunction of weir-controlled drains (if controlled flow roof drain is installed)	Contact contractor responsible for roof drain installation
					Vegetation not taking up water or media draining too quickly (if no controlled flow roof drain is installed) (Green roof only)	Contact green roof designer to assess situation
Continual bare spots in vegetation (Green roof only)	Check for footprints	Footprints present			Human traffic causing bare spots	Post signs indicating to public to walk around, not across, the green roof
		No footprints present	Check nutrient levels in soil	Deficient	Soil is nutrient deficient	Add fertilizer
				Appropriate levels	Excessive wind erosion	Check wind cover and repair if necessary

COMBINATION SYSTEMS

Combination systems use two or more types of source controls to meet DEP's performance standard. These may include both rooftop and subsurface systems in series or parallel arrangements, and combinations with impervious surface reductions or rainwater recycling. Combination systems may be desirable because subsurface systems generally have higher construction costs than other source controls, and rooftop systems alone may not adequately control runoff from the entire site (i.e. the combined runoff from non-roof areas and controlled flow roof drains may exceed the stormwater release rate). Additionally, impervious surface reductions and rainwater recycling systems may reduce a site's required storage volume while providing additional benefits to property owners. Often, meeting the stormwater performance standard while minimizing construction costs and seeking secondary benefits will involve combining source controls.



Rain gardens are located in front of each residential unit at Nehemiah Spring Creek Homes at Gateway Estates Phase 2 in Brooklyn, a development project sponsored by HPD and the Nehemiah Housing Development Company.

Figure 5-1: A 10,000 gallon tank at Remsen Yard used to store rooftop runoff to wash trucks and settle dust. The site, designed and constructed by DDC, also has a 72,000 gallon retention tank (not pictured), used to collect runoff from the entire site.

5.1 Combination Rooftop and Subsurface Systems

Combination rooftop and subsurface systems are an option for complying with DEP's stormwater performance standard. When combining rooftop and subsurface systems, it is recommended that flows from the rooftop system be routed to the subsurface system upstream of the orifice controlling subsurface discharge **(Figure 5-1)**. To maximize the benefit of a combination system, the release rate from the rooftop system should be as low as possible. The advantages of an in-series system series include:

- The required volume and area of the subsurface system may be significantly reduced;
- The subsurface system may collect excess discharge from the roof during high intensity storm events; and
- The in-series configuration requires only one outlet control structure and connection to the fronting sewer.

In the case where no physical site constraints exist, combination systems should be installed in-series. However, depending on site conditions, drainage patterns, and whether systems are constructed and operational at different times, parallel combination systems may be necessary. For parallel systems, the flow from the rooftop system and the subsurface system are either combined downstream of the subsurface system or discharged separately to the fronting sewer **(Figure 5-2)**. In either case, the sum of the flows must be in compliance with DEP's stormwater performance standard.

5.2 Rain Gardens and Subsurface Systems

Rain gardens, swales and other vegetated green infrastructure features installed in series with a subsurface system are also an acceptable option for complying with DEP's stormwater performance standard. Rain gardens are vegetated or landscaped surface depressions designed with an engineered soil layer that promotes infiltration of runoff into the underlying soil. In addition to direct rainfall, runoff from additional areas is directed to the rain garden as sheet flow or using curb cuts and/or roof drains.

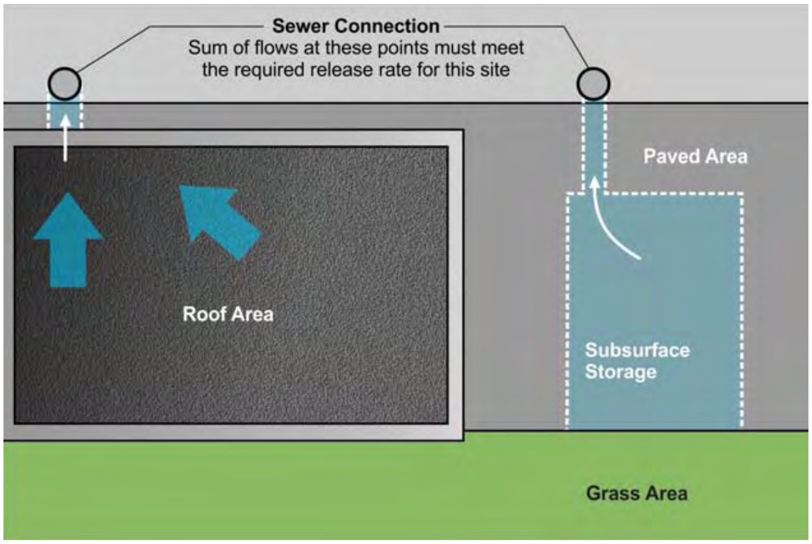


Figure 5-2:
A plan view of a site with multiple or combined source control systems in-series to meet DEP's stormwater performance standard.

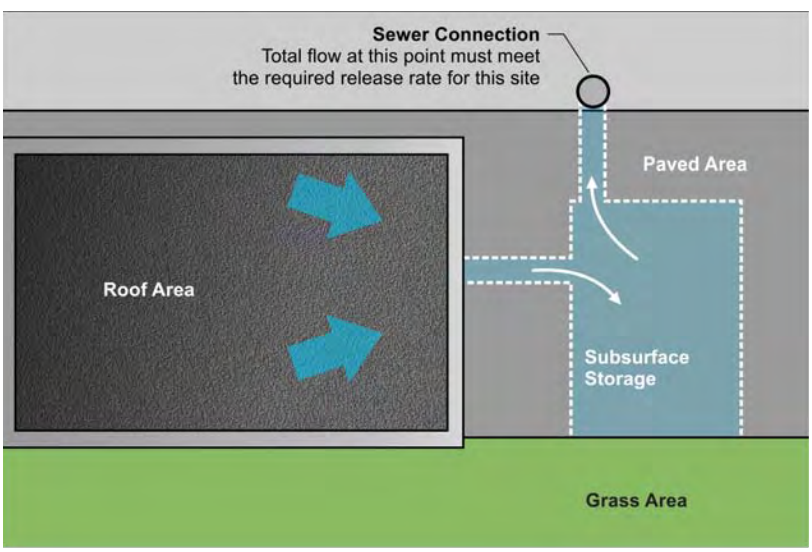


Figure 5-3:
A plan view of a site with multiple or combined source control systems in parallel to meet DEP's stormwater performance standard.

Rain gardens are typically designed to pond up to six to eight inches on the surface during large rain events, with the ponded surface draining in 8-12 hours and the engineered soil draining in 12-36 hours. This can typically be achieved by including an 18-24 inch layer of well drained structural soil with a sand content of approximately 80-90%. Soil evaluations in accordance with appendices H and I and supporting calculations are needed for the bioretention subsurface to ensure that the stored runoff can infiltrate into the underlying soil within the time frames above. The depth of structural soil should not exceed three feet. Vegetation should be selected that can survive both dry and ponded conditions. Recommended planting lists for infiltration practices can be found in Appendix E.

The storage volume of a rain garden is calculated as the sum of surface storage and storage in the voids of the structural soil. The surface storage depends upon the rain garden footprint and surface storage depth, while the structural soil storage depends on the rain garden footprint, soil depth, and void ratio (figure 5-3). The void ratio should be representative of the specified structural soil, but should not exceed 25%. There are a wide variety of possible rain garden shapes and configurations which may be utilized, provided that the storage volumes and criteria mentioned herein are addressed.

A stand alone rain garden will generally not provide the required detention or storage volume to satisfy DEP's criteria. The system must be designed with an overflow that directs excess runoff to a subsurface system adjacent to the rain garden or below it. The subsurface system receiving the overflow can be reduced in size to reflect the storage volume provided by the rain garden. For example, if the site required storage volume is 3,000 gallons and the storage volume provided by a rain garden is 1,000 gallons, the subsurface system can be sized for a required storage volume of 2,000 gallons. In order to reduce the required storage volume of the subsurface system, the majority of the runoff managed by the subsurface system must be able to first pass through the rain garden. All other design guidelines for subsurface systems still apply as detailed in Sections 2 and 3.

5.3 Impervious Surface Reductions and Rainwater Recycling

Impervious surface reductions and rainwater recycling present opportunities to decrease the storage volume required for individual rooftop or subsurface systems, as well as combination rooftop and subsurface systems. Implementing impervious surface reductions onsite lowers the weighted runoff coefficient for the site and can consequently decrease the storage volume required for rooftop and subsurface systems. Impervious surface reductions may take the form of landscaping, rain gardens, or pervious pavers.

Rainwater recycling systems retain rainwater onsite and may also decrease storage volume requirements for rooftop or subsurface systems. Rainwater recycling systems, such as cisterns connected to roof leaders, combined with rooftop or subsurface systems are encouraged on lots with opportunities for onsite stormwater use, based upon review and approval by DEP and compliance with DOB requirements.

Depending upon site conditions, there are numerous opportunities to combine rooftop and subsurface systems in various arrangements, and incorporate impervious surface reductions, infiltration and rainwater recycling. Utilizing these combinations, a comprehensive approach can be developed during planning and design to meet DEP's stormwater performance standard while minimizing construction costs and providing secondary benefits.

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The Related Companies
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Glossary

The definitions below are provided to explain terms used in these guidelines. For additional terms referenced in these guidelines or DEP's Criteria, see DEP's online Glossary of Terms.

Allowable flow: the stormwater flow from a development that can be released into an existing storm or combined sewer based on existing sewer design criteria.

Alteration: any construction, addition, change of use or occupancy, or renovation to a building or structure in existence (Construction Codes, 2008). For proposed redevelopments in combined sewer areas of the city, the Stormwater Performance Standard requirements described in these guidelines apply to alterations that include any horizontal building enlargement or any proposed increase in impervious surfaces, as defined in the Construction Codes and related requirements.

Detention system: a structure designed to store an accumulation of stormwater runoff and release it at a controlled rate into an approved outlet sewer system of limited capacity.

Existing building or structure: (i) a building or structure in existence prior to the effective date of this code or one for which a lawful building permit was issued for the erection of such building or structure prior to the effective date of the Construction Codes. (ii) a building or structure erected in accordance with the 1968 building code under a lawful building permit issued for the erection of such building or structure after the effective date of the Construction Codes in accordance with section 28-101.4.2 of the Construction Codes (2008).

Green infrastructure: a type of source control that moderates or reverses the effects of development by mimicking hydrologic processes of infiltration, evapotranspiration, and reuse.

Impervious surface: those surfaces in the urban landscape that cannot effectively infiltrate rainfall consisting of building rooftops, pavement, sidewalks, and driveways. Steep slopes and compact soils are not typically included as impervious surfaces (NYSDEC, 2010).

Infiltration practice: a system designed to infiltrate stored or detained stormwater into below soils as substantiated by soil borings taken at the location of the proposed system and a permeability test performed in situ to demonstrate that the existing soil below the system has a favorable rate of infiltration.

Licensed professional: a registered design professional whose signature and seal must accompany construction documents and other submittal documents filed with the city and attests that such documents do not contain false information and are in compliance with all applicable provisions of law (Construction Codes, 2008).

New building or construction: a building or structure which does not already exist (Construction Codes, 2008).

New development: a new building or construction.

Recycling system: a dedicated system that stores or detains stormwater for onsite uses. The recycling must not result in total site discharge to the sewer system greater than the stormwater release rate at any time.

Redevelopment: an alteration.

Retention system: a structure designed to store an accumulation of stormwater runoff and dispose of it onsite.

Runoff: overland stormwater flow that is not absorbed into the ground (RCNY Title 15, Chapter 31).

Runoff coefficient: the fraction of total rainfall that appears as total runoff volume for a given type of land cover, typically accounting for evaporation and infiltration into the ground (James, 1996).

Source control: a practice that stores stormwater onsite or at the source and releases it at a controlled rate to the sewer system to mitigate the impacts of increased runoff rates associated with development.

Stormwater management system: a series of practices and infrastructure used to collect, convey, detain, and retain stormwater.

Stormwater release rate: the rate at which stormwater is released from a site, calculated in terms of cubic feet per second (cfs) or as a percentage of the allowable flow, which is also calculated in terms of cfs.

Weighted runoff coefficient: the fraction of total rainfall that appears as total runoff volume for a drainage area, calculated as an area-based, weighted average of the runoff coefficients for the various types of land cover present in the drainage area (James, 1996).

Applicable Stormwater Codes and Regulatory Requirements

Stormwater management systems installed to meet DEP's stormwater performance standard are subject to all local, state, and federal regulations. The following codes and regulations may be applicable and may affect system design. The appropriate agency should be contacted to obtain code updates, if applicable or resolve any compliance questions. The following information should not be considered an exhaustive list of all applicable codes and requirements.

Subsurface Systems

New York City Building Code (1968)
RS-16, P110.4 Size of Storm Drains and Leaders
RS-16, P110.7 Traps on Storm Drains and Leaders

New York City Plumbing Code (2008)
Chapter 11 – Storm Drainage, Section 1102 Materials, 1102.5 Subsoil Drain Pipe
Chapter 11 – Storm Drainage, Storm Drainage, Section 1102 Materials, 1102.7 Fittings
Chapter 11 – Storm Drainage, Storm Drainage, Section 1111 Subsoil Drains

New York City Zoning Resolution
Section 23-451 – Front Yard Planting Requirements
Section 25-67, 37-90 – Landscaping Requirements for Commercial and Community Facility Parking Lots

New York State Public Service Commission Codes
Code Rule 753 -- Call DigNet of New York City and Long Island before you dig at 811 or 1-800-272-4480 to protect underground utilities and public safety

New York State Department of Environmental Conservation (NYSDEC)
State Pollutant Discharge Elimination System (SPDES)

New York State Department of Health
Title 10 – Section 128-8.1: Local government stormwater protection plans and Section 128-3.9: Stormwater pollution prevention plans and impervious surfaces

United States Environmental Protection Agency (USEPA)
Underground Injection Control Permit

United States Department of Labor – Occupational Safety and Health Administration (OSHA)
OSHA 1926.651 Specific Excavation Requirements
OSHA 1926.652 Requirements for Protective Systems

Rooftop Systems

New York City Building Code (2008)
Chapter 7 – Fire-Resistance Rated Construction
Chapter 10- Means of Egress
Chapter 15 – Roof Assemblies and Rooftop Structures
Chapter 16 – Structural Design
Chapter 17 – Structural Tests and Special Inspections

New York City Energy Conservation Code (2010)
Chapter 4 – Residential Energy Efficiency
Chapter 5 – Commercial Energy Efficiency

New York City Plumbing Code (2008)
Chapter 11 – Storm Drainage

New York City Fire Code (2008)
Chapter 10 – Means of Egress

New York State Department of Environmental Conservation (NYSDEC)
State Pollutant Discharge Elimination System (SPDES)

Required Submittals for DEP and DOB Certification

The following are some of the submittals required for sewer availability certification and to demonstrate compliance with DEP's stormwater performance standard:

- House/Site connection proposal (HCP/SCP) (6 copies). For additional information concerning site connection proposal drawings and requirements, refer to NYCDEP Guidelines for Filling Out the Site Connection Proposal Form (http://www.nyc.gov/html/dep/pdf/water_sewer/24.pdf)
- Permeability and boring test results (if applying for infiltration credit)

The following drawings should be submitted to DEP and/or DOB as required with HCP/SCPs for review. Six copies of each item below are required:

- Overall site plan
- Overall plan view of entire system or roof plan, including rooftop system, if applicable
- Overall profile view of entire system, including pretreatment structure and outlet control structure
- Details of pretreatment structure and outlet control structure
- Details of green roof (if used) or controlled flow roof drain (if used) from manufacturer specifications

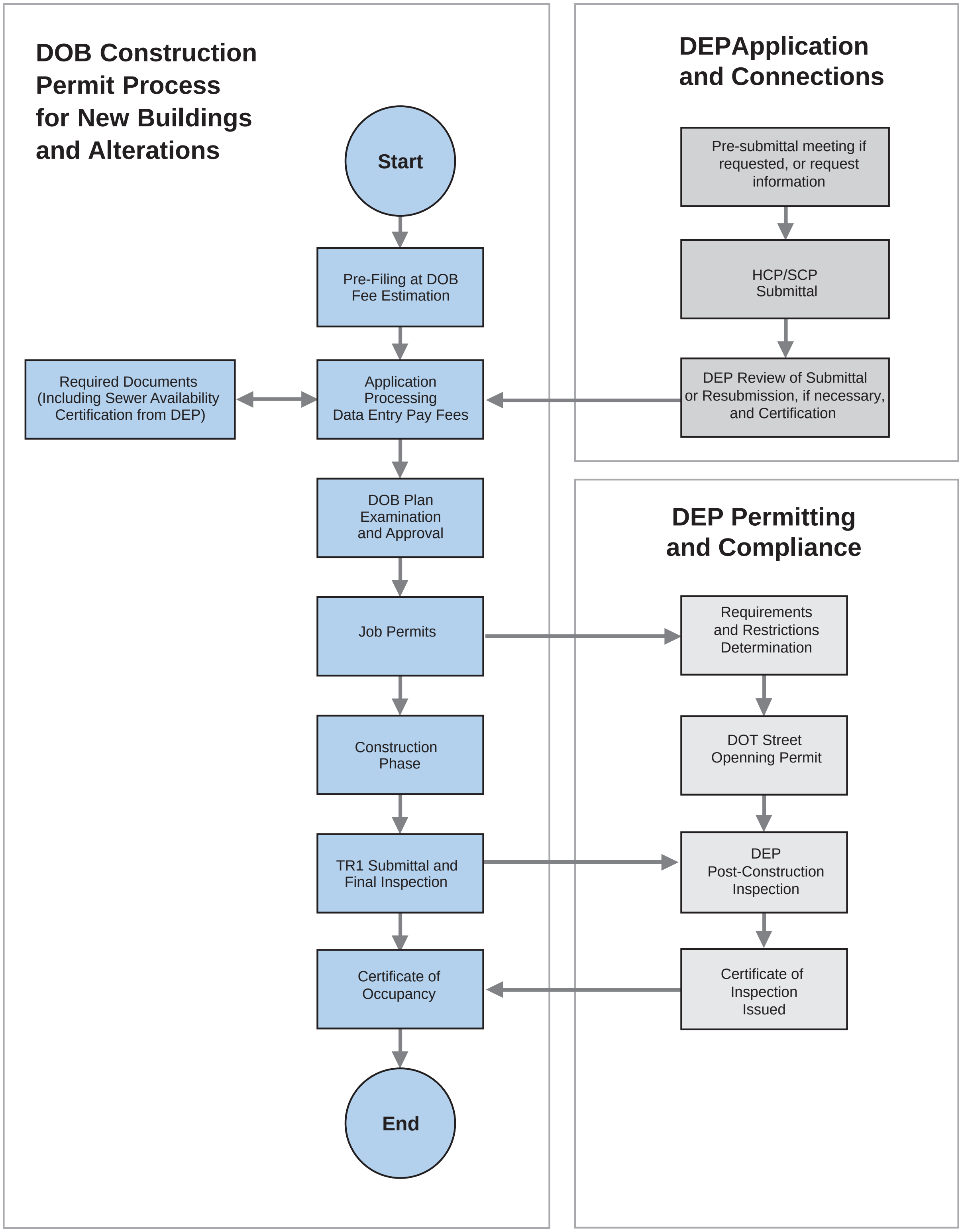
Drawings should contain the following elements or characteristics depending on the selected stormwater management system:

- Drawing to scale, not larger than 30 inch X 40 inch
- Graphic bar scale
- All drawings should be in the respective Borough Vertical Sewer Datum, except for Brooklyn where Brooklyn Highway Datum may be used, with the following note: "Elevations shown are in Brooklyn Highway Datum which is 2.56 feet above mean sea level U.S.C.&G.S., Sandy Hook. Brooklyn Sewer Datum is 1.72 feet above mean sea level U.S.C.&G.S., Sandy Hook"
- North arrow, indicating true north
- Property and easement lines and dimensions
- Adjacent utilities within the property or fronting the property in the public roadway or walkway (sewer lines, water mains, electrical lines, cable lines, gas lines, etc.)
- Areas in square feet of different surface cover types (including limits of green roof)
- Number and location of roof drains with and without outlet control structures
- Delineation of roof drainage area and/or land cover within drainage area
- Slope of roof drainage areas in direction of drains
- Location of roof drain connection to detention if applicable, and/or drainage system from non-roof areas
- Size and invert elevation of connector pipe to sewer system
- Rim and invert elevations of the pretreatment and outlet control structures

- Top and bottom elevations and interior dimensions of subsurface system structures
- Surface grade over all subsurface BMP system components
- Sizes, inverts, lengths, slopes, and materials of pipes
- Thickness of stone and backfill layers around subsurface system and associated pipes
- Distance between subsurface systems and pipes
- Depth to water table or bedrock
- Local wells, and purpose as applicable
- Size and invert elevation of orifice
- Size and invert elevation of connector pipe to sewer system
- Offsets from stormwater management system to buildings, roadways, and other utilities
- Hydraulic calculations for both stormwater and sanitary discharge in accordance with the “Guidelines” and “Criteria For Detention Facility Design”

After the construction process is complete, Technical Report 1 (TR1) certification, verifying that the stormwater management system is installed correctly, per 1704.20 from the New York Construction Codes, should be submitted to DOB and DEP to obtain a connection permit.

City Permitting Processes



Note: The flow charts above are provided for planning purposes only and do not illustrate actual timeframes, fees or notifications for reviews and approvals, or additional permits necessary. Applicants should review detailed information specific to each process above at www.nyc.gov/dep and www.nycgov/buildings.

Recommended Planting List for Infiltration Practices

The following tree, plant and grass species are recommended for rain gardens, vegetated swales and other green infrastructure practices. The planting list below includes a mix of species and selection should be based on the site conditions of the planting zones such as expected sunlight and moisture, and adjacent uses. A landscape architect or specialist should also be consulted to ensure appropriate species selection and establishment.

The United States Department of Agriculture (USDA) developed the Wetland Indicator Status to describe the moisture content of soil where specific species are most frequently found. This information should be considered to select plants appropriate for the expected ponding depth and drawdown times of the green infrastructure practice. The Wetland Indicator Status information for the Northeast (Region 1) is included below and the codes can be interpreted as follows:

UPL (Obligate Upland) – Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the specified region

FACU (Facultative Upland) – Usually occurs in non-wetlands (estimated probability 67-99%), but occasionally found in wetlands (probability 1-33%)

FAC (Facultative) – Equally likely to occur in wetlands or non-wetlands (estimated probability 33-67%)

FACW (Facultative Wetland) – Usually occurs in wetlands (estimated probability 67-99%), but occasionally found in non-wetlands

Dry Zones

Trees

- *Cornus florida†* – Flowering dogwood (FACU-)

Deciduous Shrubs

- *Arctostaphylos uva-ursi†** – Bearberry
- *Hydrangea arborescens* – Wild hydrangea (FACU)
- *Viburnum prunifolium* – Nannyberry (FACU)

Ground Covers, Grasses and Perennials

- *Aralia nudicaulis* – Wild sarsaparilla (FACU)
- *Asarum canadense* – Canadian wildginger (FACU-)
- *Aster divaricatus* – Wood aster
- *Chasmanthium latifolium* – Sea oats (FACU)
- *Dennstaedtia punctilobula* – Heyscented fern (UPL)
- *Elymus Canadensis* – Canada wildrye (FACU+)
- *Erigeron pulchellus* – Robin’s plantain (FACU)
- *Geranium maculatum* – Spotted geranium (FACU)

- *Heuchera Americana* – Coral bells (FACU)
- *Juniperus horizontalis* – Creeping juniper (FACU)
- *Panicum amarum†** – Bitter panicgrass (FACU-)
- *Parthenocissus quinquefolia* – Virginia creeper (FACU)
- *Phlox divaricata* - Woodland phlox (FACU)
- *Polemonium reptans* – Jacob's ladder (FACU)
- *Polygonatum biflorum* – Small solomon's seal (FACU)
- *Polystichum acrostichoides* – Christmas dagger fern (FACU-)
- *Solidago caesia* – Wreath goldenrod (FACU)
- *Solidago canadensis* – Canada goldenrod (FACU)
- *Sorghastrum nutans* – Indiangrass (UPL)

Dry to Moist Zones

Trees

- *Amelanchier canadensis†* – Shadbush serviceberry (FAC)
- *Quercus phellos†* – Willow oak (FAC+)

Evergreen Shrubs

- *Rhododendron PJM*

Deciduous Shrubs

- *Aronia melanocarpa†** – Chokeberry (FAC)
- *Clethra alnifolia* – Sweet pepperbush (FAC+)
- *Viburnum dentatum†** – Arrowwood (FAC)

Ground Covers, Grasses and Perennials

- *Aquilegia canadensis* – Columbine (FAC)
- *Athyrium filix-femina* – Common ladyfern (FAC)
- *Carex glauca* – Heath sedge
- *Carex pendula* – Hanging sedge
- *Carex pensylvanica* – Pennsylvania sedge
- *Cimicifuga racemosa* – Black bugbane
- *Heuchera macrorhiza* – Coral bells
- *Liriope muscari* – Bigblue lilyturf
- *Monarda didyma* – Scarlet beebalm (FAC+)
- *Panicum virgatum†** – Switch grass (FAC)
- *Solidago rugosa* – Wrinkleleaf goldenrod (FAC)
- *Thelypteris noveboracensis* – New York fern (FAC)
- *Tiarella cordifolia†* – Foam flower (FAC-)

Moist to Wet Zones

Evergreen Shrubs

- *Ilex glabra†**– Inkberry (FACW-)

Deciduous Shrubs

- *Cornus amomum* – Silky dogwood (FACW)
- *Lindera benzoin* – Spicebush (FACW-)
- *Sambucus nigra canadensis†** – American Black Elderberry (FACW-)

Ground Covers, Grasses and Perennials

- *Acorus gramineus* – Grassleaf sweet flag
- *Carex Ice Dance* – Ice dance sedge
- *Equisetum hyemal* – Scouringrush horsetail (FACW)
- *Eupatorium maculatum* – Spotted Joe Pye weed (FACW)
- *Milium effusum* – American milletgrass
- *Onoclea sensibilis* – Sensitive fern (FACW)
- *Osmunda cinnamomea* – Cinnamon fern (FACW)
- *Solidago sempervirens†**– Seaside goldenrod (FACW)
- *Typha minima* – Dwarf cattail

*Salt tolerant

†Grows well in areas adjacent to streets and pathways

Recommended Planting List for Green Roofs

The following planting list was adapted from DPR's Greenbelt Native Plant Center. The full list and additional information can be found at: www.nycgovparks.org.

Dry Zones

Graminoids

- *Bouteloua gracilis** – Blue grama
- *Carex pensylvanica* – Pennsylvania sedge
- *Cyperus echinatus* – Globe Flatsedge
- *Danthonia compressa* – Northern oatgrassW
- *Danthonia spicata* – Junegrass
- *Deschampsia fleuxosa* – Common hairgrass
- *Eragrostis spectabilis* – Purple lovegrass
- *Schizachyrium scoparium* – Little bluestem
- *Sorghastrum nutans* – Indian grass

Herbs

- *Allium schoenoprasum** – Wild chives
- *Allium senescens** – Chives
- *Antennaria dioicus 'rubra'** – Pussy toes
- *Baptisia tinctoria* – Wild indigo
- *Campanula rotundifolia** – Pluebell bellflower
- *Chrysopsis mariana* – Shaggy golden aster
- *Dianthus carthusianorum** – Clusterhead
- *Dianthus deltoides**– Maidenpink
- *Eupatorium hyssopifolium* – Hyssopleaf thoroughwort
- *Eurybia divaricata* – White wood aster
- *Euthamia tenuifolium* – Coastal plain flat–topped goldenrod
- *Monarda fistulosa* – Wild bergamot
- *Oenothera biennis* – Common evening primrose
- *Opuntia humifusa* – Eastern prickly pear
- *Phlox subulata** – Moss phlox
- *Pycnanthemum tenuifolium* – Narrowleaf mountainmint
- *Solidago caesia* – Bluestem goldenrod
- *Solidago canadensis* – Common goldenrod
- *Solidago juncea* – Early goldenrod
- *Solidago nemoralis* – Gray goldenrod
- *Solidago rigida* – Stiffleaf goldenrod

- *Symphyotrichum cordifolium* – Bluewood aster
- *Symphyotrichum ericoides* – White Wreath aster
- *Symphyotrichum leave* – Smooth Blue aster

Dry to Moist Zones

Graminoids

- *Andropogon virginicus* – Broom sedge
- *Juncus tenuis* – Slender yard rush
- *Panicum clandestinum* – Deertongue
- *Panicum virgatum* – Switchgrass
- *Tridens flavus* – Tall redtop

Herbs

- *Aster oblongifolius** – Aromatic aster
- *Eupatorium serotinum* – Late flowering thoroughwort
- *Euthamia graminifolia* – Flat top goldenrod
- *Geum canadensis* – White avens
- *Penstemon digitalis* – Tall white beard tongue
- *Rudbeckia hirta* – Black–eyed susan
- *Uvularia sessilifolia* – Bellwort
- *Verbena urticifolia* – White vervain

Shrubs

- *Rubus flagellaris* – Northern dewberry

Moist to Wet Zones

Graminoids

- *Carex lurida* – Shallow sedge
- *Carex scoparia* – Broom sedge
- *Carex vulpinoidea* – Fox sedge
- *Juncus effuses* – Smooth rush
- *Scirpus atrovirens* – Bulrush
- *Scirpus cyperinus* –Woolgrass
- *Scirpus pungens* – Chairmaker's rush

Herbs

- *Chamaecrista fasciculata* – Partridge pea

- *Chelone glabra* – Turtlehead
- *Eupatorium fistulosum* – Trumpetweed
- *Eupatorium maculatum* – Spotted joe–pye–weed
- *Helenium autumnale* – Sneezeweed
- *Lobelia cardinalis* – Cardinal flower
- *Lobelia siphilitica* – Great Blue Lobelia
- *Ludwigia alternifolia* – False loosestrife
- *Pycnanthemum virginianum* – Mountainmint
- *Solidago rugosa* – Tall hairy goldenrod
- *Symphyotrichum novae–angliae* – New England aster
- *Thalictrum pubescens* – Late meadowrue
- *Verbena hastate* – Blue vervain

Sedums*:

- *Sedum ternatum** – Woodland stonecrop – native – needs some shade
- *Sedum reflexum** – Jenny's stonecrop– needs dry conditions
- *Sedum album** – White stonecrop

*Appended based on work of:

- Charlie Miller, Roofmeadow, http://www.roofmeadow.com
- Ed Snodgrass, Green Roof Plants, Emory Knoll Farm, http://www.greenroofplants.com
- The US Department of Agriculture Plant Database: http://plants.usda.gov/

Variables Used in the Sizing of Stormwater Management Systems		
Variable Symbol	**Description**	**Units**
A	*Total site area in acres*	*ac*
A_R	*Available roof area in acres*	*ft²*
A_T	*Roof area in acres*	*ac*
AL_L	*Length of the available lot area*	*ft*
AL_W	*Width of the available lot area*	*ft*
B_W	*Width of buffer area surrounding chambers*	*t*
C_R	*Effective runoff coefficient for roof*	-
C_W	*Weighted runoff coefficient*	-
D	*Nominal diameter of perforated pipe*	*ft.*
d_R	*depth of flow for roof drains*	*in*
d_{max}	*Maximum ponding depth*	*in*
e	*Porosity of gravel, assume 1/3*	-
FA_{min}	*Minimum subsurface footprint area*	*ft³*
i_{10}	*Ten year rainfall intensity*	*in/hr*
i_{soil}	*Soil infiltration rate*	*in/hr*
L_G	*Total length of gravel bed*	*ft*
L_p	*Total length of perforated pipe for a 2:1 L/W ratio*	*ft*
L_C	*Length of individual stormwater chamber*	*ft*
N_C	*Required number of storm chambers*	-
N_{CMAX}	*Maximum number of stormwater chambers that fit in the available lot*	-
N_{CR}	*Number of chambers per row*	-
N_{CRMAX}	*Maximum number of chambers per row based on available lot area*	-
N_P	*Number of rows of perforated pipe required for 2:1 L/W ratio*	-
N_R	*Number of rows of stormwater chambers*	-
N_{RMAX}	*Maximum number of rows of chambers based on available lot area*	-
N_{RD}	*Number of roof drains*	-
P_{SL}	*Required length of perforated pipe*	*ft*
Q	*Developed flow*	*cfs*
Q_{ERR}	*Effective release rate*	*cfs*
Q_i	*Maximum release rate from each drain*	*cfs*
Q_{inf}	*Iniltration loss to subsoil*	*cfs*
Q_n	*Release rate per inch of ponding*	*gpm/in*
Q_{ROOF}	*Flow rate from roof detention*	*cfs*
Q_{RR}	*Release rate as determined from DEP's stormwater performance standard*	*cfs*
Q_{USE}	*Continuous water use rate for rainwater recycling*	*cfs*
S_D	*Maximum storage depth*	*ft*
t	*Duration of rainfall event*	*hr*
V_A	*Available storage volume for rooftop system*	*ft³*
V_C	*Available storage volume per stormwater chamber*	*ft³*
V_L	*Unit volume for perforated pipe*	*ft³/ft*
V_R	*Required storage volume*	*ft³*

Variables Used in the Sizing of Stormwater Management Systems		
Variable Symbol	**Description**	**Units**
W_B	*Minimum spacing between perforated pipes*	*ft*
W_C	*Width individual storm chamber*	*ft*
W_G	*Total width of gravel bed*	*ft*
W_M	*Width of the manifold*	*ft*
W_p	*Total width of perforate pipe system*	*ft*
W_S	*Spacing between rows of stormwater chambers*	*ft*

Soil Evaluations for Infiltration Practices

The following guidance is provided to support the determination of soil infiltration capabilities and potential application toward storage volume reductions for open-bottom subsurface systems seeking infiltration credit, also known as infiltration practices. The below requirements and recommendations are provided for planning purposes only. DEP's review of proposed storage volume reductions will be based on specific site conditions and the required documentation submitted as part of connection proposal applications. The following guidelines are intended to assist in selecting locations for infiltration practices and determine the infiltration rate of the underlying subsoil.

1. Minimum requirements for location of proposed infiltration practice (per the Plumbing Code):
   a. Infiltration practices shall be setback from buildings or other structures 10 feet down-gradient.
   b. Infiltration practices shall be located 20 feet from disposal fields and/or seepage pits.
   c. Infiltration practices shall not be located within building footprint.
   d. Infiltration practices shall be setback from lotlines by five feet or more except if practice is contiguous with street line.
2. Seasonally high groundwater shall be a minimum vertical distance of three feet from the bottom of the infiltration practice, per DEP. Minimum vertical distance to bedrock shall be three feet.
3. **A minimum infiltration rate of 0.5 in/hr** is required to consider volume reduction credit for an infiltration practice.
4. To classify depth and subsurface soil characteristics, applicant should perform approved soil borings every 2,500 square feet or two per infiltration practice, whichever is greater.
5. Applicant should perform an in-situ permeability test according to the procedure specified in Appendix I for the soil underlying the infiltration practice.
6. For cases where the infiltration practice is installed above GW soil (with a minimum permeability coefficient of 0.025 cm/sec) and where there is at least 5 feet of GW soil below the bottom of the infiltration practice, a maximum infiltration rate of 3 in/hr shall be used.
7. For other soil classifications, maximum infiltration rates in inches per hour shall equal:

   $i_{soil} = (120)(k_{soil})$
   i_{soil}: maximum infiltration rate (in/hr)
   k_{soil}: lowest measured permeability coefficient of underlying soil where infiltration would occur (cm/s)

8. For proposed infiltration practices, additional information to be submitted to DEP for review include:

    a. Rate of recharge based on system design (via bottom of system)
    b. Depth of recharge
    c. Area of influence

9. Recommended site considerations for infiltration practices:

    a. The maximum contributing drainage area to individual infiltration practices should be less than two acres and a maximum 5:1 ratio of total impervious cover to size of proposed infiltration practice.
    b. The infiltration practices should be located a minimum horizontal distance of 200 feet from down gradient slopes greater than 20%. The average slope of the contributing drainage areas should be less than 15%.
    c. The bottom of an infiltration practice should be flat (0% longitudinal slope). If an underdrain is used, a maximum longitudinal slope of 1% is permissible. Lateral slopes should be 0%.
    d. The infiltration practices should have direct soil contact with appropriate native soils (as classified above).
    e. No infiltration should be permitted up-gradient of current subway tunnel dewatering or ground water remediation "hotspot" zones.

Permeability Test Procedure

The following permeability test is based upon a procedure developed by DDC and DEP to determine, in-situ, the permeability of underlying soil. In addition to the evaluation criteria in Appendix H, these procedures should be used to demonstrate the infiltration rate and overall effectiveness of proposed infiltration practices for a particular site. Upon following the below procedures, compute the permeability in accordance with ASTM D 6391-06.

Drilling the Preliminary Boring

- During the preliminary boring, collect samples at 5-foot intervals using a 300-lb hammer and 3"-inch diameter split spoon barrel sampler.
- Samples should be stored in 12-ounce jars.
- If possible, drill the boring using augers until the groundwater table is reached.
- After the groundwater table has been reached, as indicated by a saturated sample and a measurement of the water level in the borehole, the driller should switch to 4-inch nominal diameter casing.
- The driller shall not use bentonite to stabilize the hole.
- Terminate the boring at a depth of 75 feet or at the top of the bedrock, whichever comes first.

Analysis Subsequent to Preliminary Boring

- Soil samples designated as class GW, GM, SW, SP, or SP-SM may be designated for laboratory sieve testing.
- The engineer shall designate which soil samples shall be sent to the laboratory for sieve testing.
- The theoretical permeabilities of the soil layers shall be calculated according to Hazen's formula $k = CD_{10}^2$ where k is the permeability in cm/sec, C = 1, and D_{10} is the particle size in millimeters.
- Acceptable permeability will be defined as a minimum permeability of 3.15×10^{-2} cm/sec or 0.45 gallons/ft^2/min.
- If no samples have acceptable permeability, no field permeability tests will be performed at the site.

Selecting Test Depths

- At the shallowest depth at which acceptable material is located, select test depths:
  - At the approximate top of the acceptable material
  - Approximately 5 feet below the top of the acceptable material
  - Approximately 10' feet below the top of the acceptable material
- The above depths may need to be adjusted based on the thickness of the layer being tested.
- Whenever the field permeability tests at the shallowest depth do not show acceptable permeability (3.5×10^{-2} cm/sec or 0.5 gallons/ft^2/min), repeat the above procedure at the next shallowest depth at which acceptable material is located.

Advancing the Casing for the Permeability Test Boring

- If the ground surface elevation of the permeability test boring appears to be more than 1 foot different from the elevation of the preliminary boring, determine the difference in elevation between the two borings.
- The driller shall use 4-inch nominal diameter casing.
- Before the driller begins installing the casing, the inspector shall carefully measure the length of each piece of casing to the nearest 1/8-inch (the measured permeability will be significantly effected in falling head tests above the groundwater table if the soil is slightly above or below the bottom of the casing).
- Drill or drive the casing to the required depth.
- Clean out to the bottom of the casing with a roller bit using clean water as a drilling fluid until the water exiting the casing is running clear.
- Use of augers shall not be permitted.
- If running sand is encountered, keep the casing full of water to prevent the sand from entering the casing.

Falling Head Tests in Uniform Soils above the Ground Water Table

- Measure the depth to the bottom of the hole to the nearest inch.
- The depth to the bottom of the hole should be within 1 inch of the depth to the bottom of the casing. (Note: as little as three inches of soil inside a 4-inch casing can cause the recorded permeability to be about one quarter of the actual permeability. However, since having the casing above the bottom of the hole is likely to cause the recorded permeabilities to be significantly higher than the actual permeability, it is better to have the bottom of the casing slightly below the bottom of the hole to ensure conservative readings.)
- Continue to wash cuttings out of the hole at low water pressure using clean water until the water exiting the casing is running clear.
- Saturate the soil beneath the bottom of the casing with water for 30 minutes using clean water.
- Fill the casing with clean water to the top of the casing.
- Record the time at the beginning of the test with a stopwatch.
- Record the water level in the casing at 1, 2, 3, 4, 5, 10, and 15 minutes after the beginning of the test using the stopwatch to record the time, or until the ground water level in the casing has stopped falling.
- If the water level is dropping very rapidly, either
  - Record the water level at 30-second intervals until the water level has stopped falling.
  - Place the water level indicator slightly above the bottom of the casing and record the time at which the water level in the casing drops to this level.
- At the conclusion of the test, fill the casing with water to the top of the casing and maintain the water at this level for 5 minutes.
- Repeat the test using the same procedure.
- If the permeability test boring is more than 50 feet from the original boring
  - Drive a 2-inch diameter split-spoon a distance of 18 inches to obtain a soil sample below the bottom of the casing after the conclusion of the second test at each test depth.

- Create a boring log to record the blow counts, sample descriptions, and other pertinent information.
- The driller shall retain the samples obtained, unless otherwise directed by the DDC.

Falling Head Permeability Tests below the Groundwater Table in Uniform Soils – Uncased Extension

- Repeat the procedure for advancing the casing.
- To determine the elevation of the groundwater table as precisely as possible, the elevation of the permeability test boring should be within 1 foot of the elevation of the preliminary boring.
- If the ground surface elevation of the permeability boring is within 1 foot of the ground surface elevation of the preliminary boring, measure the groundwater level in the existing well and use this groundwater level to calculate the permeability.
- If the surface elevation of the permeability boring differs by more than 1 foot from the elevation of the preliminary boring, it will be necessary to determine the groundwater elevation in the permeability boring.
- Measure the depth to the bottom of the hole to the nearest inch.
- Fill the casing with about 40 inches of #4 well sand.
- Bump the casing up using the hammer so that the bottom of the casing is 32 inches above the bottom of the hole, this distance being measured to the nearest inch (if the soil is slightly above or below the bottom of the casing, the distance the casing is pulled up will differ slightly from 32 inches).
- Measure the level of the #4 well sand inside the casing.
- The #4 well sand inside the casing should be about six inches above the bottom of the casing at the final bottom of casing elevation.
- Fill the casing with clean water to the top of the casing.
- Record the time at the beginning of the test with a stopwatch.
- Record the water level in the casing at 1, 2, 3, 4, and 5 minutes after the beginning of the test using the stopwatch to record the time, or until the ground water level in the casing has stopped falling.
- If the water level is dropping very rapidly, either
- Record the water level at 30-second intervals until the water level has stopped falling.
- Place the water level indicator slightly above the bottom of the groundwater level and record the time at which the water level in the casing drops to this level.
- Repeat the test using the same procedure.
- If the permeability test boring is more than 50 feet from the original boring
  - Drive a 2-inch diameter split-spoon a distance of 18 inches to obtain a soil sample below the bottom of the casing after the conclusion of the second test at each test depth.
  - Create a boring log to record the blow counts, sample descriptions, and other pertinent information.
  - The driller shall retain the samples obtained, unless otherwise directed by the DDC.

Acronyms

AASHTO – American Association of State Highway and Transportation Officials
ADA – Americans with Disabilities Act
ASTM – American Society for Testing and Materials
BMP – best management practice
BUR – built-up roof
CAL – calcium acetate lactate
CAT – Calcium chloride Diethylene triamine pentaacetic acid
CGI – combustible gas indicator
CMP – corrugated metal pipe
CO – certificate of occupancy
CSA – Canadian Standards Association
CSO – combined sewer overflows
DEC – New York State Department of Environmental Conservation
DEP – New York City Department of Environmental Protection
DDC – New York City Department of Design and Construction
DOB – New York City Department of Buildings
DOT – New York City Department of Transportation
DPR – New York City Department of Parks and Recreation
FAR – floor area ratio
FLL – Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau
Fps – feet per second
HASP – Health and Safety Plan
HCP – house connection proposals
HDPE – high density polyethylene
IRMA – inverted roof membrane assembly
LEED – Leadership in Energy and Environment Design
MBR – modified bitumen roof
NYCBC – New York City Building Codes
NYCCC – New York City Construction Codes
NYCHA – New York City Housing Authority
NYCPC – New York City Plumbing Codes
OVA – organic vapor analyzer
PID – photoionization detector
PMR – protected membrane roofing
PVC – polyvinyl chloride
SCA – New York City School Construction Authority
SCP – site connection proposals
SPF – spray polyurethane foam
TR1 – Technical Report 1
US EPA – United States Environmental Protection Agency

Environmental Protection

New York City Department of Environmental Protection

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