2013 Stormwater Management Rule and Guidebook

Section 3.2

Green Roofs

3.2 Green Roofs

Definition. Practices that capture and store rainfall in an engineered growing media that is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites. Green roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Extensive green roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation and requires minimal, infrequent fertilization after vegetation is initially established.

Design variants include extensive and intensive green roofs.

G-1 Extensive green roofs have a much shallower growing media layer that typically ranges from 3 to 6 inches thick.

G-2 Intensive green roofs have a growing media layer that ranges from 6 to 48 inches thick.

Green roofs are typically not designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year) although some intensive green roof systems may be designed to meet these criteria. Most green roof designs shall generally be combined with a separate facility to provide large storm controls.

This specification is intended for situations where the primary design objective of the green roof is stormwater management and, unless specified otherwise, addresses the design of extensive roof systems. While rooftop practices such as urban agriculture may provide some retention, their primary design objective is not stormwater management and is not addressed in this specification.

3.2.1 Green Roof Feasibility Criteria

Green roofs are ideal for use on commercial, institutional, municipal, and multi-family residential buildings. They are particularly well-suited for use on ultra-urban development and redevelopment sites. Key constraints with green roofs include the following:

Structural Capacity of the Roof. When designing a green roof, designers must not only consider the stormwater storage capacity of the green roof but also its structural capacity to support the weight of the additional water. A conventional rooftop should typically be designed to support an additional 15 to 30 pounds per square foot (psf) for an extensive green roof. As a result, a structural engineer, architect, or other qualified professional should be involved with all green roof designs to ensure that the building has enough structural capacity to support a green roof. See Section 3.2.4 Green Roof Design Criteria for more information on structural design considerations.

Roof Pitch. Green roof storage volume is maximized on relatively flat roofs (a pitch of 1 to 2 percent). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Green roofs can be installed on rooftops with slopes up to 30 percent if baffles, grids, or strips are used to prevent slippage of the media. These baffles must be designed to ensure the roof provides adequate storage for the design storm. Slopes greater than 30 percent would be considered a green wall, which is not specifically identified as a stormwater best management practice (BMP). Green walls can be used to receive cistern discharge (calculations are necessary to determine demand) and can be used to comply with Green Area Ratio Requirements.

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane) and how the roof structure can accommodate material stockpiles and equipment loads. If material and equipment storage is required, rooftop storage areas must be identified and clearly marked based on structural load capacity of the roof.

Roof Type. Green roofs can be applied to most roof surfaces. Certain roof materials, such as exposed treated wood and uncoated galvanized metal, may not be appropriate for green rooftops due to pollutant leaching through the media (Clark et al, 2008).

Setbacks. Green roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may be relaxed for small or low green roof applications where parapets have been properly designed.

Contributing Drainage Area. It is recommended that the entire contributing drainage area to a green roof (including the green roof itself) be no more than 25 percent larger than the area of the green roof. In cases where the area exceeds this threshold, the designer must provide supporting documentation of rooftop loading, sufficient design to distribute runoff throughout the green roof and prevent erosion of the roof surface, and justification for incorporating a sizable external drainage area to the green roof.

District Building Codes. The green roof design must comply with the District's building codes with respect to roof drains and emergency overflow devices. Additionally, a District of Columbia registered structural engineer must certify that the design complies with District Building structural codes. This is true for new construction as well as retrofit projects.

3.2.2 Green Roof Conveyance Criteria

The green roof drainage layer (refer to Section 3.2.4) must convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. The green roof drainage layer must be adequate to convey the volume of stormwater equal to the flow capacity of the overflow or downspout system without backing water up onto the rooftop or into the green roof media. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging. However, an adequate number of roof drains that are not immediately adjacent to the growing media must be provided so as to allow the roof to drain without 3 inches of ponding above the growing media.

3.2.3 Green Roof Pretreatment Criteria

Pretreatment is not necessary for green roofs.

3.2.4 Green Roof Design Criteria

Structural Capacity of the Roof. Green roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer shall consult with a licensed structural engineer to ensure that the building will be able to support the additional live and dead structural load and to determine the maximum depth of the green roof system and any needed structural reinforcement. Typically, the green roof manufacturer can provide specific background specifications and information on their product for planning and design.

In most cases, fully saturated extensive green roofs have loads of about 15 to 30 pounds per square foot, which is fairly similar to traditional new rooftops (12 to 15 pounds per square foot) that have a waterproofing layer anchored with stone ballast. For a discussion of green roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, Standard Practice for Determination of Dead Loads and Live Loads Associated with Vegetative (Green) Roof Systems.

Functional Elements of a Green Roof System. A green roof is composed of up to nine different systems or layers that combine to protect the roof and maintain a vigorous cover (see Figure 3.1).

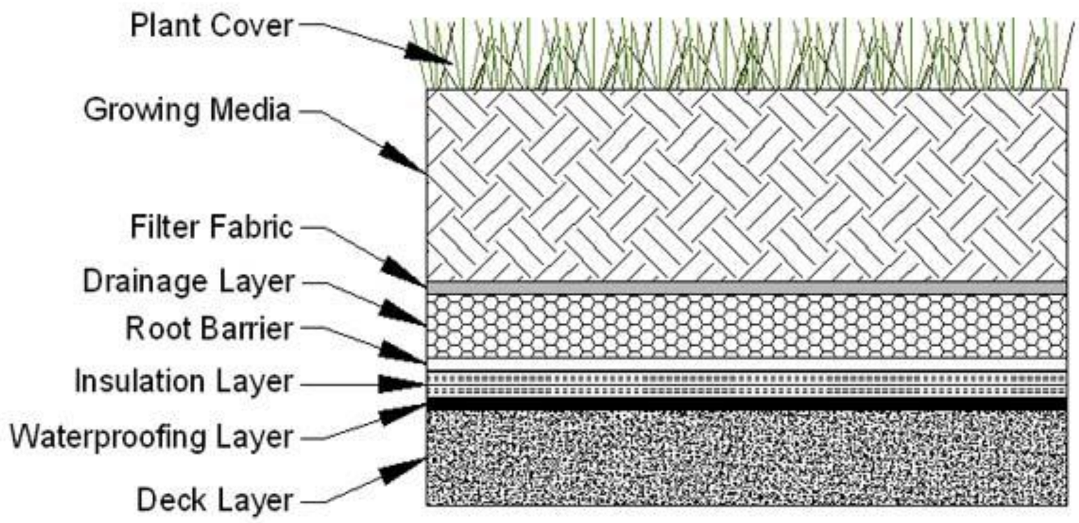

Figure 3.1 Typical layers for a green roof. Note: the relative placement of various layers may vary depending on the type and design of the green roof system.

The design layers include the following:

1. **Deck Layer**. The roof deck layer is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity, and potential need for insulation in the green roof system.
2. **Leak Detection System (optional).** Leak detection systems are often installed above the deck layer to identify leaks, minimize leak damage through timely detection, and locate leak locations.
3. **Waterproofing Layer.** All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including hot applied rubberized asphalt, built up bitumen, modified bitumen, thermoplastic membranes, polyvinyl chloride (PVC), thermoplastic olefin membrane (TPO), and elastomeric membranes (EPDM) (see Weiler and Scholz-Barth, 2009, and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100 percent waterproof and have an expected life span as long as any other element of the green roof system. The waterproofing material may be loose laid or bonded (recommended). If loose laid, overlapping and additional construction techniques should be used to avoid water migration.
4. **Insulation Layer.** Many green rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside of the building, in part to avoid mildew problems. The designer should consider the use of open or closed cell insulation depending on whether the insulation layer is above or below the waterproofing layer (and thus exposed to wetness), with closed cell insulation recommended for use above the waterproofing layer.
5. **Root Barrier.** Another layer of a green roof system, which can be either above or below the insulation layer depending on the system, is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers which have been impregnated with pesticides, metals, or other chemicals that could leach into stormwater runoff, must be avoided in systems where the root barrier layer will come in contact with water or allow water to pass through the barrier.
6. **Drainage Layer and Drainage System.** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection and thickness of the drainage layer type is an important design decision that is governed by the desired stormwater storage capacity, the required conveyance capacity, and the structural capacity of the rooftop. The effective depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive green roof system and increases for intensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., 1-2 inch layer of clean, washed granular material (ASTM D448 size No. 8 stone or lightweight granular mix), high density polyethylene (HDPE)) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as

a traditional system of protected roof drains, conductors, and roof leaders. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.

7. **Root-Permeable Filter Fabric**. A semi-permeable needled polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it. The filter fabric must not impede the downward migration of water into the drainage layer.

8. **Growing Media.** The next layer in an extensive green roof is the growing media, which is typically 3 to 6 inches deep (minimum 3 inches). The recommended growing media for extensive green roofs is typically composed of approximately 70 to 80 percent lightweight inorganic materials, such as expanded slates, shales or clays; pumice; scoria; or other similar materials. The remaining media must contain no more than 30 percent organic matter, normally well-aged compost (see Appendix J). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media typically has a maximum water retention of approximately 30 percent. Proof of growing media maximum water retention must be provided by the manufacturer. It is advisable to mix the media in a batch facility prior to delivery to the roof. As there are many different types of proprietary growing medias and roof systems, the values provided here are recommendations only. Manufacturer's specifications should be followed for all proprietary roof systems. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

   The composition of growing media for intensive green roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the green roof planting plan, the growing media must be sufficient to provide enough soil volume for the root structure of mature trees.

9. **Plant Cover.** The top layer of an extensive green roof typically consists of plants that are non-native, slow-growing, shallow-rooted, perennial, and succulent. These plants are chosen for their ability to withstand harsh conditions at the roof surface. Guidance on selecting the appropriate green roof plants can often be provided by green roof manufacturers and can also be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually *Sedum* species) and accent plants can be used to enhance the visual amenity value of a green roof. See Section 3.2.4 Green Roof Design Criteria for additional plant information. The design must provide for temporary, manual, and/or permanent irrigation or watering systems, depending on the green roof system and types of plants. For most application, some type of watering system should be accessible for initial establishment or drought periods. The use of water efficient designs and/or use of non-potable sources are strongly encouraged.

Material Specifications. Standard specifications for North American green roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The ASTM has recently issued several overarching green roof standards, which are described and referenced in Table 3.1 below.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary "complete" green roof systems or modules.

Table 3.1 Extensive Green Roof Material Specifications

Material	Specification
Roof	Structural capacity must conform to ASTM E-2397-05, *Practice for Determination of Live Loads and Dead Loads Associated with Vegetative (Green) Roof Systems*. In addition, use standard test methods ASTM E2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems* and ASTME 2399-05 for *Maximum Media Density for Dead Load Analysis*.
Leak Detection System	Optional system to detect and locate leaks in the waterproof membrane.
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, high density polyethylene (HDPE), etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors, and roof leaders. Designers should consult the material specifications as outlined in ASTM E2396 and E2398. Roof drains and emergency overflow must be designed in accordance with the District's construction code (DCMR, Title 12).
Filter Fabric	Generally needle-punched, non-woven, polypropylene geotextile, with the following qualities: ▪ Strong enough and adequate puncture resistance to withstand stresses of installing other layers of the green roof. Density as per ASTM D3776 ≥ 8 oz/yd^2. Puncture resistance as per ASTM D4833 ≥ 130 lb. These values can be reduced with submission of a Product Data Sheet and other documentation that demonstrates applicability for the intended use. ▪ Adequate tensile strength and tear resistance for long term performance. ▪ Allows a good flow of water to the drainage layer. Apparent Opening Size, as per ASTM D4751, of ≥ 0.06mm ≤ 0.2mm, with other values based on Product Data Sheet and other documentation as noted above. ▪ Allows at least fine roots to penetrate. ▪ Adequate resistance to soil borne chemicals or microbial growth both during construction and after completion since the fabric will be in contact with moisture and possibly fertilizer compounds.
Growth Media	70% to 80% lightweight inorganic materials and a maximum of 30% organic matter (e.g., well-aged compost). Media typically has a maximum water retention of approximately 30%. Material makeup and proof of maximum water retention of the growing media must be provided. Media must provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-05.
Plant Materials	*Sedum*, herbaceous plants, and perennial grasses that are shallow-rooted, low maintenance, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*.

Green Roof Sizing. Green roof areas can be designed to capture the entire Stormwater Retention Volume (SWRv). In some cases, they could be designed to capture larger design storm volumes as well. The required size of a green roof will depend on several factors, including maximum water retention of the growing media and the underlying drainage and storage layer materials (e.g., prefabricated water cups or plastic modules). As maximum water retention can vary significantly between green roof products, verification of this value must be included with the Stormwater Management Plan (SWMP). ASTM tests E2396, E2397, E2398, or E2399, as appropriate, and performed by an ASTM-certified lab are considered acceptable verification. In the absence of ASTM test results the baseline default values must be used. Site designers and planners should consult with green roof manufacturers and material suppliers as they can often provide specific sizing information and hydrology design tools for their products. Equation 3.1 below shall be used to determine the storage volume retained by a green roof.

Equation 3.1 Storage Volume for Green Roofs

$$Sv = \frac{SA \times \left[\left(d \times \eta_1 \right) + \left(DL \times \eta_2 \right) \right]}{12}$$

where:

Sv	=	storage volume (ft^3)
SA	=	green roof area (ft^2)
d	=	media depth (in.) (minimum 3 in.)
η_1	=	verified media maximum water retention (use 0.15 as a baseline default in the absence of verification data)
DL	=	drainage layer depth (in.)
η_2	=	verified drainage layer maximum water retention (use 0.15 as a baseline default in the absence of verification data)

The appropriate Sv can then be compared to the required SWRv for the entire rooftop area (including all conventional roof areas) to determine the portion of the design storm captured.

Green roofs can have dramatic rate attenuation effects on larger storm events and may be used, in part, to manage a portion of the 2-year and 15-year events. Designers can model various approaches by factoring in storage within the drainage layer. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

3.2.5 Green Roof Landscaping Criteria

Plant selection, landscaping, and maintenance are critical to the performance and function of green roofs. Therefore, a landscaping plan shall be provided for green roofs.

A planting plan must be prepared for a green roof by a landscape architect, botanist, or other professional experienced with green roofs and submitted with the SWMP.

Plant selection for green roofs is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most green roof installations is a hardy, low-growing succulent, such as *Sedum*, *Delosperma*, *Talinum*, *Semperivum*, or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006).

A list of some common green roof plant species that work well in the Chesapeake Bay watershed can be found in Table 3.2 below.

Table 3.2 Ground Covers Appropriate for Green Roofs in the District of Columbia

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self-sows

Note: Designers should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for a definitive list of green roof plants, including accent plants.

- Plant choices can be much more diverse for deeper intensive green roof systems. Herbs, forbs, grasses, shrubs, and even trees can be used, but designers should understand they may have higher watering, weeding, and landscape maintenance requirements.
- The species and layout of the planting plan must reflect the location of the building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and impacts from surrounding buildings. (Wind scour and solar burning have been observed on green roof installations that failed to adequately account for neighboring building heights and surrounding window reflectivity.) In addition, plants must be selected that are fire resistant and able to withstand heat, cold, and high winds.
- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on green roof plant selection, consult Snodgrass and Snodgrass (2006).

- It is also important to note that most green roof plant species will not be native to the Chesapeake Bay watershed (which contrasts with native plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of green roof plant nurseries in the region, it may be necessary for designers to order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract grown.
- When appropriate species are selected, most green roofs will not require supplemental irrigation, except for temporary irrigation during drought or initial establishment. The design must provide for temporary, manual, and/or permanent irrigation or watering systems, and the use of water efficient designs and/or use of non-potable sources is strongly encouraged. The planting window extends from the spring to early fall; although, it is important to allow plants to root thoroughly before the first killing frost. Green roof manufacturers and plant suppliers may provide guidance on planting windows as well as winter care. Proper planting and care may also be required for plant warranty eligibility.
- Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary green roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for green roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining (not requiring fertilizer inputs) and requires minimal mowing, trimming, and weeding.

The green roof design should include non-vegetated walkways (e.g., paver blocks) to allow for easy access to the roof for weeding and making spot repairs (see Section 3.2.4 Green Roof Design Criteria).

3.2.6 Green Roof Construction Sequence

Green Roof Installation. Given the diversity of extensive vegetated roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is watertight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system. Alternately, electric field vector mapping (EFVM) can be done to test for the presence of leaks; however, not all impermeable membranes are testable with this method. Problems have been noted with the use of EFVM on black EPDM and with aluminized protective coatings commonly used in conjunction with modified bituminous membranes.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric) per the manufacturer's specifications, taking care not to damage the waterproofing. Any damage occurring must be reported immediately. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.

- The growing media should be mixed prior to delivery to the site. Media must be spread evenly over the filter fabric surface as required by the manufacturer. If a delay between the installation of the growing media and the plants is required, adequate efforts must be taken to secure the growing media from erosion and the seeding of weeds. The growing media must be covered and anchored in place until planting. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction beyond manufacturer's recommendations.
- The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 2 to 3 growing seasons to fully establish the vegetated roof. The growing medium should contain enough organic matter to support plants for the first growing season, so initial fertilization is not required. Extensive green roofs may require supplemental irrigation during the first few months of establishment. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth (2009) for a photo guide of common rooftop weeds).
- Most construction contracts should contain a Care and Replacement Warranty that specifies at least 50 percent coverage after one year and 80 percent coverage after two years for plugs and cuttings, and 90 percent coverage after one year for *Sedum* carpet/tile.

Construction Supervision. Supervision during construction is recommended to ensure that the vegetated roof is built in accordance with these specifications. Inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction supervision/inspection is needed throughout the installation of a vegetated roof, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight.
- During placement of the drainage layer and drainage system.
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth (certification for vendor or source should be provided).
- Upon installation of plants, to ensure they conform to the planting plan (certification from vendor or source should be provided).
- Before issuing use and occupancy approvals.
- At the end of the first or second growing season to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

DDOE's construction phase inspection checklist for green roof practices can be found in Appendix K.

3.2.7 Green Roof Maintenance Criteria

Maintenance Inspections. A green roof should be inspected by a qualified professional twice a year during the growing season to assess vegetative cover and to look for leaks, drainage problems, and any rooftop structural concerns (see Table 3.3). In addition, the green roof should be hand weeded to remove invasive or volunteer plants, and plants and/or media should be added to repair bare areas (refer to ASTM E2400 (ASTM, 2006)).

If a roof leak is suspected, it is advisable to perform an electric leak survey (e.g., EVFM), if applicable, to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of some waterproofing membranes. Check with the membrane manufacturer for approval and warranty information. Also, power washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the green roof plant communities.

Fertilization is generally not recommended due to the potential for leaching of nutrients from the green roof. Supplemental fertilization may be required following the first growing season, but only if plants show signs of nutrient deficiencies and a media test indicates a specific deficiency. Addressing this issue with the holder of the vegetation warranty is recommended. If fertilizer is to be applied, it must be a slow-release type, rather than liquid or gaseous form.

DDOE's maintenance inspection checklist for green roofs and the Maintenance Service Completion Inspection form can be found in Appendix L.

Table 3.3 Typical Maintenance Activities Associated with Green Roofs

Schedule (following construction)	**Activity**
As needed or as required by manufacturer	▪ Water to promote plant growth and survival. ▪ Inspect the green roof and replace any dead or dying vegetation.
Semi-annually	▪ Inspect the waterproof membrane for leaks and cracks. ▪ Weed to remove invasive plants (do not dig or use pointed tools where there is potential to harm the root barrier or waterproof membrane). ▪ Inspect roof drains, scuppers, and gutters to ensure they are not overgrown and have not accumulated organic matter deposits. Remove any accumulated organic matter or debris. ▪ Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Materials. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.2.8 Green Roof Stormwater Compliance Calculations

Green roofs receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (see Table 3.4). Since the practice gets 100 percent retention value, it is not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.4 Green Roof Design Performance

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

The practice must be designed using the guidance detailed in Section 3.2.4.

Green roofs also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Sv from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.2.9 References

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2013 Stormwater Management Rule and Guidebook

Section 3.3

Rainwater Harvesting

3.3 Rainwater Harvesting

Definition. Rainwater harvesting systems store rainfall and release it for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground tank (also referred to as a cistern), where it is stored for non-potable uses or for on-site disposal or infiltration as stormwater. Cisterns can be sized for commercial as well as residential purposes. Residential cisterns are commonly called rain barrels.

Non-potable uses of harvested rainwater may include the following:

- Landscape irrigation,
- Exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, and fire trucks),
- Flushing of toilets and urinals,
- Fire suppression (i.e., sprinkler systems),
- Supply for cooling towers, evaporative coolers, fluid coolers, and chillers,
- Supplemental water for closed loop systems and steam boilers,
- Replenishment of water features and water fountains,
- Distribution to a green wall or living wall system,
- Laundry, and
- Delayed discharge to the combined sewer system.

In many instances, rainwater harvesting can be combined with a secondary (down-gradient) stormwater practice to enhance stormwater retention and/or provide treatment of overflow from the rainwater harvesting system. Some candidate secondary practices include the following:

- Disconnection to a pervious area (compacted cover) or conservation area (natural cover) or soil amended filter path (see Section 3.4 Impervious Surface Disconnection)
- Overflow to bioretention practices (see Section 3.6 Bioretention)
- Overflow to infiltration practices (see Section 3.8 Stormwater Infiltration)
- Overflow to grass channels or dry swales (see Section 3.12 Storage Practices)

By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal water supply, decreased water costs for the end user, and potential for increased groundwater recharge).

The seven primary components of a rainwater harvesting system are discussed in detail in Section 3.3.4. Some are depicted in Figure 3.2. The components include the following:

- Contributing drainage area (CDA) surface,
- Collection and conveyance system (e.g., gutter and downspouts) (number 1 in Figure 3.2)
- Pretreatment, including prescreening and first flush diverters (number 2 in Figure 3.2)
- Cistern (no number, but depicted in Figure 3.2)
- Water quality treatment (as required by Tiered Risk Assessment Management (TRAM))
- Distribution system
- Overflow, filter path or secondary stormwater retention practice (number 8 in Figure 3.2)

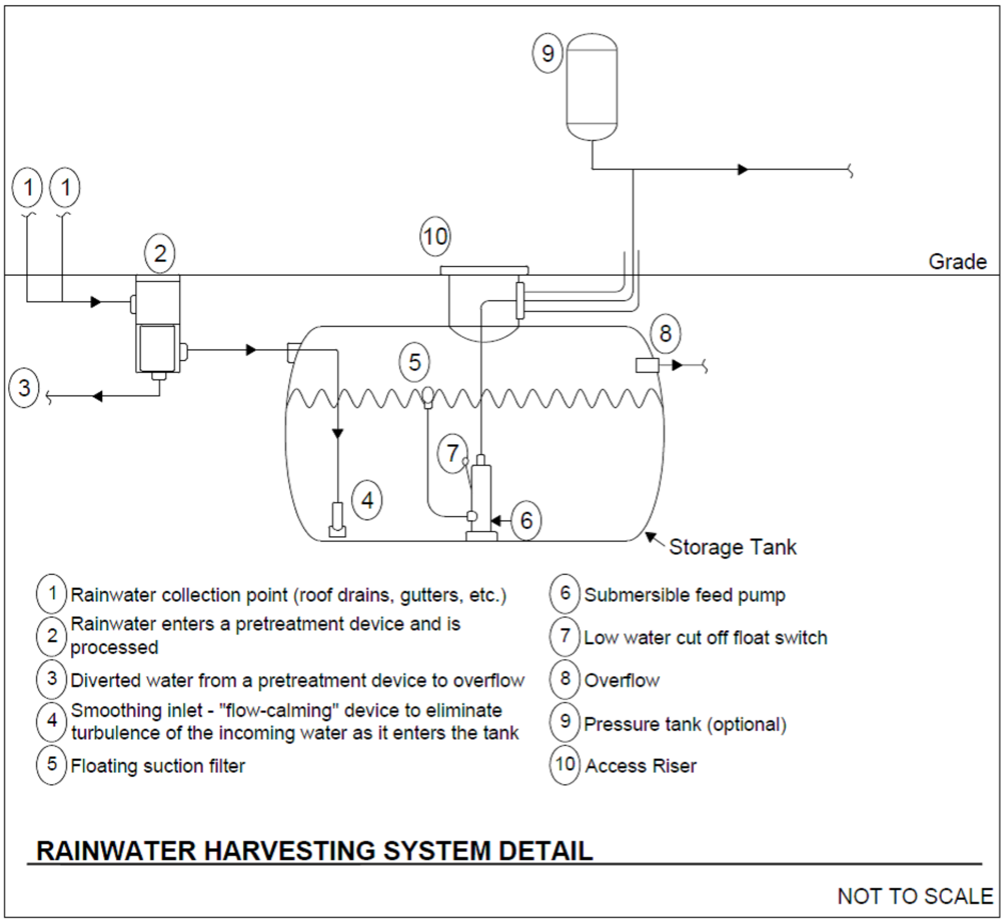

Figure 3.2 Example of a rainwater harvesting system detail.

3.3.1 Rainwater Harvesting Feasibility Criteria

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. The following are key considerations for rainwater harvesting feasibility. They are not comprehensive or conclusive; rather, they are recommendations to consider during the planning process to incorporate rainwater harvesting systems into the site design.

Plumbing Code. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult the District's construction codes (DCMR, Title 12) to determine the allowable indoor uses and required treatment for harvested rainwater. In cases where a municipal backup supply is used, rainwater harvesting systems must have backflow preventers or air gaps to keep harvested water separate from the main water supply. Distribution and waste pipes, internal to the building, must be stamped non-potable and colored purple consistent with the District's building codes. Pipes and spigots using rainwater must be clearly labeled as non-potable with an accompanying pictograph sign.

Mechanical, Electrical, Plumbing (MEP). For systems that call for indoor use of harvested rainwater, the seal of an MEP engineer is required.

Water Use. When rainwater harvesting will be used, a TRAM (see Appendix M) must be completed and the appropriate form submitted to DDOE. This will outline the design assumptions, outline water quality risks and provide water quality end use standards.

Available Space. Adequate space is needed to house the cistern and any overflow. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Cisterns can be placed underground, indoors, adjacent to buildings, and on rooftops that are structurally designed to support the added weight. Designers can work with architects and landscape architects to creatively site the cisterns. Underground utilities or other obstructions should always be identified prior to final determination of the cistern location.

Site Topography. Site topography and cistern location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system.

The final invert of the cistern outlet pipe at the discharge point must match the invert of the receiving mechanism (e.g., natural channel, storm drain system) and be sufficiently sloped to adequately convey this overflow. The elevation drops associated with the various components of a rainwater harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the rainwater harvesting system is feasible for the particular site.

Site topography and cistern location will also affect pumping requirements. Locating cisterns in low areas will make it easier to get water into the cisterns; however, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing cisterns at higher elevations may require larger diameter pipes with smaller slopes but will generally reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building or drainage area, to limit the amount of pipe needed.

Available Hydraulic Head. The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern may be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building, which then serves the internal water demands. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure.

Water Table. Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that is not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from floating), and conducting buoyancy calculations when the tank is empty. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The combined weight of the tank and hold-down ballast must meet or exceed the buoyancy force of the cistern. The cistern must also be installed according to the cistern manufacturer's specifications.

Soils. Cisterns should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete foundation, may be appropriate depending on the soils and cistern characteristics. Where the installation requires a foundation, the foundation must be designed to support the cistern's weight when the cistern is full consistent with the bearing capacity of the soil and good engineering practice. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems, treating all of the rainwater harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground cisterns and piping associated with the system.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the cistern. Rooftop surfaces are what typically make up the CDA, but paved areas can be used with appropriate treatment (oil/water separators and/or debris excluders). Areas of any size, including portions of roofs, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from the drainage area to rainwater harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water.

Contributing Drainage Area Material. The quality of the harvested rainwater will vary according to the roof material or drainage area over which it flows. Water harvested from certain types of rooftops and CDAs, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal, or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such surfaces should be avoided. If harvesting from a sealed or painted roof surface is desired, it is recommended that the sealant or paint be certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard).

Water Quality of Rainwater. Designers should also note that the pH of rainfall in the District tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from roof surfaces, cistern lining or water laterals, to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Limestone or other materials may be added in the cistern to buffer acidity, if desired.

Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation.

Setbacks from Buildings. Cistern overflow devices must be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. While most systems are generally sited underground and more than ten feet laterally from the building foundation wall, some cisterns are incorporated into the basement of a building or underground parking areas. In any case, cisterns must be designed to be watertight to prevent water damage when placed near building foundations.

Vehicle Loading. Whenever possible, underground rainwater harvesting systems should be placed in areas without vehicle traffic or other heavy loading, such as deep earth fill. If site constraints dictate otherwise, systems must be designed to support the loads to which they will be subjected.

3.3.2 Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts, and pipes that channel rainfall into cisterns. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Typically, gutters should be hung at a minimum of 0.5 percent for 2/3 of the length and at 1 percent for the remaining 1/3 of the length in order to adequately convey the design storm (i.e.., Stormwater Retention Volume (SWRv)). If the system will be used for management of the 2-year and 15-year storms, the gutters must be designed to convey the appropriate 2-year and 15-year storm intensities.

Pipes, which connect downspouts to the cistern, should be at a minimum slope of 1.5 percent and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Overflow. An overflow mechanism must be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the cistern. Overflow pipe(s) must have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe(s) must be screened to prevent access to the cistern by small mammals and birds. All overflow from the system must be directed to an acceptable flow path that will not cause erosion during a 2-year storm event.

3.3.3 Rainwater Harvesting Pretreatment Criteria

Prefiltration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for prefiltration of small systems, although direct water filtration is preferred. The purpose of prefiltration is to significantly cut down on maintenance by preventing organic buildup in the cistern, thereby decreasing microbial food sources.

Diverted flows (i.e., first flush diversion and/or overflow from the filter, if applicable) must be directed to an appropriate BMP or to a settling tank to remove sediment and pollutants prior to discharge from the site.

Various pretreatment devices are described below. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the cistern. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the cistern at all. A design intensity of 1 inch/hour (for design storm = SWRv) must be used for the purposes of sizing pre-cistern conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004). If the system will be used for channel and flood protection, the 2-year and 15-year storm intensities must be used for the design of the conveyance and pretreatment portion of the system. The Rainwater Harvesting Retention Calculator, discussed more in Section 3.3.4, allows for input of variable filter efficiency rates for the SWRv design storm. To meet the requirements to manage the 2-year and 15-year storms, a minimum filter efficiency of 90 percent must be met.

- **First Flush Diverters.** First flush diverters (see Figure 3.3) direct the initial pulse of rainfall away from the cistern. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces.
- **Leaf Screens.** Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the cisterns. Built-up debris can also harbor bacterial growth within gutters or downspouts (Texas Water Development Board, 2005).
- **Roof Washers.** Roof washers are placed just ahead of cisterns and are used to filter small debris from harvested rainwater (see Figure 3.4). Roof washers consist of a cistern, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30 microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.
- **Hydrodynamic Separator.** For large-scale applications, hydrodynamic separators and other devices can be used to filter rainwater from larger CDAs.

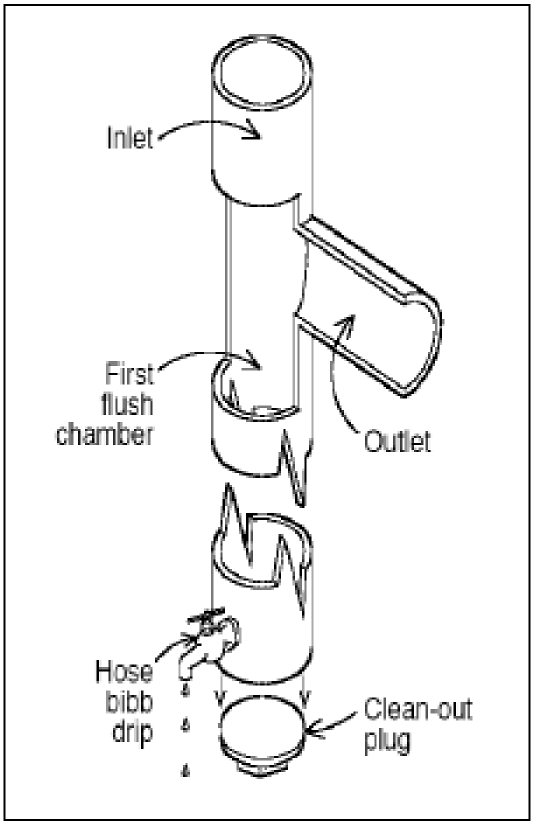

Figure 3.3 Diagram of a first flush diverter. (Texas Water Development Board, 2005)

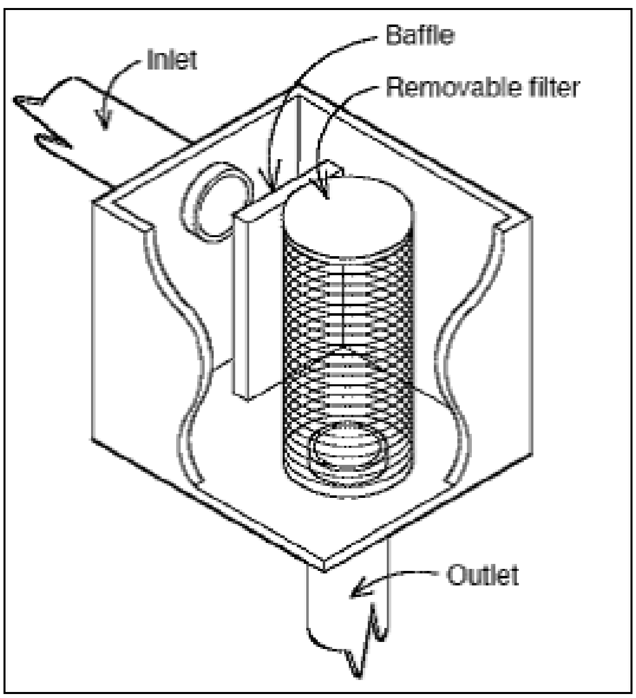

Figure 3.4 Diagram of a roof washer. (Texas Water Development Board, 2005)

3.3.4 Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system require special considerations (some of these are depicted in Figure 3.2):

- CDA or CDA surface
- Collection and conveyance system (i.e., gutter and downspouts)
- Cisterns
- Pretreatment, including prescreening and first flush diverters
- Water quality treatment (as required by TRAM)
- Distribution systems
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

- **CDA Surface.** When considering CDA surfaces, note smooth, non-porous materials will drain more efficiently. Slow drainage of the CDA leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be directed towards uses with significant human exposure (e.g., pool filling, public sprinkler fountain), care should be taken in the choice of CDA materials. Some materials may leach toxic chemicals making the water unsafe for humans. In all cases, follow the advice of the TRAM found in Appendix M.

  Rainwater can also be harvested from other impervious surfaces, such as parking lots and driveways; however, this practice requires more extensive pretreatment and treatment prior to reuse.

- **Collection and Conveyance System.** See Section 3.3.2 Rainwater Harvesting Conveyance Criteria.
- **Pretreatment.** See Section 3.3.3 Rainwater Harvesting Pretreatment Criteria.
- **Cisterns.** The cistern is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities generally range from 250 to 30,000 gallons, but they can be as large as 100,000 gallons or more for larger projects. Multiple cisterns can be placed adjacent to each other and connected with pipes to balance water levels and to tailor the storage volume needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Cistern volumes are calculated to meet the water demand and stormwater storage volume retention objectives, as described further below in this specification.

  While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the cisterns can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the cisterns will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site. The following factors should be considered when designing a rainwater harvesting system and selecting a cistern:

- Aboveground cisterns should be ultraviolet and impact resistant.
- Underground cisterns must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic).
- Underground rainwater harvesting systems must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. The access opening must be installed in such a way as to prevent surface- or groundwater from entering through the top of any fittings, and it must be secured/locked to prevent unwanted entry. Confined space safety precautions/requirements should be observed during cleaning, inspection, and maintenance.
- All rainwater harvesting systems must be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. Table 3.5 below compares the advantages and disadvantages of different cistern materials.
- Cisterns must be opaque or otherwise protected from direct sunlight to inhibit growth of algae, and they must be screened to discourage mosquito breeding.
- Dead storage below the outlet to the distribution system and an air gap at the top of the cistern must be included in the total cistern volume. For gravity-fed systems, a minimum of 6 inches of dead storage must be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

Table 3.5 Advantages and Disadvantages of Typical Cistern Materials (Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009)

Cistern Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of watertight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications

Cistern Material	Advantages	Disadvantages
Steel Drums	Commercially available, alterable, and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast-in-Place Concrete	Durable, immoveable, and versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or Concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

- **Water Quality Treatment.** Depending upon the collection surface, method of dispersal, and proposed use for the harvested rainwater, a water quality treatment device may be required by the TRAM (see Appendix M).
- **Distribution Systems.** Most distribution systems require a pump to convey harvested rainwater from the cistern to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary stormwater treatment practice. The rainwater harvesting system should be equipped with an appropriately sized pump that produces sufficient pressure for all end-uses.

  The typical pump and pressure tank arrangement consists of a multi-stage, centrifugal pump, which draws water out of the cistern and sends it into the pressure tank, where it is stored for distribution. Some systems will not require this two-tank arrangement (e.g., low-pressure and gravel systems). When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

  Distribution lines from the rainwater harvesting system should be buried beneath the frost line. Lines from the rainwater harvesting system to the building should have shut-off valves that are accessible when snow cover is present. A drain plug or cleanout sump must be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter if winter use is planned.
- **Overflow.** See Section 3.3.2 Rainwater Harvesting Conveyance Criteria.

Rainwater Harvesting Material Specifications. The basic material specifications for rainwater harvesting systems are presented in Table 3.6. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated cisterns and other system components.

Table 3.6 Design Specifications for Rainwater Harvesting Systems

Item	Specification
Gutters and Downspouts	Materials commonly used for gutters and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum, and galvanized steel. Lead must not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. ▪ The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the cisterns. ▪ Be sure to include needed bends and tees.
Pretreatment	At least one of the following (all rainwater to pass through pretreatment): ▪ First flush diverter ▪ Hydrodynamic separator ▪ Roof washer ▪ Leaf and mosquito screen (1 mm mesh size)
Cisterns	▪ Materials used to construct cisterns must be structurally sound. ▪ Cisterns should be constructed in areas of the site where soils can support the load associated with stored water. ▪ Cisterns must be watertight and sealed using a water-safe, non-toxic substance. ▪ Cisterns must be opaque or otherwise shielded to prevent the growth of algae. ▪ The size of the rainwater harvesting system(s) is determined through design calculations.

Note: This table does not address indoor systems or pumps.

Design Objectives and System Configuration. Rainwater harvesting systems can have many design variations that meet user demand and stormwater objectives. This specification provides a design framework to achieve the SWRv objectives that are required to comply with the regulations, and it adheres to the following concepts:

- Give preference to use of rainwater as a resource to meet on-site demand or in conjunction with other stormwater retention practices.
- Reduce peak flow by achieving volume reduction and temporary storage of runoff.

Based on these concepts, this specification focuses on system design configurations that harvest rainwater for internal building uses, seasonal irrigation, and other activities, such as cooling tower use and vehicle washing. While harvested rainwater will be in year-round demand for many internal building uses, some other uses will have varied demand depending on the time of year (e.g., cooling towers and seasonal irrigation). Thus, a lower retention value is assigned to a type of use that has reduced demand.

Design Objectives and Cistern Design Set-Ups. Prefabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. Three basic cistern designs meet the various rainwater harvesting system configurations in this section.

- **Cistern Design 1.** The first cistern set-up (Figure 3.5) maximizes the available storage volume associated with the SWRv to meet the desired level of stormwater retention. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the cistern as the only gravity release outlet device (not including the pump, manway, or inlets). It should be noted that it is possible to address 2-year and 15-year storm volumes with this cistern configuration, but the primary purpose is to address the smaller SWRv design storm.

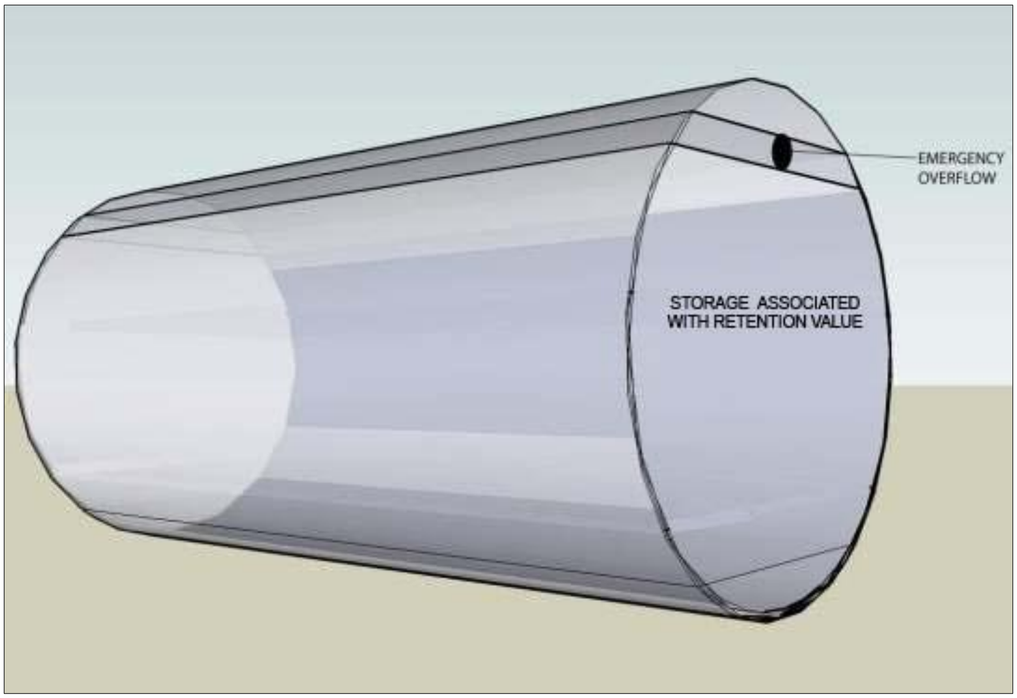

Figure 3.5 Cistern Design 1: Storage associated with the design storm volume only.

- **Cistern Design 2.** The second cistern set-up (Figure 3.6) uses cistern storage to meet the SWRv storage objectives and also uses additional detention volume to meet some or all of the 2-year and 15-year storm volume requirements. An orifice outlet is provided at the top of the design storage for the SWRv level, and an emergency overflow is located at the top of the detention volume level.

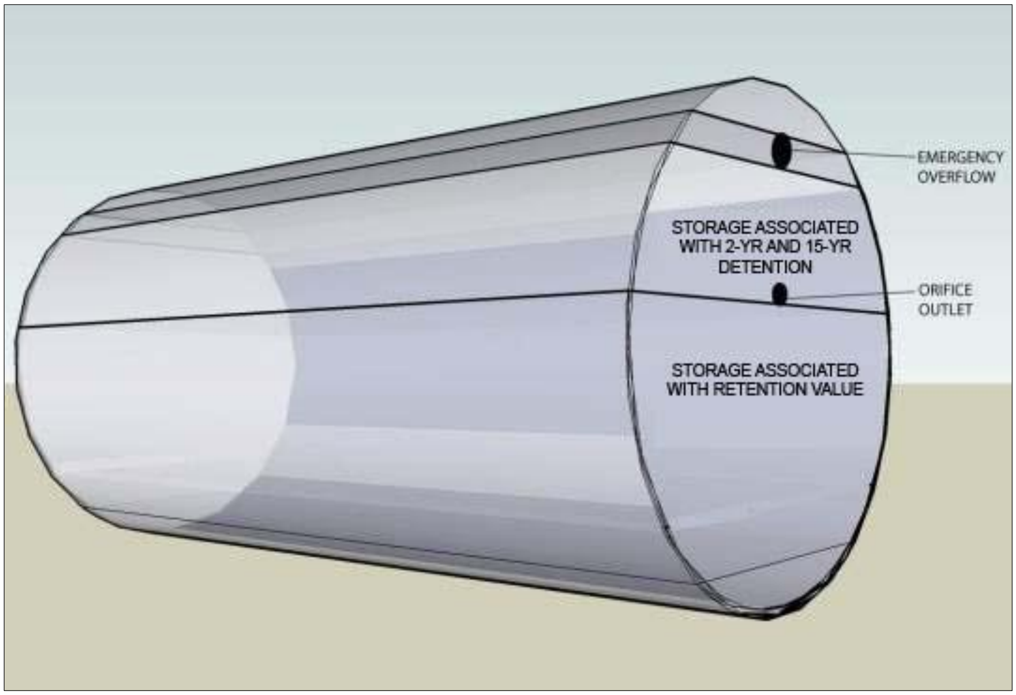

Figure 3.6 Cistern Design 2: Storage associated with design storm, channel protection, and flood volume.

- **Cistern Design 3.** The third cistern set-up (Figure 3.7) creates a constant drawdown within the system. The small orifice at the bottom of the cistern needs to be routed to an appropriately designed secondary practice (i.e., bioretention, stormwater infiltration) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release must not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

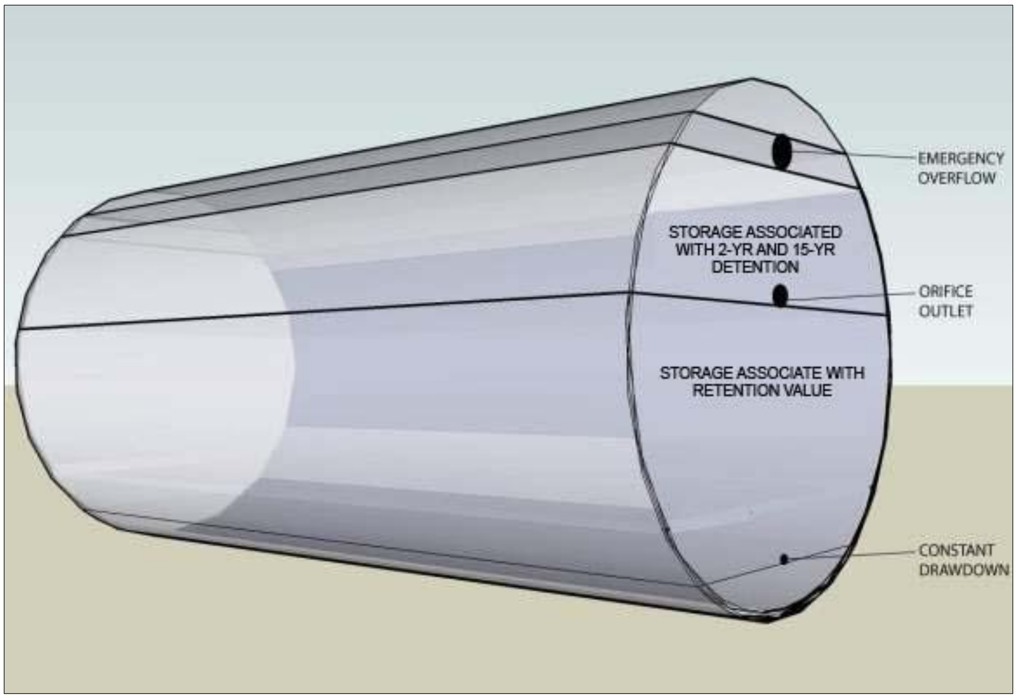

Figure 3.7 Cistern Design 3: Constant drawdown version where storage is associated with design storm, channel protection, and flood volume.

Design Storm, Channel Protection, and Flood Volume. For the purposes of the third cistern design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the storage volume percentage calculated in the General Retention Compliance Calculator (discussed in Chapter 5 and Appendix A). In other words, the storage volume associated with the secondary practice must not be added (or double-counted) to the rainwater harvesting percentage because the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown. The exception to this requirement would be if the secondary practice were also sized to capture and treat impervious and/or turf area beyond the area treated by rainwater harvesting (for example from the adjacent yard or a driveway). In this case, only these additional areas should be added into the General Retention Compliance Calculator to receive retention volume achieved for the secondary practice.

While a small orifice is shown at the bottom of the cistern in Figure 3.7, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

Sizing of Rainwater Harvesting Systems. The rainwater harvesting cistern sizing criteria presented in this section were developed using a spreadsheet model that used best estimates of indoor and outdoor water demand, long-term rainfall data, and CDA capture area data (Forasté2011). The Rainwater Harvesting Retention Calculator is for cistern sizing guidance and to quantify the retention value for storage volume achieved. This retention value is required for input into the General Retention Compliance Calculator and is part of the submission of a Stormwater Management Plan (SWMP) using rainwater harvesting systems for compliance. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource. More information on the Rainwater Harvesting Retention Calculator can be found later in this section. The spreadsheet can be found on DDOE's website at http://ddoe.dc.gov/swregs.

Rainwater Harvesting Retention Calculator. The design specification provided in this section (Rainwater Harvesting) is linked with the Rainwater Harvesting Retention Calculator. The spreadsheet uses daily rainfall data from September 1, 1977 to September 30, 2007 to model performance parameters of the cistern under varying CDAs, demands on the system, and cistern size.

The runoff that reaches the cistern each day is added to the water level that existed in the cistern the previous day, with all of the total demands subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the cistern runs dry (reaches the cut-off volume level), then the volume in the cistern is fixed at the low level, and a dry-frequency day is recorded. The full or partial demand met in both cases is quantified and recorded. A summary of the water balance for the system is provided below.

Incremental Design Volumes within Cistern. Rainwater cistern sizing is determined by accounting for varying precipitation levels, captured CDA runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for the design storm (permanent storage), storage needed for 2-year or 15-year volume (temporary detention storage), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See Figure 3.8 for a graphical representation of these various incremental design volumes.

The design specification described in this section (Rainwater Harvesting) does not provide guidance for sizing larger storms (e.g., Qp_2, Qp_{15}, and Q_f), but rather provides guidance on sizing for the SWRv design storms.

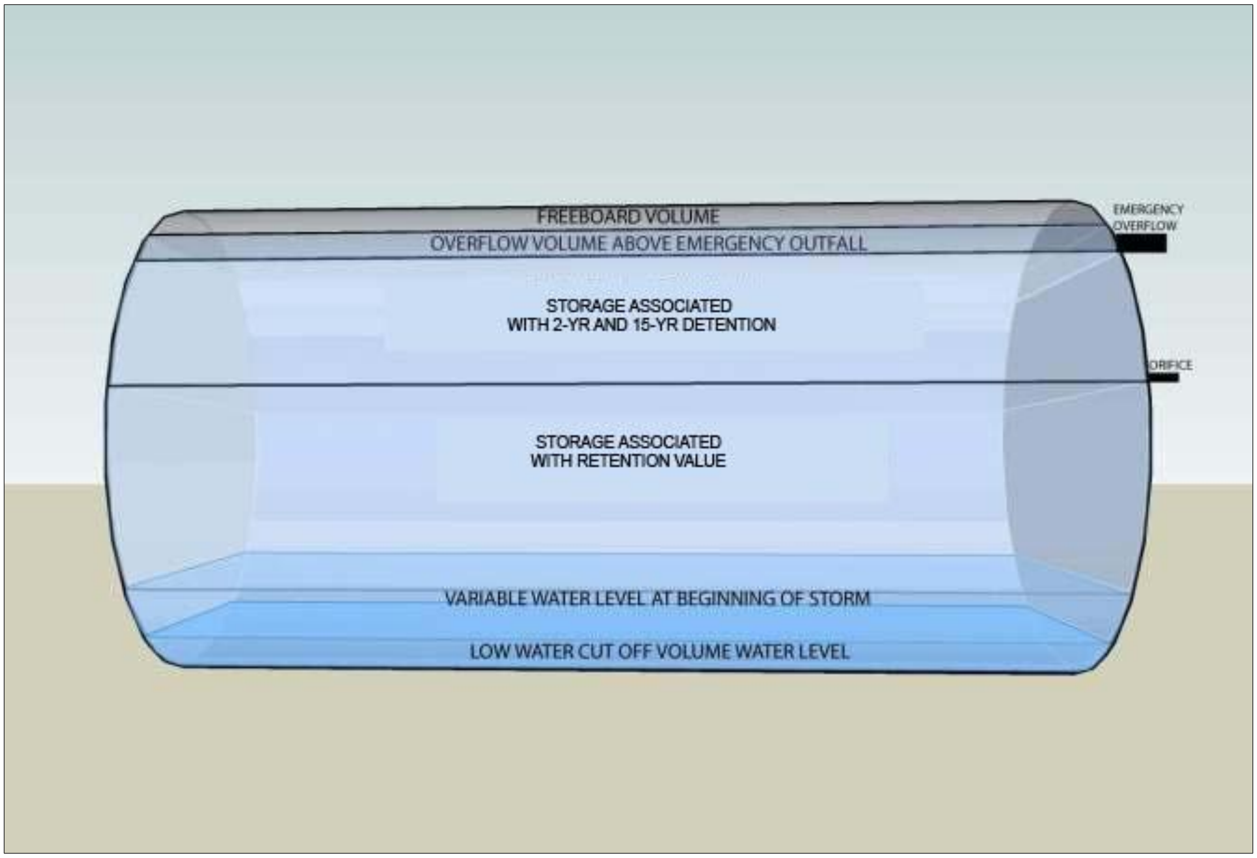

Figure 3.8 Incremental design volumes associated with cistern sizing.

The "Storage Associated with the Retention Value" is the storage within the cistern that is modeled and available for reuse. While the SWRv will remain the same for a specific CDA, the "Storage Associated with the Retention Value" may vary depending on demand and storage volume retention objectives. It includes the variable water level at the beginning of a storm and the low water cut-off volume that is necessary to satisfy pumping requirements.

Water Contribution

- **Precipitation.** The volume of water contributing to the rainwater harvesting system is a function of the rainfall and CDA, as defined by the designer.
- **Municipal Backup (optional).** In some cases, the designer may choose to install a municipal backup water supply to supplement cistern levels. Note that municipal backups may also be connected post-cistern (i.e., a connection is made to the non-potable water line that is used for pumping water from the cistern for reuse), thereby not contributing any additional volume to the cistern. Municipal backup designs that supply water directly to the cistern are not accounted for in the Rainwater Harvesting Retention Calculator.

Water Losses

- **Drainage Area Runoff Coefficient.** The CDA is assumed to convey 95 percent of the rainfall that lands on its surface (i.e., Rv = 0.95).
- **First Flush Diversion.** The first 0.02 to 0.06 inches of rainfall that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is assumed to be contained within the filter efficiency rate.
- **Filter Efficiency.** It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the SWRv storm will be successfully captured. For the 1.2-inch storm, a minimum of 95 percent of the runoff should be conveyed into the cistern. For the 3.2-inch storm, a minimum of 90 percent of the runoff should be conveyed. These minimum values are included as the filter efficiencies in the Rainwater Harvesting Retention Calculator, although they can be altered (increased) if appropriate. The Rainwater Harvesting Retention Calculator applies these filter efficiencies, or interpolated values, to the daily rainfall record to determine the volume of runoff that reaches the cistern. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1 inch per hour shall be used for the SWRv. The appropriate rainfall intensity values for the 2-year (3.2-inch) and 15-year storms shall be used when designing for larger storm events.
- **Drawdown (Storage Volume).** This is the stored water within the cistern that is reused or directed to a secondary stormwater practice. It is the volume of runoff that is reduced from the CDA. This is the water loss that translates into the achievable storage volume retention.
- **Overflow.** For the purposes of addressing the SWRv (not for addressing larger storm volumes), orifice outlets for both detention and emergency overflows are treated the same. This is the volume of water that may be lost during large storm events or successive precipitation events.

Results for all Precipitation Events. The performance results of the rainwater harvesting system for all days during the entire period modeled, including the full spectrum of precipitation events, is included in the “Results” tab. This tab is not associated with determining the storage volume achieved, but instead may be a useful tool in assisting the user to realize the performance of the various rainwater harvesting system sizes with the design parameters and demands specified.

- **Percentage of Demand Met.** This is where the percentage of demand met for various size cisterns and CDA/demand scenarios is reported. A graph displaying the percentage of demand met versus the percentage of overflow frequency for various cistern sizes is provided in this tab. Normally, this graph assists the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided below in Figure 3.9.

  At some point, larger cisterns no longer provide significant increases in percentages of demand met. Conversely, the curve informs the user when a small increase in cistern size can yield a significant increase in the percentage of time that demand is met.

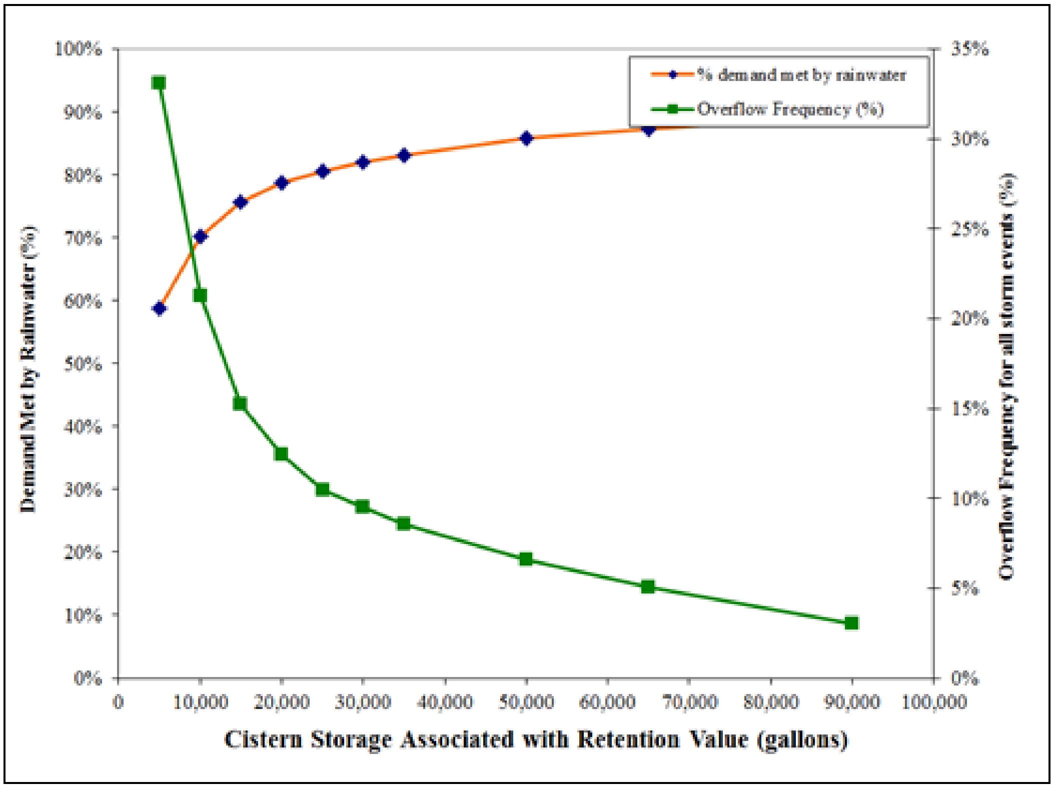

Figure 3.9 Example of percent demand met versus cistern storage.

- **Dry Frequency.** Another useful measure is the dry frequency. If the cistern is dry a substantial portion of the time, this measure can inform the user that he/she may want to decrease the size of the cistern, decrease the demand on the system, or explore capturing more CDA to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a municipal backup supply to ensure sufficient water supply through the system at all times.
- **Overflow Frequency.** This is a metric of both overflow frequency and average volume per year for the full spectrum of rainfall events. This metric will inform the user regarding the design parameters, magnitude of demand, and associated performance of the system. If the system overflows at a high frequency, then the designer may want to increase the size of the cistern, decrease the CDA captured, or consider other mechanisms that could increase drawdown (e.g., increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).
- **Inter-relationships and Curves of Diminishing Returns.** Plotting various performance metrics against one another can be very informative and reveal relationships that are not evident otherwise. An example of this usefulness is demonstrated when the plot of “percentage-of-demand-met versus cistern size” is compared against the plot of “the percentage-of-overflow-frequency versus cistern size.” By depicting these plots on the same graph, a range of optimum cistern sizes emerges. This informs the designer where a small increase or decrease in cistern size will have a significant impact on dry frequency and overflow frequency. Looking outside this range will indicate where changes in cistern sizes

will not have significant influence over dry frequency and overflow frequency, but may offer a large trade-off compared to the cost of the rainwater harvesting system.

Results for Retention Value. The retention value percentage of CDA runoff volume that the cistern can capture for a 1.7-inch storm on an average daily basis given the water demands by the user is presented on the “Results-Retention Value” tab. This information is used to calculate the retention value percentage, which is used as an input to the General Retention Compliance Calculator.

- **Retention Value Percentage Achieved.** The percentage of retention value achieved is calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the retention achieved versus cistern size. While larger cisterns yield more retention, they are more costly. The curve helps the user to choose the appropriate cistern size, based on the design objectives and site needs, and to understand the rate of diminishing returns.
- **Overflow Volume.** The volume of the overflows resulting from a 1.7-inch precipitation event is also reported in this tab. A chart of the retention value and overflow frequency versus the storage volume is provided. An example is shown in Figure 3.10.

  These plotted results establish a trade-off relationship between these two performance metrics. In the example in Figure 3.10, a 13,000 gallon cistern optimizes the storage volume achieved and the overflow frequency (near the inflection point of both curves).

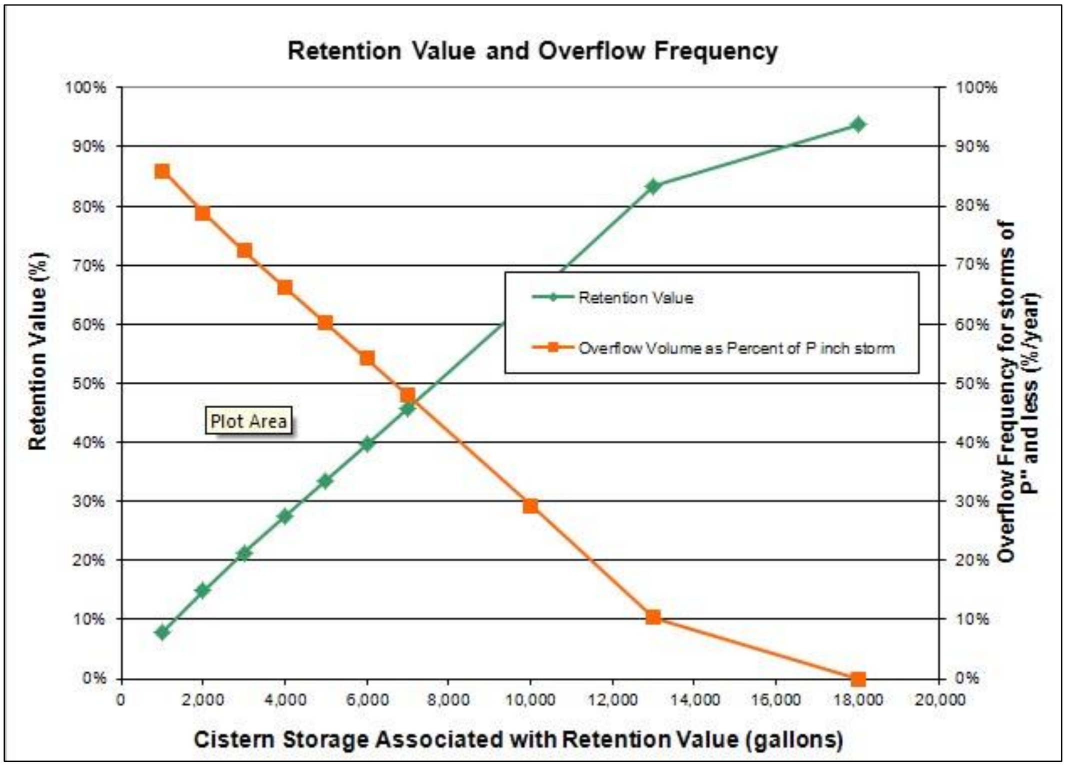

Figure 3.10 Example of retention value percentage achieved versus storage for non-potable uses.

Results from the Rainwater Harvesting Retention Calculator to be Transferred to the General Retention Compliance Calculator. There are two results from the Rainwater Harvesting Retention Calculator that are to be transferred to the General Retention Compliance Calculator, as follows:

- **Contributing Drainage Area (CDA).** Enter the CDA that was used in the Rainwater Harvesting Retention Calculator in the same row into the Drainage Area columns in the blue cell (cell B26-D31).
- **Retention Value.** Once the cistern storage volume associated with the retention value has been selected, transfer that achieved percentage into the General Retention Compliance Calculator column called "% Retention Value" in the "Rainwater Harvesting" row (cell I33).

Completing the Sizing Design of the Cistern. The total size of the cistern is the sum of the following four volume components:

- **Low Water Cutoff Volume (Included).** A dead storage area must be included so the pump will not run the cistern dry. This volume is included in the Rainwater Harvesting Retention Calculator's modeled volume.
- **Cistern Storage Associated with Design Volume (Included).** This is the design volume from the Rainwater Harvesting Retention Calculator.
- **Adding Channel Protection and Flood Volumes (Optional).** Additional detention volume may be added above and beyond the cistern storage associated with the design storm volumes for the 2-year or 15-year events. Typical routing software programs may be used to design for this additional volume.
- **Adding Overflow and Freeboard Volumes (Required).** An additional volume above the emergency overflow must be provided in order for the cistern to allow very large storms to pass. Above this overflow water level, there will be an associated freeboard volume that should account for at least 5 percent of the overall cistern size. Sufficient freeboard must be verified for large storms, and these volumes must be included in the overall size of the cistern.

3.3.5 Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan elements must include the proposed delineation of planting areas to be irrigated, the planting plan, and quantification of the expected water demand. The default water demand for irrigation is 1.0 inches per week over the area to be irrigated. Justification must be provided if larger volumes are to be used.

3.3.6 Rainwater Harvesting Construction Sequence

Installation. It is advisable to have a single contractor to install the rainwater harvesting system, outdoor irrigation system, and secondary retention practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system.

A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions.

1. Choose the cistern location on the site
2. Route all downspouts or pipes to prescreening devices and first flush diverters
3. Properly install the cistern
4. Install the pump (if needed) and piping to end uses (indoor, outdoor irrigation, or cistern dewatering release)
5. Route all pipes to the cistern
6. Stormwater must not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.

Construction Supervision. The following items should be inspected by a qualified professional prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Mosquito screens are installed on all openings
- Overflow device is directed as shown on plans
- Rainwater harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary stormwater treatment practice(s) is installed as shown on plans

DDOE's construction phase inspection checklist for rainwater harvesting practices and the Stormwater Facility Leak Test form can be found in Appendix K.

3.3.7 Rainwater Harvesting Maintenance Criteria

Maintenance Inspections. Periodic inspections and maintenance shall be conducted for each system by a qualified professional.

DDOE's maintenance inspection checklists for rainwater harvesting systems and the Maintenance Service Completion Inspection form can be found in Appendix L.

Maintenance Schedule. Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. Table 3.7 describes routine maintenance tasks necessary to keep rainwater harvesting systems in working condition. Maintenance tasks must be performed by an "Inspector Specialist," certified by the American Rainwater Catchment Association.

Maintenance tasks must be documented and substantially comply with the maintenance responsibilities outlined in the declaration of covenants.

Table 3.7 Typical Maintenance Tasks for Rainwater Harvesting Systems

<table>
<tr><th>Responsible Person</th><th>Frequency</th><th>Activity</th></tr>
<tr><td rowspan="4">Owner</td><td>Four times a year</td><td>Inspect and clean prescreening devices and first flush diverters</td></tr>
<tr><td>Twice a year</td><td>Keep gutters and downspouts free of leaves and other debris</td></tr>
<tr><td>Once a year</td><td>▪ Inspect and clean storage cistern lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately
▪ Inspect condition of overflow pipes, overflow filter path, and/or secondary stormwater treatment practices</td></tr>
<tr><td>Every third year</td><td>Clear overhanging vegetation and trees over roof surface</td></tr>
<tr><td rowspan="3">Qualified Third Party Inspector</td><td>According to Manufacturer</td><td>Inspect water quality devices</td></tr>
<tr><td>As indicated in TRAM</td><td>Provide water quality analysis to DDOE</td></tr>
<tr><td>Every third year</td><td>▪ Inspect cistern for sediment buildup
▪ Check integrity of backflow preventer
▪ Inspect structural integrity of cistern, pump, pipe and electrical system
▪ Replace damaged or defective system components</td></tr>
</table>

Mosquitoes. In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding. Designers must provide screens on above- and below-ground cisterns to prevent mosquitoes and other insects from entering the cisterns. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

Cold Climate Considerations. Rainwater harvesting systems have a number of components that can be impacted by freezing temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, wintertime operation may be more challenging, depending on cistern size and whether heat tape is used on piping. If not protected from freezing, these rainwater harvesting systems must be taken offline for the winter and stormwater treatment values may not be granted for the practice during that off-line period. At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions should be disconnected and drained. It may be possible to reconnect former roof leader systems for the winter.

For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner’s primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.3.8 Rainwater Harvesting: Stormwater Compliance Calculations

Rainwater harvesting practices receive a partial retention value for the SWRv that is equivalent to the percent retention achieved determined by using the Rainwater Harvesting Retention Calculator, as described in Section 3.3.4. Rainwater harvesting is not an accepted total suspended solids treatment practice.

3.3.9 References

Cabell Brand Center. 2007. Virginia Rainwater Harvesting Manual. Salem, VA. http://www.cabellbrandcenter.org

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National Oceanic and Atmospheric Administration (NOAA). 2004. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0. Revised 2006. Silver Spring, MD.

Texas Water Development Board (TWDB). 2005. The Texas Manual on Rainwater Harvesting. Third Ed. Austin, TX.

2013 Stormwater Management Rule and Guidebook

Section 3.6

Bioretention

3.6 Bioretention

Definition. Practices that capture and store stormwater runoff and pass it through a filter bed of engineered soil media composed of sand, soil, and organic matter. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil. Design variants include:

B-1 Traditional bioretention

B-2 Streetscape bioretention

B-3 Engineered tree pits

B-4 Stormwater planters

B-5 Residential rain gardens

Bioretention systems are typically not designed to provide stormwater detention of larger storms (e.g., 2-year, 15-year), but they may be in some circumstances. Bioretention practices shall generally be combined with a separate facility to provide those controls.

There are two different types of bioretention design configurations:

- **Standard Designs**. Practices with a standard underdrain design and less than 24 inches of filter media depth (see Figure 3.17). If trees are planted using this design, the filter media depth must be at least 24 inches to support the trees.
- **Enhanced Designs**. Practices with underdrains that contain at least 24 inches of filter media depth and an infiltration sump/storage layer (see Figure 3.18) or practices that can infiltrate the design storm volume in 72 hours (see Figure 3.19).

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are further discussed in this chapter.

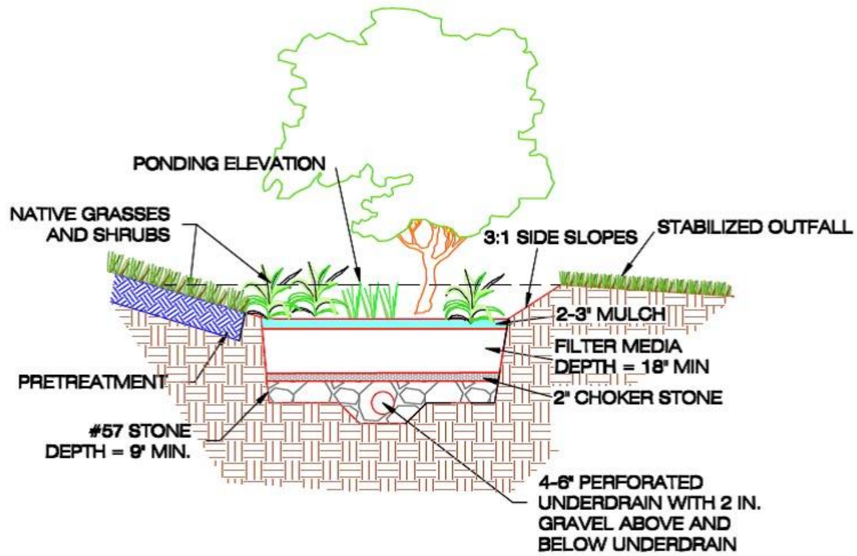

Figure 3.17 Example of standard bioretention design.

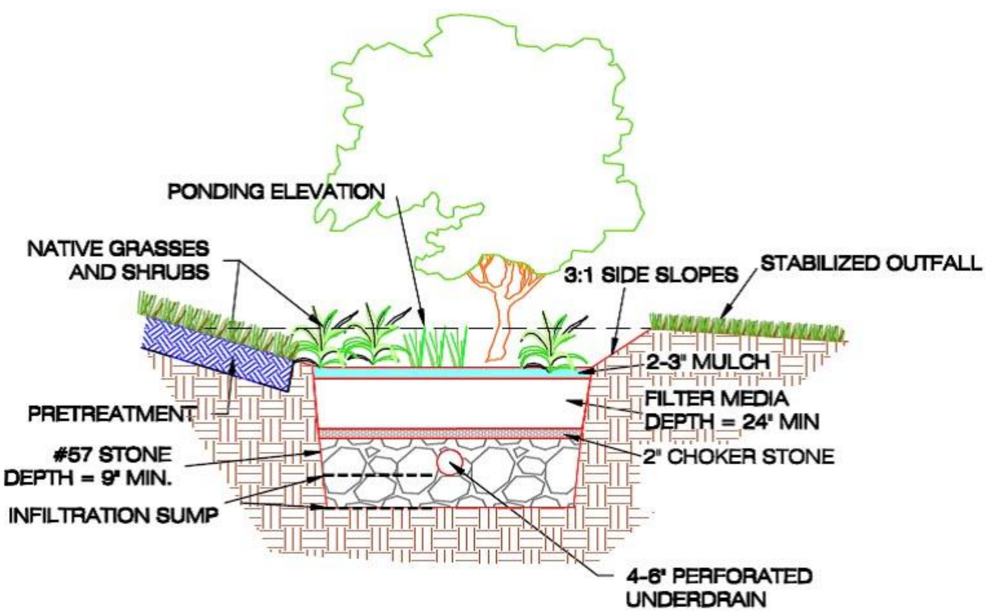

Figure 3.18 Example of an enhanced bioretention design with an underdrain and infiltration sump/storage layer.

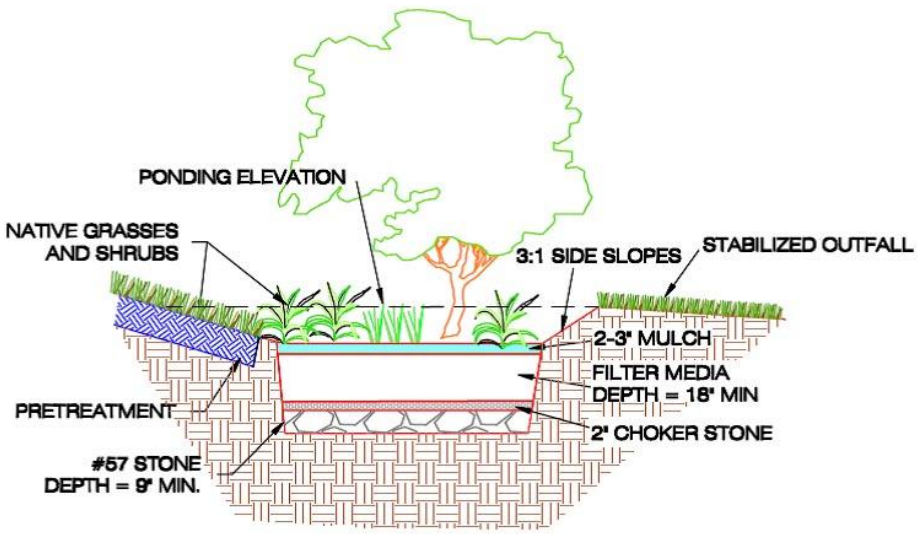

Figure 3.19 Example of enhanced bioretention design without an underdrain.

3.6.1 Bioretention Feasibility Criteria

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and is infiltrated or returned to the stormwater system via an underdrain. Key constraints with bioretention include the following:

Required Space. Planners and designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area (CDA), and the corresponding bioretention surface area. The surface area is recommended to be approximately 3 to 6 percent of CDA, depending on the imperviousness of the CDA and the desired bioretention ponding depth.

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention area into the storm drain system). In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and filter media depths. If the practice does not include an underdrain or if an inverted or elevated underdrain design is used, less hydraulic head may be adequate.

Water Table. Bioretention must be separated from the water table to ensure that groundwater does not intersect the filter bed. Mixing can lead to possible groundwater contamination or failure of the bioretention facility. A separation distance of 2 feet is required between the bottom of the excavated bioretention area and the seasonally high ground water table.

Soils and Underdrains. Soil conditions do not typically constrain the use of bioretention, although they do determine whether an underdrain is needed. Underdrains may be required if the measured permeability of the underlying soils is less than 0.5 in./hr. When designing a bioretention practice, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix O. Impermeable soils will require an underdrain.

For fill soil locations, geotechnical investigations are required to determine if it is necessary to use an impermeable liner and underdrain.

Contributing Drainage Area. Bioretention cells work best with smaller CDAs, where it is easier to achieve flow distribution over the filter bed. The maximum drainage area to a traditional bioretention area (B-1) is 2.5 acres and can consist of up to 100 percent impervious cover. The drainage area for smaller bioretention practices (B-2, B-3, B-4, and B-5) is a maximum of 1 acre. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger drainage areas, such as off-line or low-flow diversions, or forebays, there may be case-by-case instances where the maximum drainage areas can be adjusted. Table 3.18 summarizes typical recommendations for bioretention CDAs.

Table 3.18 Maximum Contributing Drainage Area to Bioretention

Bioretention Type	Design Variants	Maximum Contributing Drainage Area (acres of impervious cover)
Traditional	B-1	2.5
Small-scale and urban bioretention	B-2, B-3, B-4, and B-5	1.0

Hotspot Land Uses. An impermeable bottom liner and an underdrain system must be employed when a bioretention area will receive untreated hotspot runoff, and the Enhanced Design configuration cannot be used. However, bioretention can still be used to treat parts of the site that are outside of the hotspot area. For instance, roof runoff can go to bioretention while vehicular maintenance areas would be treated by a more appropriate hotspot practice.

For a list of potential stormwater hotspots, please consult Appendix P.

On sites with existing contaminated soils, as indicated in Appendix P, infiltration is not allowed. Bioretention areas must include an impermeable liner, and the Enhanced Design configuration cannot be used.

No Irrigation or Baseflow. The planned bioretention area should not receive baseflow, irrigation water, chlorinated wash-water or any other flows not related to stormwater. However, irrigation is allowed during the establishment period of the bioretention area to ensure plant survival.

Setbacks. To avoid the risk of seepage, bioretention areas must not be hydraulically connected to structure foundations. Setbacks to structures must be at least 10 feet and adequate water-proofing protection must be provided for foundations and basements. Where the 10-foot setback is not possible, an impermeable liner may be used along the sides of the bioretention area (extending from the surface to the bottom of the practice).

Proximity to Utilities. Designers should ensure that future tree canopy growth in the bioretention area will not interfere with existing overhead utility lines. Interference with underground utilities should be avoided, if possible. When large site development is undertaken the expectation of achieving avoidance will be high. Conflicts may be commonplace on smaller sites and in the public right-of-way. Consult with each utility company on recommended offsets, which will allow utility maintenance work with minimal disturbance to the bioretention system. For bioretention in the public right-of-way a consolidated presentation of the various utility offset recommendations can be found in Chapter 33.14.5 of the District of Columbia Department of Transportation Design and Engineering Manual, latest edition. Consult the District of Columbia Water and Sewer Authority (DC Water) Green Infrastructure Utility Protection Guidelines, latest edition, for water and sewer line recommendations. Where conflicts cannot be avoided, follow these guidelines:

- Consider altering the location or sizing of the bioretention to avoid or minimize the utility conflict. Consider an alternate BMP type to avoid conflict.
- Use design features to mitigate the impacts of conflicts that may arise by allowing the bioretention and the utility to coexist. The bioretention design may need to incorporate impervious areas, through geotextiles or compaction, to protect utility crossings. Other a key design feature may need to be moved or added or deleted
- Work with the utility to evaluate the relocation of the existing utility and install the optimum placement and sizing of the bioretention.
- If utility functionality, longevity and vehicular access to manholes can be assured accept the bioretention design and location with the existing utility. Incorporate into the bioretention design sufficient soil coverage over the utility or general clearances or other features such as an impermeable linear to assure all entities the conflict is limited to maintenance.

Note: When accepting utility conflict into the bioretention location and design, it is understood the bioretention will be temporarily impacted during utility work but the utility will replace the bioretention or, alternatively, install a functionally comparable bioretention according to the specifications in the current version of this Stormwater Management Guidebook. If the bioretention is located in the public right-of-way the bioretention restoration will also conform with the District of Columbia Department of Transportation Design and Engineering Manual with special attention to Chapter 33, Chapter 47, and the Design and Engineering Manual supplements for Low Impact Development and Green Infrastructure Standards and Specifications.

Minimizing External Impacts. Urban bioretention practices may be subject to higher public visibility, greater trash loads, pedestrian traffic, vandalism, and even vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous vegetation. The urban landscape context may feature naturalized landscaping or a more formal design. When urban bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences, grates, or other measures to prevent damage from pedestrian short-cutting across the practices.

When bioretention will be included in public rights-of-way or spaces, design manuals and guidance developed by agencies or organizations other than DDOE may also apply (e.g., District Department of Transportation, Office of Planning, and National Capital Planning Commission).

3.6.2 Bioretention Conveyance Criteria

There are two basic design approaches for conveying runoff into, through, and around bioretention practices:

1. Off-line: Flow is split or diverted so that only the design storm or design flow enters the bioretention area. Larger flows bypass the bioretention treatment.
2. On-line: All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

If runoff is delivered by a storm drain pipe or is along the main conveyance system, the bioretention area shall be designed off-line so that flows to do not overwhelm or damage the practice.

Off-line Bioretention. Overflows are diverted from entering the bioretention cell. Optional diversion methods include the following:

- Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filters through the soil media. With this design configuration, an overflow structure in the bioretention area is not required.
- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design storm volume (i.e., the Stormwater Retention Volume (SWRv)) to enter the facility (calculations must be made to determine the peak flow from the 1.2-inch, 24-hour storm). This may be achieved with a weir, curb opening, or orifice for the target flow, in combination with a bypass channel or pipe. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. With this design configuration, an overflow structure in the bioretention area is required (see on-line bioretention below).

On-line Bioretention. An overflow structure must be incorporated into on-line designs to safely convey larger storms through the bioretention area. The following criteria apply to overflow structures:

- An overflow shall be provided within the practice to pass storms greater than the design storm storage to a stabilized water course. A portion of larger events may be managed by the bioretention area so long as the maximum depth of ponding in the bioretention cell does not exceed 18 inches.
- The overflow device must convey runoff to a storm sewer, stream, or the existing stormwater conveyance infrastructure, such as curb and gutter or an existing channel.

- Common overflow systems within bioretention practices consist of an inlet structure, where the top of the structure is placed at the maximum ponding depth of the bioretention area, which is typically 6 to 18 inches above the surface of the filter bed.
- The overflow device should be scaled to the application. This may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.
- At least 3–6 inches of freeboard must be provided between the top of the overflow device and the top of the bioretention area to ensure that nuisance flooding will not occur.
- The overflow associated with the 2-year and 15-year design storms must be controlled so that velocities are non-erosive at the outlet point, to prevent downstream erosion.

3.6.3 Bioretention Pretreatment Criteria

Pretreatment of runoff entering bioretention areas is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Pretreatment measures must be designed to evenly spread runoff across the entire width of the bioretention area. Several pretreatment measures are feasible, depending on the type of the bioretention practice and whether it receives sheet flow, shallow concentrated flow, or deeper concentrated flows. The following are appropriate pretreatment options:

Small-Scale Bioretention (B-2, B-3, B-4, and B-5)

- **Leaf Screens**. A leaf screen serves as part of the gutter system to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- **Pretreatment Cells** (for channel flow). Pretreatment cells are located above ground or covered by a manhole or grate. Pretreatment cells are atypical in small-scale bioretention and are not recommended for residential rain gardens (B-5).
- **Grass Filter Strips** (for sheet flow). Grass filter strips are applied on residential lots, where the lawn area can serve as a grass filter strip adjacent to a rain garden.
- **Stone Diaphragm** (for either sheet flow or concentrated flow). The stone diaphragm at the end of a downspout or other concentrated inflow point should run perpendicular to the flow path to promote settling.

  Note: stone diaphragms are not recommended for school settings.
- **Trash Racks** (for either sheet flow or concentrated flow).Trash racks are located between the pretreatment cell and the main filter bed or across curb cuts to allow trash to collect in specific locations and make maintenance easier.

Traditional Bioretention (B-1)

- **Pretreatment Cells** (for channel flow). Similar to a forebay, this cell is located at piped inlets or curb cuts leading to the bioretention area and consists of an energy dissipater sized for the expected rates of discharge. It has a storage volume equivalent to at least 15 percent of the total storage volume (inclusive) with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen or rock berm. Pretreatment cells do not need underlying engineered soil media, in contrast to the main bioretention cell. However, if the volume of the pretreatment cell will be included as part of the bioretention storage volume, the pretreatment cell must de-water between storm events. It cannot have a permanent ponded volume.

- **Grass Filter Strips** (for sheet flow). Grass filter strips that are perpendicular to incoming sheet flow extend from the edge of pavement, with a slight drop at the pavement edge, to the bottom of the bioretention basin at a 5:1 slope or flatter. Alternatively, if the bioretention basin has side slopes that are 3:1 or flatter, a 5-foot grass filter strip can be used at a maximum 5 percent (20:1) slope.
- **Stone Diaphragms** (for sheet flow). A stone diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pretreat lateral runoff, with a 2 to 4 inch drop from the pavement edge to the top of the stone. The stone must be sized according to the expected rate of discharge.
- **Gravel or Stone Flow Spreaders** (for concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel must extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin.
- **Filter System** (see Section 3.7 Stormwater Filtering Systems). If using a filter system as a pretreatment facility, the filter will not require a separate pretreatment facility.
- **Innovative or Proprietary Structure**. An approved proprietary structure with demonstrated capability of reducing sediment and hydrocarbons may be used to provide pretreatment. Refer to Section 3.13 Proprietary Practices for information on approved proprietary structures.

Other pretreatment options may be appropriate as long as they trap coarse sediment particles and evenly spread runoff across the entire width of the bioretention area.

3.6.4 Bioretention Design Criteria

Design Geometry. Bioretention basins must be designed with an internal flow path geometry such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited. In order for the bioretention area to have an acceptable internal geometry, the travel time from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible. In addition, incoming flow must be distributed as evenly as possible across the entire filter surface area.

Inlets and Energy Dissipation. Where appropriate, the inlet(s) to streetscape bioretention (B-2), engineered tree boxes (B-3), and stormwater planters (B-4) should be stabilized using No. 3 stone, splash block, river stone, or other acceptable energy dissipation measures. The following types of inlets are recommended:

- Downspouts to stone energy dissipaters.
- Sheet flow over a depressed curb with a 3-inch drop.
- Curb cuts allowing runoff into the bioretention area.

- Covered drains that convey flows across sidewalks from the curb or downspouts.
- Grates or trench drains that capture runoff from a sidewalk or plaza area.
- Drop structures that appropriately dissipate water energy.

Ponding Depth. The recommended surface ponding depth is 6–12 inches. Minimum surface ponding depth is 3 inches (averaged over the surface area of the BMP). Ponding depths can be increased to a maximum of 18 inches. However, when higher ponding depths are utilized, the design must consider carefully issues such as safety, fencing requirements, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. This is especially true where bioretention areas are built next to sidewalks or other areas were pedestrians or bicyclists travel. Shallower ponding depths (typically 6–12 inches) are recommended for streetscape bioretention (B-2), engineered tree boxes (B-3), and stormwater planters (B-4).

Side Slopes. Traditional bioretention areas (B-1) and residential rain gardens (B-5) should be constructed with side slopes of 3:1 or flatter. In highly urbanized or space constrained areas, a drop curb design or a precast structure can be used to create a stable, vertical side wall. These drop curb designs should not exceed a vertical drop of more than 12 inches, unless safety precautions, such as railings, walls, grates, etc. are included.

Filter Media. The filter media and surface cover are the two most important elements of a bioretention facility in terms of long-term performance.

- **Particle Size Composition.** The bioretention soil mixture shall be classified as a loamy sand on the USDA Texture Triangle, with the following particle size composition:
  - 80–90 percent sand (at least 75 percent of which must be classified as coarse or very coarse sand)
  - 10–20 percent soil fines (silt and clay)
  - Maximum 10 percent clay
  - The particle size analysis must be conducted on the mineral fraction only or following appropriate treatments to remove organic matter before particle size analysis.
- **Organic Matter.** The filter media must contain 3 to 5 percent organic matter by the conventional Walkley-Black soil organic matter determination method or similar analysis. Soil organic matter is expressed on a dry weight basis and does not include coarse particulate (visible) components.
- **Available Soil Phosphorus (P).** The filter media should contain sufficient available P to support initial plant establishment and growth, but not serve as a significant source of P for long-term leaching. Plant-available soil P should be within the range of Low+ (L+) to Medium (M) as defined in Table 2.2 of Virginia Nutrient Management Standards and Criteria (2005). For the Mehlich I extraction procedure this equates to a range of 5 to 15 mg/kg P or 18 to 40 mg/kg P for the Mehlich III procedure.
- **Cation Exchange Capacity (CEC).** The relative ability of soils to hold and retain nutrient cations like Ca and K is referred to as cation exchange capacity (CEC) and is measured as the total amount of positively charged cations that a soil can hold per unit dry mass. CEC is also

used as an index of overall soil reactivity and is commonly expressed in milliequivalents per 100 grams (meq/100g) of soil or cmol+/kg (equal values). A soil with a moderate to high CEC indicates a greater ability to capture and retain positively charged contaminants, which encourages conditions to remove phosphorus, assuming that soil fines (particularly fine silts and clays) are at least partially responsible for CEC. The minimum CEC of the filter media is 5.0 (meq/100 g or cmol+/kg). The filter media CEC should be determined by the Unbuffered Salt, Ammonium Acetate, Summation of Cations or Effective CEC techniques (Sumner and Miller, 1996) or similar methods that do not utilize strongly acidic extracting solutions.

The goal of the filter media mixture described in this section is to create a soil media that maintains long-term permeability while also providing enough nutrients to support plant growth. The initial permeability of the mixture will exceed the desired long-term permeability of 1 to 2 in./hr. The limited amount of topsoil and organic matter is considered adequate to help support initial plant growth, and it is anticipated that the gradual increase of organic material through natural processes will continue to support growth while gradually decreasing the permeability. Finally, the root structure of maturing plants and the biological activity of a self-sustaining organic content will maintain sufficient long-term permeability as well as support plant growth without the need to add fertilizer.

The following is the recommended composition of the three media ingredients:

- **Sand.** Sand shall consist of silica-based coarse aggregate, angular or round in shape and meet the mixture grain size distribution specified in Table 3.19. No substitutions of alternate materials (such as diabase, calcium carbonate, rock dust, or dolomitic sands) are accepted. In particular, mica can make up no more than 5 percent of the total sand fraction. The sand fraction may also contain a limited amount of particles greater than 2.0 mm and less than 9.5 mm per the table below, but the overall sand fraction must meet the specification containing greater than 75 percent coarse or very coarse sand. Consult Table 3.19 for recommended sand sizing criteria.

Table 3.19 Sand Sizing Criteria

Sieve Type	Particle Size (mm)	Percent Passing (%)
3/8 in.	9.50	100
No. 4	4.75	95– 100
No. 8	2.36	80– 100
No. 16	1.18	45– 85
No. 30	0.60	15– 60
No. 50	0.30	3– 15
No. 100	0.15	0– 4

Note: Effective particle size (D10) > 0.3mm. Uniformity coefficient (D60/D10) < 4.0.

- **Topsoil.** Topsoil is generally defined as the combination of the ingredients referenced in the bioretention filter media: sand, fines (silt and clay), and any associated soil organic matter. Since the objective of the specification is to carefully establish the proper blend of these ingredients, the designer (or contractor or materials supplier) must carefully select the topsoil source material in order to not exceed the amount of any one ingredient.

Generally, the use of a topsoil defined as a loamy sand, sandy loam, or loam (per the USDA Textural Triangle) will be an acceptable ingredient and in combination with the other ingredients meet the overall performance goal of the soil media.

- **Organic Matter.** Organic materials used in the soil media mix should consist of well-decomposed natural C-containing organic materials such as peat moss, humus, compost (consistent with the material specifications found in Appendix J), pine bark fines or other organic soil conditioning material. However, per above, the combined filter media should contain 3 to 5 percent soil organic matter on dry weight basis (grams organic matter per 100 grams dry soil) by the Walkley-Black method or other similar analytical technique.

  In creating the filter media, it is recommended to start with an open-graded coarse sand material and proportionately mix in the topsoil materials to achieve the desired ratio of sand and fines. Sufficient suitable organic amendments can then be added to achieve the 3 to 5 percent soil organic matter target. The exact composition of organic matter and topsoil material will vary, making the exact particle size distribution of the final total soil media mixture difficult to define in advance of evaluating available materials. Table 3.20 summarizes the filter media requirements.

Table 3.20 Filter Media Criteria for Bioretention

<table>
<tr><th>Soil Media Criterion</th><th>Description</th><th colspan="3">Standard(s)</th></tr>
<tr><td>General Composition</td><td>Soil media must have the proper proportions of sand, fines, and organic matter to promote plant growth, drain at the proper rate, and filter pollutants</td><td colspan="3">80% to 90% sand
(75% of which is coarse or very coarse);
10% to 20% soil fines;
maximum of 10% clay; and
3% to 5% organic matter</td></tr>
<tr><td rowspan="9">Sand</td><td rowspan="9">Silica based coarse aggregate[1]</td><td>Sieve Type</td><td>Particle Size (mm)</td><td>Percent Passing (%)</td></tr>
<tr><td>3/8 in.</td><td>9.50</td><td>100</td></tr>
<tr><td>No. 4</td><td>4.75</td><td>95–100</td></tr>
<tr><td>No. 8</td><td>2.36</td><td>80–100</td></tr>
<tr><td>No. 16</td><td>1.18</td><td>45–85</td></tr>
<tr><td>No. 30</td><td>0.6</td><td>15–60</td></tr>
<tr><td>No. 50</td><td>0.3</td><td>3–15</td></tr>
<tr><td>No. 100</td><td>0.15</td><td>0–4</td></tr>
<tr><td colspan="3">Effective Particle size (D10) > 0.3mm
Uniformity Coefficient (D60/D10) < 4.0</td></tr>
<tr><td>Top Soil</td><td>Loamy sand or sandy loam</td><td colspan="3">USDA Textural Triangle</td></tr>
<tr><td>Organic Matter</td><td>Well-aged, clean compost</td><td colspan="3">Appendix J</td></tr>
<tr><td>P-Index or Phosphorus (P) Content</td><td>Soil media with high P levels will export P through the media and potentially to downstream conveyances or receiving waters</td><td colspan="3">P content = 5 to 15 mg/kg (Mehlich I) or 18 to 40 mg/kg (Mehlich III)</td></tr>
<tr><td>Cation Exchange Capacity (CEC)</td><td>The CEC is determined by the amount of soil fines and organic matter. Higher CEC will promote pollutant removal</td><td colspan="3">CEC > 5 milliequivalents per 100 grams</td></tr>
</table>

[1]Many specifications for sand refer to ASTM C-33. The ASTM C-33 specification allows a particle size distribution that contains a large fraction of fines (silt and clay sized particles< 0.05 mm). The smaller fines fill the voids between the larger sand sized particles, resulting in smaller and more convoluted pore spaces. While this condition provides a high degree of treatment, it also encourages clogging of the remaining void spaces with suspended solids and biological growth, resulting in a greater chance of a restrictive biomat forming. By limiting the fine particles allowed in the sand component, the combined media recipe of sand and the fines associated with the soil and organic material will be less prone to clogging, while also providing an adequate level of filtration and retention.

In cases where greater removal of specific pollutants is desired, additives with documented pollutant removal benefits, such as water treatment residuals, alum, iron, or other materials may be included in the filter media if accepted by DDOE.

- **Filter Media Depth.** The filter media bed depth must be a minimum of 18 inches for the Standard Design. The media depth must be 24 inches or greater to qualify for the Enhanced Design, unless an infiltration-based design is used. The media depth must not exceed 6 feet. Turf, perennials, or shrubs should be used instead of trees to landscape shallower filter beds. See Table 3.23 and Table 3.24 for a list of recommended native plants.

During high intensity storm events, it is possible for the bioretention to fill up faster than the collected stormwater is able to filter through the soil media. This is dependent upon the surface area of the BMP (*SA*) relative to the contributing drainage area (CDA) and the runoff coefficient (*Rv*) from the CDA. To ensure that the design runoff volume is captured and filtered appropriately, a maximum filter media depth must not be exceeded (see Table 3.24). The maximum filter media depth is based on the runoff coefficient of the CDA to the BMP (Rv_{CDA}) and the bioretention ratio of BMP surface area to the BMP CDA (SA:CDA) (in percent). The applicable filter media depth from Table 3.21 should be used as d_{media} in Equation 3.5.

Table 3.21 Determining Maximum Filter Media Depth (feet)

*S*A:CDA (%)	RvCDA								
	0.25	**0.3**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**0.95**
0.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.0	5.0	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
1.5	3.5	4.0	5.0	6.0	6.0	6.0	6.0	6.0	6.0
2.0	2.5	3.0	4.0	5.0	5.5	6.0	6.0	6.0	6.0
2.5	2.0	2.5	3.5	4.0	4.5	5.0	5.5	6.0	6.0
3.0	1.5	2.0	3.0	3.5	4.0	4.5	5.0	5.5	5.5
3.5	1.5	1.5	2.5	3.0	3.5	4.0	4.5	5.0	5.0
4.0	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.5	4.5
4.5	1.5	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
5.0	1.5	1.5	1.5	2.0	2.5	3.0	3.5	4.0	4.0
5.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.5	3.5
6.0	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0	3.5
6.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	3.0	3.0
7.0	1.5	1.5	1.5	1.5	1.5	2.0	2.5	3.0	3.0
7.5	1.5	1.5	1.5	1.5	1.5	2.0	2.5	2.5	2.5
8.0	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5	2.5
8.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.5
9.0	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0
9.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0
10.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0	2.0

Surface Cover. Mulch is the recommended surface cover material, but other materials may be substituted, as described below:

- Mulch. A 2- to 3-inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, pretreats runoff before it reaches the filter media, and prevents rapid evaporation of rainwater. Shredded hardwood bark mulch, aged for at least 6 months, makes a very good surface cover, as it retains a significant amount of pollutants and typically will not float away.

- Alternative to Mulch Cover. In some situations, designers may consider alternative surface covers, such as turf, native groundcover, erosion control matting (e.g., coir or jute matting), river stone, or pea gravel. The decision regarding the type of surface cover to use should be based on function, expected pedestrian traffic, cost, and maintenance. When alternative surface covers are used, methods to discourage pedestrian traffic should be considered. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have low water-holding capacity.
- Media for Turf Cover. One adaptation suggested for use with turf cover is to design the filter media primarily as a sand filter with organic content only at the top. Compost, as specified in Appendix J, tilled into the top layers will provide organic content for the vegetative cover. If grass is the only vegetation, the ratio of organic matter in the filter media composition may be reduced.

Choking Layer. A 2 to 4 inch layer of choker stone (e.g., typically ASTM D448 No. 8 or No. 89 washed gravel) should be placed beneath the soil media and over the underdrain stone.

Geotextile. If the available head is limited, or the depth of the practice is a concern, geotextile fabric may be used in place of the choking layer. An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements, and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used. Geotextile fabric may be used on the sides of bioretention areas, as well.

Underdrains. Many bioretention designs will require an underdrain (see Section 3.6.1 Bioretention Feasibility Criteria). The underdrain should be a 4- or 6-inch perforated schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with 3/8-inch perforations at 6 inches on center. The underdrain must be encased in a layer of clean, double washed ASTM D448 No.57 or smaller (No. 68, 8, or 89) stone. The underdrain must be sized so that the bioretention BMP fully drains within 72 hours or less.

Multiple underdrains are necessary for bioretention areas wider than 40 feet, and each underdrain must be located no more than 20 feet from the next pipe or the edge of the bioretention. (For long and narrow applications, a single underdrain running the length of the bioretention is sufficient.)

All traditional bioretention practices must include at least one observation well and/or cleanout pipe (minimum 4 inches in diameter). The observation wells should be tied into any of the Ts or Ys in the underdrain system and must extend upward above the surface of the bioretention area.

Underground Storage Layer (optional). For bioretention systems with an underdrain, an underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer and underdrain to increase the infiltration sump volume or the storage for larger storm events. To qualify for the Enhanced Design, this storage layer must be designed to infiltrate in 72 hours, at ½ the measured infiltration rate. The may also be designed to provide detention for the 2-year, 15-year, or 100-year storms, as needed. The depth and volume of the storage layer will then depend on the target storage volumes needed to meet the applicable detention criteria.

Impermeable Liner. An impermeable liner is not typically required, although it may be utilized in fill applications where deemed necessary by a geotechnical investigation, on sites with contaminated soils, or on the sides of the practice to protect adjacent structures from seepage. Use a 30-mililiter (minimum) PVC geomembrane liner. (Follow manufacturer's instructions for installation.) Field seams must be sealed according to the liner manufacturer's specifications. A minimum 6-inch overlap of material is required at all seams.

Material Specifications. Recommended material specifications for bioretention areas are shown in Table 3.22.

Table 3.22 Bioretention Material Specifications

Material	Specification	Notes
Filter Media	▪ See Table 3.20	Minimum depth of 24 inches (18 inches for small-scale practices) To account for settling/compaction, it is recommended that 110% of the plan volume be utilized.
Mulch Layer	Use aged, shredded hardwood bark mulch	Lay a 2 to 3-inch layer on the surface of the filter bed.
Alternative Surface Cover	Use river stone or pea gravel, coir and jute matting, or turf cover.	Lay a 2 to 3-inch layer of to suppress weed growth.
Top Soil For Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%.	3-inch tilled into surface layer.
Geotextile or Choking Layer	An appropriate geotextile fabric that complies with AASHTO M-288 Class 2, latest edition, requirements and has a permeability of at least an order of magnitude higher (10x) than the soil subgrade permeability must be used	Can use in place of the choking layer where the depth of the practice is limited. Geotextile fabric may be used on the sides of bioretention areas, as well.
	Lay a 2 to 4 inch layer of choker stone (e.g., typically No.8 or No.89 washed gravel) over the underdrain stone.	
Underdrain stone	1-inch diameter stone must be double-washed and clean and free of all fines (e.g., ASTM D448 No. 57 or smaller stone).	At least 2 inches above and below the underdrain.
Storage Layer (optional)	To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer	
Impermeable Liner (optional)	Where appropriate, use a thirty mil (minimum) PVC Geomembrane liner	
Underdrains, Cleanouts, and Observation Wells	Use 4- or 6-inch rigid schedule 40 PVC pipe, or equivalent corrugated HDPE for small bioretention BMPs, with 3/8-inch perforations at 6 inches on center. Multiple underdrains are necessary for bioretention areas wider than 40 feet, and each underdrain must be located no more than 20 feet from the next pipe or the edge of the bioretention.	Lay the perforated pipe under the length of the bioretention cell, and install non-perforated pipe as needed to connect with the storm drain system or to daylight in a stabilized conveyance. Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface.

Material	Specification	Notes
Plant Materials	See Section 3.6.5 Bioretention Landscaping Criteria	Establish plant materials as specified in the landscaping plan and the recommended plant list.

Signage. Bioretention units in highly urbanized areas should be stenciled or otherwise permanently marked to designate it as a structural BMP. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

Specific Design Issues for Streetscape Bioretention (B-2). Streetscape bioretention is installed in the road right-of way either in the sidewalk area or in the road itself. In many cases, streetscape bioretention areas can also serve as a traffic calming or street parking control devices. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the right-of-way. Roadway stability can be a design issue where streetscape bioretention practices are installed. Designers should consult design standards pertaining to roadway drainage. It may be necessary to provide an impermeable liner on the road side of the bioretention area to keep water from saturating the road's sub-base.

Specific Design Issues for Engineered Tree Boxes (B-3). Engineered tree boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree pit is increased and used to capture and treat stormwater. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

When designing engineered tree boxes, the following criteria must be considered:

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Engineered tree box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing an engineered tree pit grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree pit bed and serve as a protective barrier if there is a drop-off from the pavement to the micro-bioretention cell.
- A removable grate may be used to allow the tree to grow through it.
- Each tree needs a minimum rootable soil volume as described in Section 3.14.

Specific Design Issues for Stormwater Planters (B-4). Stormwater planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. They consist of confined planters that store and/or infiltrate runoff in a soil bed to reduce runoff volumes and pollutant loads. Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation. The two basic design variations for stormwater planters are the infiltration planter and the filter planter. A filter planter is illustrated in Figure 3.2 below.

An infiltration planter filters rooftop runoff through soil in the planter followed by infiltration into soils below the planter. The minimum filter media depth is 18 inches, with the shape and length determined by architectural considerations. Infiltration planters should be placed at least 10 feet away from a building to prevent possible flooding or basement seepage damage.

A filter planter does not allow for infiltration and is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage. Since a filter planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building. The minimum filter media depth is 18 inches, with the shape and length determined by architectural considerations. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded, to avoid water spilling over the side of the planter. In addition, an underdrain is used to carry runoff to the storm sewer system.

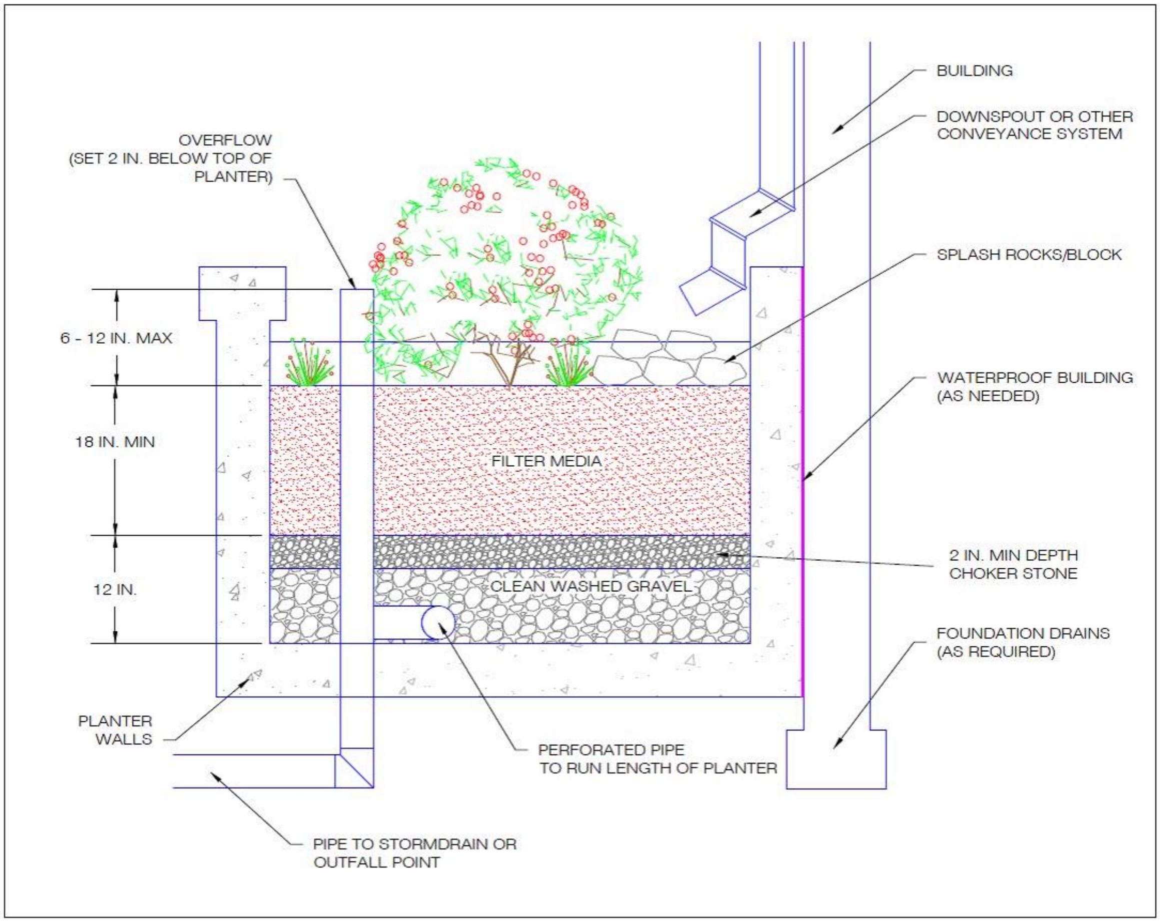

Figure 3.20 Example of a stormwater planter (B-4).

All planters should be placed at grade level or above ground. Plant materials must be capable of withstanding moist and seasonally dry conditions. The sand and gravel on the bottom of the planter should have a minimum infiltration rate of 5 inches per hour. The planter can be constructed of stone, concrete, brick, wood, or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter.

Specific Design Issues for Residential Rain Gardens (B-5). For some residential applications, front, side, and/or rear yard bioretention may be an attractive option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium- density residential lots in a depressed area (i.e., 6 to 12 inches) between the home and the primary stormwater conveyance system (i.e., roadside ditch or pipe system). The bioretention area connects to the drainage system with an underdrain.

The bioretention filter media must be at least 18 inches deep. The underdrain is directly connected into the storm drain pipe running underneath the street or in the street right-of-way. A trench needs to be excavated during construction to connect the underdrain to the street storm drain system.

Construction of the remainder of the bioretention system is deferred until after the lot has been stabilized. Residential rain gardens require regular maintenance to perform effectively.

BMP Sizing. Bioretention is typically sized to capture the SWRv or larger design storm volumes in the surface ponding area, soil media, and gravel reservoir layers of the BMP.

Total storage volume of the BMP is calculated using Equation 3.5.

Equation 3.5 Bioretention Storage Volume

$$Sv = SA_{bottom} \times [(d_{media} \times \eta_{media}) + (d_{gravel} \times \eta_{gravel})] + (SA_{average} \times d_{ponding})$$

where:

Sv	=	total storage volume of bioretention (ft^3)
SA_{bottom}	=	bottom surface area of bioretention (ft^2)
d_{media}	=	depth of the filter media (ft)
η_{media}	=	effective porosity of the filter media (typically 0.25)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer (ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
$SA_{average}$	=	average surface area of bioretention (ft^2) typically, where SA_{top} is the top surface area of bioretention, $SA_{average} = \frac{SA_{bottom} + SA_{top}}{2}$
$d_{ponding}$	=	maximum ponding depth of bioretention (ft)

Equation 3.5 can be modified if the storage depths of the filter media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the bioretention must not exceed 18 inches. If storage practices will be provided off-line or in series with the bioretention area, the storage practices should be sized using the guidance in Section 3.12.

Bioretention can be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The *Sv* can be counted as part of the 2-year or 15-year runoff volumes to satisfy stormwater quantity control requirements. At least 3–6 inches of freeboard are required between the top of the overflow device and the top of the bioretention area when bioretention is used as detention storage for 2-year and 15-year storms.

Note: In order to increase the storage volume of a bioretention area, the ponding surface area may be increased beyond the filter media surface area. However, the top surface area of the practice (i.e., at the top of the ponding elevation) may not be more than twice the size of the surface area of the filter media (SA_{bottom}).

3.6.5 Bioretention Landscaping Criteria

Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan shall be provided for bioretention areas.

Minimum plan elements include the proposed bioretention template to be used, delineation of planting areas, and the planting plan including the following:

- Common and botanical names of the plants used
- Size of planted materials
- Mature size of the plants
- Light requirements
- Maintenance requirements
- Source of planting stock
- Any other specifications
- Planting sequence

It is recommended that the planting plan be prepared by a qualified landscape architect professional (e.g. licensed professional landscape architect, certified horticulturalist) in order to tailor the planting plan to the site-specific conditions.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. Some popular native species that work well in bioretention areas and are commercially available can be found in Table 3.23 and Table 3.24. Internet links to more detailed bioretention plant lists developed in the Chesapeake Bay region are provided below:

- Prince Georges County, MD
  http://www.aacounty.org/DPW/Highways/Resources/Raingarden/RG_Bioretention_PG%20CO.pdf
- Delaware Green Technology Standards and Specifications
  http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20&%20Specs_06-05.pdf

The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model where the turf is mowed along with other turf areas on the site. Spaces for herbaceous flowering plants can be included.

Table 3.23 Herbaceous Plants Appropriate for Bioretention Areas in the District

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Aster, New York (*Aster novi-belgii*)	Full Sun-Part Shade	FACW+	Perennial	Yes	Attractive flowers; tolerates poor soils
Aster, New England (*Aster novae-angliae*)	Full Sun-Part Shade	FACW	Perennial	Yes	Attractive flowers
Aster, Perennial Saltmarsh (*Aster tenuifolius*)	Full Sun-Part Shade	OBL	Perennial	Yes	Salt tolerant
Coreopsis, Threadleaf (*Coreopsis verticillata*)	Full Sun-Part Shade	FAC	Perennial	No	Drought tolerant
Beardtongue (*Penstemon digitalis*)	Full Sun	FAC	Perennial	No	Tolerates poor drainage
Beebalm (*Monarda didyma*)	Full Sun-Part Shade	FAC+	Perennial	Saturated	Herbal uses; attractive flower
Black-Eyed Susan (*Rudbeckia hirta*)	Full Sun-Part Shade	FACU	Perennial	No	Common; Maryland state flower
Bluebells, Virginia (*Mertensia virginica*)	Part Shade-Full Shade	FACW	Perennial	Yes	Attractive flower; dormant in summer
Blueflag,Virginia (*Iris virginica*)	Full Sun-Part Shade	OBL	Perennial	Yes	Tolerates standing water
Bluestem, Big (*Andropogon gerardii*)	Full Sun	FAC	Grass	No	Attractive in winter; forms clumps
Bluestem, Little (*Schizachyrium scoparium*)	Full Sun	FACU	Grass	No	Tolerates poor soil conditions
Broom-Sedge (Andropogon virginicus)	Full Sun	FACU	Grass	No	Drought tolerant; attractive fall color
Cardinal Flower (*Lobelia cardinalis*)	Full Sun-Part Shade	FACW+	Perennial	Yes	Long boom time
Fern, New York (*Thelypteris noveboracensis*)	Part Shade-Full Shade	FAC	Fern	Saturated	Drought tolerant; spreads
Fern, Royal (*Osmunda regalis*)	Full Sun-Full Shade	OBL	Fern	Saturated	Tolerates short term flooding; drought tolerant
Fescue, Red (*Festuca rubra*)	Full Sun-Full Shade	FACU	Ground-cover	No	Moderate growth; good for erosion control
Iris, Blue Water (*Iris versicolor*)	Full Sun-Part Shade	OBL	Perennial	0-6"	Spreads
Lobelia, Great Blue (*Lobelia siphilitica*)	Part Shade-Full Shade	FACW+	Perennial	Yes	Blooms in late summer; bright blue flowers
Phlox, Meadow (*Phlox maculata*)	Full Sun	FACW	Perennial	Yes	Aromatic; spreads
Sea-Oats (*Uniola paniculata*)	Full Sun	FACU-	Grass	No	Salt tolerant; attractive seed heads
Swamp Milkweed (*Asclepias incarnata*)	Full Sun-Part Shade	OBL	Perennial	Saturated	Drought tolerant
Switchgrass (*Panicum virgatum*)	Full Sun	FAC	Grass	Seasonal	Adaptable; great erosion control

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Turtlehead, White (*Chelone glabra*)	Full Sun-Part Shade	OBL	Perennial	Yes	Excellent growth; herbal uses
Violet, Common Blue (*Viola papilionacea*)	Full Sun-Full Shade	FAC	Perennial	No	Stemless; spreads
Virginia Wild Rye (*Elymus virginicus*)	Part Shade-Full Shade	FACW-	Grass	Yes	Adaptable

[1]Notes:
FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

Sources: Prince George's County Maryland Bioretention Manual; Virginia DCR Stormwater Design Specification No. 9: Bioretention.

Table 3.24 Woody Plants Appropriate for Bioretention Areas in the District

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Arrow-wood *(Viburnum dentatum)*	Full Sun-Part Shade	FAC	Shrub	Seasonal	Salt tolerant
River Birch *(Betula nigra)*	Full Sun-Part Shade	FACW	Tree	Seasonal	Attractive bark
Bayberry, Northern *(Myrica pennsylvanica)*	Full Sun-Part Shade	FAC	Shrub	Seasonal	Salt tolerant
Black Gum *(Nyssa sylvatica)*	Full Sun-Part Shade	FACW+	Tree	Seasonal	Excellent fall color
Dwarf Azalea *(Rhododendron atlanticum)*	Part Shade	FAC	Shrub	Yes	Long lived
Black-Haw *(Viburnum prunifolium)*	Part Shade-Full Shade	FACU+	Shrub	Yes	Edible Fruit
Choke Cherry *(Prunus virginiana)*	Full Sun	FACU+	Shrub	Yes	Tolerates some salt; can be maintained as hedge
Cedar, Eastern Red *(Juniperus virginiana)*	Full Sun	FACU	Tree	No	Pollution tolerant
Cotton-wood, Eastern *(Populus deltoides)*	Full Sun	FAC	Tree	Seasonal	Pollutant tolerant; salt tolerant
Silky Dogwood *(Cornus amomum)*	Full Sun-Part Shade	FACW	Shrub	Seasonal	High wildlife value
Hackberry, Common *(Celtis occidentalis)*	Full Sun-Full Shade	FACU	Tree	Seasonal	Pollution Tolerant
Hazelnut, American *(Corylus americana)*	Part Shade	FACU	Shrub	No	Forms thickets; edible nut
Holly, Winterberry *(Ilex laevigata)*	Full Sun-Part Shade	OBL	Shrub	Yes	Winter food source for birds

Plant	Light	Wetland Indicator[1]	Plant Form	Inundation Tolerance	Notes
Holly, American *(Ilex opaca)*	Full Sun-Full Shade	FACU	Shrub-Tree	Limited	Pollution Tolerant
Maple, Red *(Acer rubrum)*	Full Sun-Part Shade	FAC	Tree	Seasonal	Very adaptable; early spring flowers
Ninebark, Eastern *(Physocarpus opulifolius)*	Full Sun-Part Shade	FACW-	Shrub	Yes	Drought tolerant; attractive bark
Oak, Pin *(Quercus palustris)*	Full Sun	FACW	Tree	Yes	Pollution Tolerant
Pepperbush, Sweet *(Clethra alnifolia)*	Part Shade-Full Shade	FAC+	Shrub	Seasonal	Salt tolerant
Winterberry, Common *(Ilex verticillata)*	Full Sun-Full Shade	FACW+	Shrub	Seasonal	Winter food source for birds
Witch-Hazel, American *(Hamamelia virginiana)*	Part Shade-Full Shade	FAC-	Shrub	No	Pollution tolerant

[1]Notes:
FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
FACW = FACW Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

Sources: Prince George's County Maryland Bioretention Manual; Virginia DCR Stormwater Design Specification No. 9: Bioretention

Planting recommendations for bioretention facilities are as follows:

- The primary objective of the planting plan is to cover as much of the surface areas of the filter bed as quickly as possible. Herbaceous or ground cover layers are as or more important than more widely spaced trees and shrubs.
- Native plant species should be specified over non-native species.
- Plants should be selected based on a specified zone of hydric tolerance and must be capable of surviving both wet and dry conditions ("Wet footed" species should be planted near the center, whereas upland species do better planted near the edge).
- Woody vegetation should not be located at points of inflow; trees should not be planted directly above underdrains but should be located closer to the perimeter.
- Shrubs and herbaceous vegetation should generally be planted in clusters and at higher densities (i.e., 10 feet on-center and 1 to 1.5 feet on-center, respectively).
- If trees are part of the planting plan, a tree density of approximately one tree per 250 square feet (i.e., 15 feet on-center) is recommended.
- Designers should also remember that planting holes for trees must be at least 3 feet deep to provide enough soil volume for the root structure of mature trees. This applies even if the remaining soil media layer is shallower than 3 feet.

- Tree species should be those that are known to survive well in the compacted soils and the polluted air and water of an urban landscape.
- If trees are used, plant shade-tolerant ground covers within the drip line.
- If the bioretention area is to be used for snow storage or is to accept snowmelt runoff, it should be planted with salt-tolerant, herbaceous perennials.

3.6.6 Bioretention Construction Sequence

Soil Erosion and Sediment Controls. The following soil erosion and sediment control guidelines must be followed during construction:

- All Bioretention areas must be fully protected by silt fence or construction fencing.
- Bioretention areas intended to infiltrate runoff must remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment and loss of design infiltration rate.
    - Where it is infeasible keep the proposed bioretention areas outside of the limits of disturbance, there are several possible outcomes for the impacted area. If excavation in the proposed bioretention area can be restricted then the remediation can be achieved with deep tilling practices. This is only possible if in-situ soils are not disturbed any deeper than 2 feet above the final design elevation of the bottom of the bioretention. In this case, when heavy equipment activity has ceased, the area is excavated to grade, and the impacted area must be tilled to a depth of 12 inches below the bottom of the bioretention.
    - Alternatively, if it is infeasible to keep the proposed permeable pavement areas outside of the limits of disturbance, and excavation of the area cannot be restricted, then infiltration tests will be required prior to installation of the bioretention to ensure that the design infiltration rate is still present. If tests reveal the loss of design infiltration rates then deep tilling practices may be used in an effort to restore those rates. In this case further testing must be done to establish design rates exist before the permeable pavement can be installed.
    - Finally, if it is infeasible to keep the proposed bioretention areas outside of the limits of disturbance, and excavation of the area cannot be restricted, and infiltration tests reveal design rates cannot be restored, then a resubmission of the SWMP will be required.
- Bioretention areas must be clearly marked on all construction documents and grading plans.
- Large bioretention applications may be used as small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the soil erosion and sediment control plan specifying that (1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the post-construction (final) invert (bottom of the facility), and (2) the facility must contain an underdrain. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent bioretention BMP, including dewatering, cleanout, and stabilization.

Bioretention Installation. The following is a typical construction sequence to properly install a bioretention basin. The construction sequence for micro-bioretention is more simplified. These steps may be modified to reflect different bioretention applications or expected site conditions:

Step 1: **Stabilize Drainage Area.** Construction of the bioretention area may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

Step 2: **Preconstruction Meeting.** The designer, the installer, and DDOE inspector must have a preconstruction meeting, checking the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed bioretention area. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the inspector. Material certifications for aggregate, soil media and any geotextiles must be submitted for approval to the inspector at the preconstruction meeting.

Step 3: **Install Soil Erosion and Sediment Control Measures to Protect the Bioretention.** Temporary soil erosion and sediment controls (e.g., diversion dikes, reinforced silt fences) are needed during construction of the bioretention area to divert stormwater away from the bioretention area until it is completed. Special protection measures, such as erosion control fabrics, may be needed to protect vulnerable side slopes from erosion during the construction process.

Step 4: **Install Pretreatment Cells.** Any pretreatment cells should be excavated first and then sealed to trap sediment.

Step 5: **Avoid Impact of Heavy Installation Equipment.** Excavators or backhoes should work from the sides to excavate the bioretention area to its appropriate design depth and dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the bioretention area. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500- to 1,000-square foot temporary cells with a 10- to15-foot earth bridge in between, so that cells can be excavated from the side.

Step 6: **Promote Infiltration Rate.** It may be necessary to rip the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

Step 7: **Order of Materials.** If using a geotextile fabric, place the fabric on the sides of the bioretention area with a 6-inch overlap on the sides. If a stone storage layer will be used, place the appropriate depth of No. 57 stone (clean double washed) on the bottom, install the perforated underdrain pipe, pack No. 57 stone to 3 inches above the underdrain pipe, and add the choking layer or appropriate geotextile layer as a filter between the underdrain and the soil media layer. If no stone storage layer is used, start with 6 inches of No. 57 stone on the bottom and proceed with the layering as described above.

Step 8: **Layered Installation of Media**. Apply the media in 12-inch lifts until the desired top elevation of the bioretention area is achieved. Wait a few days to check for settlement and add additional media, as needed, to achieve the design elevation.

Note: The batch receipt confirming the source of the soil media must be submitted to the DDOE inspector.

Step 9: **Prepare Filter Media for Plants.** Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10: **Planting.** Install the plant materials as shown in the landscaping plan, and water them as needed.

Step 11: **Secure Surface Area.** Place the surface cover (i.e., mulch, river stone, or turf) in both cells, depending on the design. If coir or jute matting will be used in lieu of mulch, the matting will need to be installed prior to planting (Step 10), and holes or slits will have to be cut in the matting to install the plants.

Step 12: **Inflows.** If curb cuts or inlets are blocked during bioretention installation, unblock these after the drainage area and side slopes have good vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the drainage area includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

Step 13: **Final Inspection.** Conduct the final construction inspection using a qualified professional, providing DDOE with an as-built, then log the GPS coordinates for each bioretention facility, and submit them for entry into the maintenance tracking database.

Construction Supervision. Supervision during construction is recommended to ensure that the bioretention area is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists that include sign-offs at critical stages of construction, to ensure that the contractor’s interpretation of the plan is consistent with the designer’s intentions.

DDOE’s construction phase inspection checklist can be found in Appendix K.

3.6.7 Bioretention Maintenance Criteria

When bioretention practices are installed, it is the owner’s responsibility to ensure they, or those managing the practice, (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance covenant or agreement, as described below.

Maintenance of bioretention areas should be integrated into routine landscape maintenance tasks. If landscaping contractors will be expected to perform maintenance, their contracts should contain specifics on unique bioretention landscaping needs, such as maintaining elevation differences needed for ponding, proper mulching, sediment and trash removal, and limited use of fertilizers and pesticides.

Maintenance tasks and frequency will vary depending on the size and location of the bioretention, the landscaping template chosen, and the type of surface cover in the practice. A generalized summary of common maintenance tasks and their frequency is provided in Table 3.25.

Table 3.25 Typical Maintenance Tasks for Bioretention Practices

Frequency	Maintenance Tasks
Upon establishment	▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization. ▪ Inspectors should look for bare or eroding areas in the contributing drainage area or around the bioretention area, and make sure they are immediately stabilized with grass cover. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Watering is needed once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall. ▪ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.
At least 4 times per year	▪ Mow grass filter strips and bioretention with turf cover ▪ Check curb cuts and inlets for accumulated grit, leaves, and debris that may block inflow
Twice during growing season	▪ Spot weed, remove trash, and rake the mulch
Annually	▪ Conduct a maintenance inspection ▪ Supplement mulch in devoid areas to maintain a 3 inch layer ▪ Prune trees and shrubs ▪ Remove sediment in pretreatment cells and inflow points
Once every 2–3 years	▪ Remove sediment in pretreatment cells and inflow points ▪ Remove and replace the mulch layer
As needed	▪ Add reinforcement planting to maintain desired vegetation density ▪ Remove invasive plants using recommended control methods ▪ Remove any dead or diseased plants ▪ Stabilize the contributing drainage area to prevent erosion

Standing water is the most common problem outside of routine maintenance. If water remains on the surface for more than 72 hours after a storm, adjustments to the grading may be needed or underdrain repairs may be needed. The surface of the filter bed should also be checked for accumulated sediment or a fine crust that builds up after the first several storm events. There are several methods that can be used to rehabilitate the filter. These are listed below, starting with the simplest approach and ranging to more involved procedures (i.e., if the simpler actions do not solve the problem):

- Open the underdrain observation well or cleanout and pour in water to verify that the underdrains are functioning and not clogged or otherwise in need of repair. The purpose of this check is to see if there is standing water all the way down through the soil. If there is standing water on top, but not in the underdrain, then there is a clogged soil layer. If the underdrain and stand pipe indicates standing water, then the underdrain must be clogged and will need to be cleaned out.
- Remove accumulated sediment and till 2 to 3 inches of sand into the upper 6 to 12 inches of soil.

- Install sand wicks from 3 inches below the surface to the underdrain layer. This reduces the average concentration of fines in the media bed and promotes quicker drawdown times. Sand wicks can be installed by excavating or auguring (i.e., using a tree auger or similar tool) down to the top of the underdrain layer to create vertical columns which are then filled with a clean open-graded coarse sand material (e.g., ASTM C-33 concrete sand or similar approved sand mix for bioretention media). A sufficient number of wick drains of sufficient dimension should be installed to meet the design dewatering time for the facility.
- Remove and replace some or all of the soil media.

Maintenance Inspections. It is recommended that a qualified professional conduct a spring maintenance inspection and cleanup at each bioretention area. Maintenance inspections should include information about the inlets, the actual bioretention facility (sediment buildup, outlet conditions, etc.), and the state of vegetation (water stressed, dead, etc.) and are intended to highlight any issues that need or may need attention to maintain stormwater management functionality.

DDOE’s maintenance inspection checklists for bioretention areas and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner’s primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in Exhibit C of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.6.8 Bioretention Stormwater Compliance Calculations

Bioretention performance varies depending on the design configuration of the system.

Enhanced Designs. These designs are bioretention applications with no underdrain or at least 24 inches of filter media and an infiltration sump. Enhanced designs receive 100 percent retention value for the amount of storage volume (Sv) provided by the practice (Table 3.26), and, therefore, are not considered an accepted total suspended solids (TSS) treatment practice.

Table 3.26 Enhanced Bioretention Retention Value and Pollutant Removal

Retention Value	= *Sv*
Accepted TSS Treatment Practice	N/A

Standard Designs. These designs are bioretention applications with an underdrain and less than 24 inches of filter media. Standard designs receive 60 percent retention value and are an accepted TSS removal practice for the amount of storage volume (Sv) provided by the practice (Table 3.27).

Table 3.27 Standard Bioretention Design Retention Value and Pollutant Removal

Retention Value	= 0.6 × *Sv*
Accepted TSS Treatment Practice	Yes

The practice must be sized using the guidance detailed in Section 3.6.4.

Note: Additional retention value can be achieved if trees are utilized as part of a bioretention area (see Section 3.2.3 Green Roof Pretreatment Criteria).

Bioretention also contributes to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the Sv or Rv from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service (NRCS) Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.6.9 References

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2013 Stormwater Management Rule and Guidebook

Section 3.14

Tree Planting and Reservation

3.14 Tree Planting and Preservation

Definition. Existing trees can be preserved or new trees can be planted to reduce stormwater runoff.

Tree canopy can intercept a significant amount of rainfall before it becomes runoff, particularly if the tree canopy covers impervious surface, such as in the case of street trees. Through the processes of evapotranspiration and nutrient uptake, trees located on a development site have the capacity to reduce stormwater runoff volumes and improve water quality. Further, through root growth, trees can improve the infiltration capacity of the soils in which they grow.

Both tree planting and tree preservation can contribute to stormwater management on a site.

3.14.1 Preserving Existing Trees During Construction

The preferred method for increasing tree cover at a development site is to preserve existing trees during construction, particularly where mature trees are present. Existing trees are preserved during construction through a four-step process:

Step 1: Inventory existing trees.

Step 2: Identify trees to preserve.

Step 3: Protect trees and soil during construction.

Step 4: Protect trees after construction.

Inventory Existing Trees. A licensed forester or arborist must conduct an inventory of existing trees and forested areas at the development site before any site design, clearing, or construction takes place, as specified by the Urban Forestry Administration (UFA).

The inventory must include a survey of existing trees and determine their size, species, condition, and ecological value. Locations of trees and forest stands must be recorded.

Identify Trees to Preserve. From the tree inventory, individual trees can be identified for preservation and protection during site development. In order to receive retention value, preserved trees must be a species with an average mature spread of at least 35 feet. Additional selection criteria may include tree species, size, condition, and location (Table 3.52).

Table 3.52 Selecting Priority Trees and Forests for Preservation

Selection Criteria for Tree Preservation	Examples of Priority Tree and Forests to Conserve
Species	▪ Rare, threatened, or endangered species ▪ Specimen trees ▪ High quality tree species (e.g., white oaks and sycamores because they are structurally strong and live longer than trees such as silver maple and cottonwood) ▪ Species that are tolerant of specific site conditions and soils
Size	▪ Trees over a specified diameter at breast height (d.b.h.) or other size measurement ▪ Trees designated as national, state, or local champions ▪ Contiguous forest stands of a specified minimum area
Condition	▪ Healthy trees that are structurally sound ▪ High quality forest stands with high forest structural diversity
Location	▪ Trees located where they will provide direct benefits at the site (e.g., shading, privacy, windbreak, buffer from adjacent land use) ▪ Forest stands that are connected to off-site forests that create wildlife habitat and corridors ▪ Trees located in protected natural areas such as floodplains, stream buffers, wetlands, erodible soils, critical habitat areas, and steep slopes. ▪ Forest stands that are connected to off-site non-forested natural areas or protected land (e.g., has potential to provide wildlife habitat)

Trees selected for preservation and protection must be clearly marked both on construction drawings and at the actual site. Flagging or fencing is typically used to protect trees at the construction site. Areas of trees to preserve should be marked on the site map and walked during preconstruction meetings.

Protect Trees and Soil During Construction. Physical barriers must be properly installed around the Critical Root Zone (CRZ) of trees to be preserved. The CRZ shall be determined by a licensed forester or ISA certified arborist, and in general includes a circular area with a radius (in feet) equal to 15 times the diameter of the trunk (in inches). The barriers must be maintained and enforced throughout the construction process. Tree protection barriers include highly visible, well-anchored temporary protection devices, such as 4-foot fencing, blaze orange plastic mesh fencing, or snow fencing (Greenfeld and others, 1991).

All protection devices must remain in place throughout construction

When excavation is proposed immediately adjacent to the CRZ, roots must first be pruned at the edge of the excavation with a trenching machine, vibratory knife or rock saw to a depth of 18 inches.

Protect Trees After Construction. Maintenance covenants, as described below, are required to ensure that preserved trees are protected.

3.14.2 Planting Trees

Considerations at Development Sites. New development sites provide many opportunities to plant new trees. Planting trees at development sites is done in three steps:

Step 1: Select tree species.

Step 2: Evaluate and improve planting sites.

Step 3: Plant and maintain trees.

Tree Species. In order to receive retention value, the tree species planted must have an average mature spread of at least 35 feet. Trees to be planted must be container grown, or ball and burlap, and have a minimum caliper size of 1.5 inches. Bare root trees or seedlings do not qualify for retention value.

Planting Sites. Ideal planting sites within a development are those that create interception opportunities around impervious surfaces. These include areas along pathways, roads, islands and median strips, and parking lot interiors and perimeters. Other areas of a development site may benefit from planting trees (including stream valleys and floodplains, areas adjacent to existing forest, steep slopes, and portions of the site where trees would provide buffers, screening, noise reduction, or shading).

It is important to evaluate and record the conditions, such as soil type, soil pH, soil compaction, and the hydrology of proposed planting sites to ensure they are suitable for planting. These evaluations provide a basis for species selection and determination of the need for any special site preparation techniques.

A minimum of 1,500 cubic feet of rootable soil volume must be provided per tree. In planting arrangements that allow for shared rooting space amongst multiple trees, a minimum of 1,000 cubic feet of rootable soil volume must be provided for each tree. Rootable soil volume must be within 3 feet of the surface.

Site characteristics determine what tree species will flourish there and whether any of the conditions, such as soils, can be improved through the addition of compost or other amendments. Table 3.53 presents methods for addressing common constraints to urban tree planting.

Table 3.53 Methods for Addressing Urban Planting Constraints

Potential Impact	Potential Resolution
Limited Soil Volume	▪ Provide 1,500 cubic feet of rootable soil volume per tree ▪ Use planting arrangements that allow shared rooting space. A minimum of 1.000 cubic feet of rootable soil volume must be provided for each tree in shared rooting space arrangements. ▪ Provide 1500 cubic feet of rootable soil volume per tree (this soil must be within 3 feet of the surface)
Poor Soil Quality	▪ Test soil and perform appropriate restoration ▪ Select species tolerant of soil pH, compaction, drainage, etc. ▪ Replace very poor soils if necessary
Air Pollution	Select species tolerant of air pollutants
Damage from Lawnmowers	Use mulch to protect trees
Damage from Vandalism	▪ Use tree cages or benches to protect trees ▪ Select species with inconspicuous bark or thorns ▪ Install lighting nearby to discourage vandalism
Damage from Vehicles	Provide adequate setbacks between vehicle parking stalls and trees
Damage from animals such as deer, rodents, rabbits, and other herbivores	Use protective fencing or chemical retardants
Exposure to pollutants in stormwater and snowmelt runoff	Select species that are tolerant of specific pollutants, such as salt and metals
Soil moisture extremes	▪ Select species that are tolerant of inundation or drought ▪ Install underdrains if necessary ▪ Select appropriate backfill soil and mix thoroughly with site soil ▪ Improve soil drainage with amendments and tillage if needed
Increased temperature	Select drought tolerant species
Increased wind	Select drought tolerant species
Abundant populations of invasive species	▪ Control invasive species prior to planting ▪ Continually monitor for and remove invasive species
Conflict with infrastructure	▪ Design the site to keep trees and infrastructure separate ▪ Provide appropriate setbacks from infrastructure ▪ Select appropriate species for planting near infrastructure ▪ Use alternative materials to reduce conflict
Disease or insect infestation	Select resistant species

Planting trees at development sites requires prudent species selection, a maintenance plan, and careful planning to avoid impacts from nearby infrastructure, runoff, vehicles or other urban elements.

Trees Along Streets and in Parking Lots. When considering a location for planting clear lines of sight must be provided, as well as safe travel surfaces, and overhead clearance for pedestrians and vehicles. Also, ensure enough future soil volume for healthy tree growth. At least two cubic feet of useable soil per square foot of average mature tree canopy is required. (Useable soil must be uncompacted, and may not be covered by impervious material). Having at least a 6-foot wide planting strip or locating sidewalks between the trees and street allows more rooting space for trees in adjacent property.

Select tree species that are drought tolerant, can grow in poor or compacted soils, and are tolerant to typical urban pollutants (oil and grease, metals, and chlorides). Additionally, select species that do not produce excessive fruits, nuts, or leaf litter, that have fall color, spring flowers or some other aesthetic benefit, and can be limbed up to 6 feet to provide pedestrian and vehicle traffic underneath. The District Department of Transportation, Urban Forestry Administration (DDOT UFA) provides guidance on preferred street tree species based on neighborhoods.

Planting Techniques. Prepare a hole no deeper than the root ball or mass but two to three times wider than the spread of the root ball or mass. The majority of the roots on a newly planted tree will develop in the top 12 inches of soil and spread out laterally. There are some additional considerations depending on the type of plant material being used (Table 3.54).

Table 3.54 Tree Planting Techniques

Plant Material	Planting Technique	Planting Season
Container grown	Hand plant or use mechanical planting tools (e.g., auger)	Spring or fall, summer if irrigated
Balled and burlapped	Use backhoe (or other specialized equipment) or hand plant	Spring or fall

Sources: Palone and Todd (1998), WSAHGP (2002)

One of the most important planting guidelines is too make sure the tree is not planted too deeply. The root collar, the lowest few inches of trunk just above its junction with the roots (often indicated by a flare), should be exposed (Flott, 2004). Trees planted too deeply have buried root collars, and are weakened, stressed, and predisposed to pests and disease (Flott, 2004). Trees planted too deeply can also form adventitious roots near the soil surface in an attempt to compensate for the lack of oxygen available to buried roots. Adventitious roots are not usually large enough to provide support for a large tree and may eventually lead to collapse (Flott, 2004). ISA (2005) provides additional guidance on how to avoid planting too deeply. It is generally better to plant the tree a little high, that is, with the base of the trunk flare 2 to 3 inches above the soil, rather than at or below the original growing level (ISA, 2003b).

Proper handling during planting is essential to avoid prolonged transplant shock and ensure a healthy future for new trees and shrubs. Trees should always be handled by the root ball or container, never by the trunk. Specifications for planting a tree are illustrated in Figure 3.42. Trees must be watered well after planting.

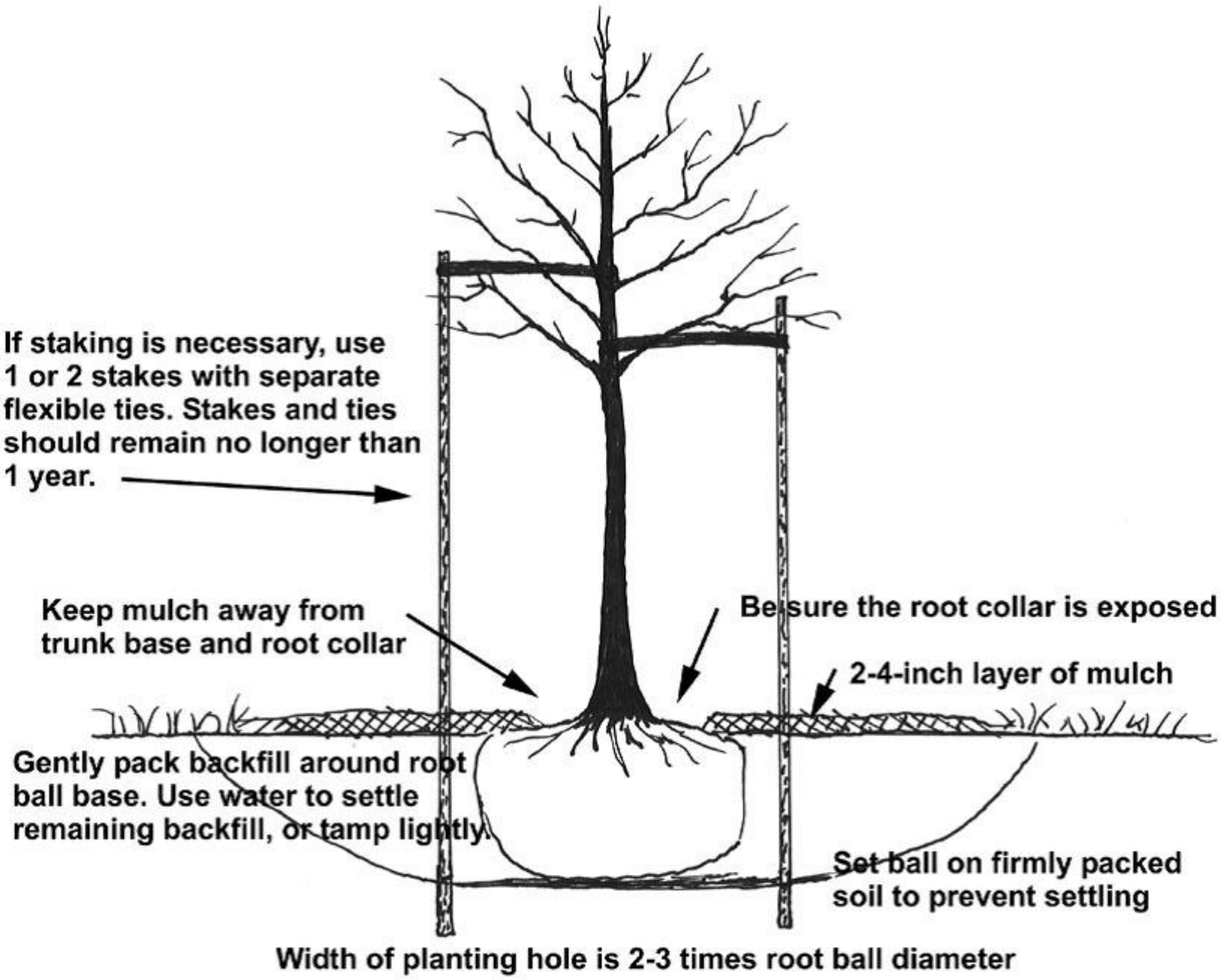

Figure 3.42 Tree planting guidelines. (Adapted from Flott, 2004 and ISA, 2003b).

Steep slopes require additional measures to ensure planting success and reduce erosion, especially if the slope receives stormwater runoff from upland land uses. Depending on the steepness of the slope and the runoff volume, rill or gully erosion may occur on these slopes, requiring a twofold approach: controlling the stormwater and stabilizing the slope.

Erosion control blankets are recommended to temporarily stabilize soil on slopes until vegetation is established (Caraco, 2000; Morrow and others, 2002). Erosion control fabrics come in a variety of weights and types, and should be combined with vegetation establishment such as seeding. Other options for stabilizing slopes include applying compost or bark mulch, plastic sheeting, or sodding (Caraco, 2000).

Trees will add stability to slopes because of their deep roots, provided they are not planted by digging rows of pits across a slope (Morrow and others, 2002). Required maintenance will include mowing (if slopes are not too steep), and establishing cover on bare or eroded areas.

Planting methods for slopes steeper than 3:1 (1 foot vertical change for every 3 horizontal feet) involve creating a level planting space on the slope (see Figure 3.43). A terrace can be dug into the slope in the shape of a step. The existing slope can be cut and the excavated soil can be used as fill. A low soil berm (or rock berm) can be formed at the front edge of each step or terrace to slow the flow of water. Trees can also be planted in clusters on slopes (using the above method) to limit potential for desiccation. Staggering tree placement and mulching will prevent water from running straight downhill.

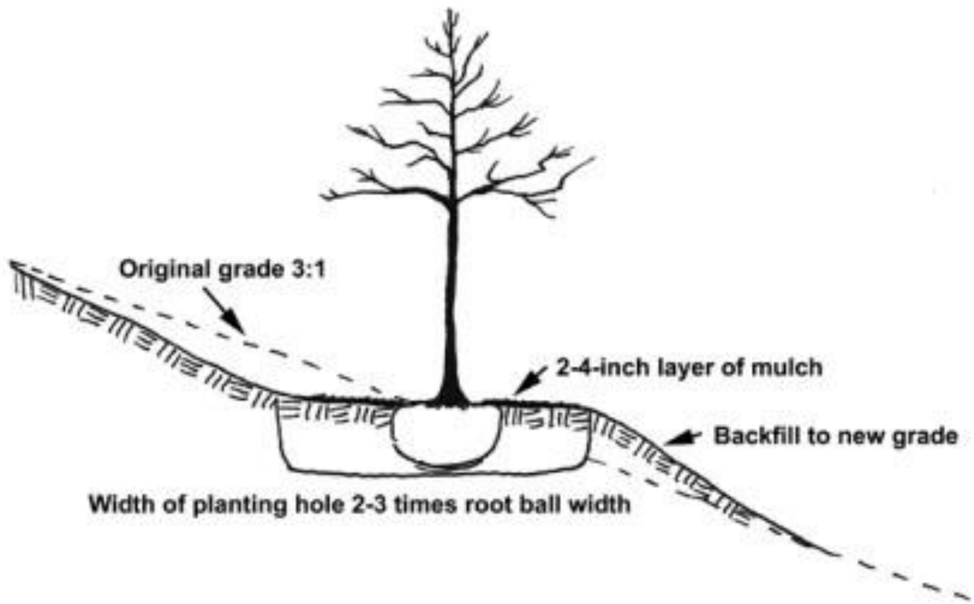

Figure 3.43 The specifications for planting on a steep slope, require creating a level planting surface.

Post-Planting Tree Protection. Once the tree has been properly planted, 2 to 4 inches of organic mulch must be spread over the soil surface out to the drip line of the tree. If planting a cluster of trees, mulch the entire planting area. Slow-decomposing organic mulches, such as shredded bark, compost, leaf mulch, or wood chips provide many added benefits for trees. Mulch that contains a combination of chips, leaves, bark, and twigs is ideal for reforestation sites. (ACB, 2000; ISA, 2003a). Grass clippings and sawdust are not recommended as mulches because they decompose rapidly and require frequent application, resulting in reduced benefits.

For well-drained sites up to 4 inches of mulch may be applied, and for poorly drained sites a thinner layer of mulch should be applied. Mulch should never be more than 4 inches deep or applied right next to the tree trunk; however, a common sight in many landscaped areas is the “mulch volcano”. This over-mulching technique can cause oxygen and moisture-level problems, and decay of the living bark at the base of the tree. A mulch-free area, 2- to 3-inches wide at the base of the tree, must be provided to avoid moist bark conditions and prevent decay (ISA, 2003a).

Studies have shown that trees will establish more quickly and develop stronger trunk and root systems if they are not staked at the time of planting (ISA, 2003b). Staking for support may be necessary only for top-heavy trees or at sites where vandalism or windy exposure are a concern (Buckstrup and Bassuk, 2003; Doherty and others, 2003; ISA, 2003b).

If staking is necessary for support, two stakes used in conjunction with a wide flexible tie material will hold the tree upright, provide flexibility, and minimize injury to the trunk. To prevent damage to the root ball, stakes should be placed in undisturbed soil beyond the outer edges of the root ball. Perhaps the most important part of staking is its removal. Over time, guy wires (or other tie material) can cut into the growing trunk bark and interfere with the movement of water and nutrients within the tree. Staking material should be removed within 1 year of planting (Doherty and others, 2003).

3.14.3 Tree Inspection Criteria

An initial inspection by a qualified professional must be done to ensure the tree has been planted, watered, and protected correctly with locations flagged if appropriate. For newly planted trees, transplant shock is common and causes stress on a new tree. For this reason, newly planted trees must be inspected more frequently than established trees. The time it takes for a tree to become established varies with the size at planting, species, stock, and site conditions, but generally, trees should be inspected every few months during the first 3 years after planting, to identify problems and implement repairs or modify maintenance strategies (WSAHGP, 2002).

After the first 3 years, annual inspections are sufficient to check for problems. Trees must also be inspected after major storm events for any damage that may have occurred. The inspection should take only a few minutes per tree, but prompt action on any problems encountered results in healthier, stronger trees. Inspections should include an assessment of overall tree health, an assessment of survival rate of the species planted, cause of mortality, if maintenance is required, insect or disease problems, tree protection adjustment, and weed control condition.

DDOE’s construction phase inspection checklist for tree planting and preservation can be found in Appendix K.

3.14.4 Tree Maintenance Criteria

Water newly planted trees regularly (at least once a week) during the first growing season. Water trees less frequently (about once a month) during the next two growing seasons. After three growing seasons, water trees only during drought. The exact watering frequency will vary for each tree and site.

A general horticultural rule of thumb is that trees need 1 inch of rainfall per week during the growing season (Petit and others, 1995). This means new trees need a minimum of 25 gallons of water a week to stay alive (http://caseytrees.org/get-involved/water/). Water trees deeply and slowly near the roots. Light, frequent watering of the entire plant can actually encourage roots to grow at the surface. Soaker hoses and drip irrigation work best for deep watering of trees. It is recommend that slow leak watering bags or tree buckets are installed to make watering easier and more effective. Continue watering until mid-fall, tapering off during lower temperatures.

Pruning is usually not needed for newly planted trees but may be beneficial for tree structure. If necessary, prune only dead, diseased, broken or crossing branches at planting (Doherty and others, 2003; Trowbridge and Bassuk, 2004). As the tree grows, lower branches may be pruned to provide clearance above the ground, or to remove dead or damaged limbs.

DDOE's maintenance inspection checklist for tree planting and preservation and the Maintenance Service Completion Inspection form can be found in Appendix L.

Declaration of Covenants. A maintenance covenant is required for all stormwater management practices. The covenant specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The covenant is attached to the deed of the property (see standard form, variations exist for scenarios where stormwater crosses property lines). A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. There may be a maintenance schedule on the drawings themselves or the plans may refer to the maintenance schedule (Exhibit C in the covenant).

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste Material. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.14.5 Tree Stormwater Compliance Calculations

Trees receive retention value but they are not accepted total suspended solids (TSS) treatment practices.

To ensure appropriate stormwater benefits associated with proposed tree preservation or planting, all trees receiving retention value must be properly maintained until redevelopment of the area occurs. If trees die they must be replaced with a similar tree no longer than 6 months from time of death in an appropriate location.

Preserved trees that meet the requirements described above receive a retention value of 20 cubic feet each. Planted trees that meet the requirements described above receive a retention value of 10 cubic feet each.

Note: Trees planted as part of another BMP, such as a bioretention area, also receive the 10 cubic foot retention value. Retention values are shown in Tables 3.55 and 3.56 below.

Table 3.55 Preserved Tree Retention Value and Pollutant Removal

Retention Value	= 20*cf* (150 gallons)
Accepted TSS Treatment Practice	No

Table 3.56 Planted Tree Retention Value and Pollutant Removal

Retention Value	= 10*cf* (75 gallons)
Accepted TSS Treatment Practice	No

Trees also contribute to peak flow reduction. This contribution can be determined in several ways. One method is to subtract the retention value from the total runoff volume for the 2-year, 15-year, and 100-year storms. The resulting reduced runoff volumes can then be used to calculate a Reduced Natural Resource Conservation Service (NRCS) Curve Number for the site or drainage area. The Reduced Curve Number can then be used to calculate peak flow rates for the various storm events. Other hydrologic modeling tools that employ different procedures may be used as well.

3.14.6 References

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