5 DESIGN AND CONSTRUCTION CONSIDERATIONS FOR COMMON STRUCTURAL LID BMPS

5.1 INTRODUCTION

This chapter provides technical guidance on design and construction specifications for commonly used structural LID BMPs, as introduced in Chapter 2. Detailed descriptions, planning considerations, design considerations, components and materials, construction considerations and maintenance requirements are outlined for:

- Bioretention
- Vegetated Swales
- Vegetated Filter Strips
- Permeable Pavements
- Rainwater Harvesting
- Green Roofs

This chapter is intended to be used primarily by professionals engaged in master planning, designing, constructing, and maintaining stormwater projects at military facilities. Others who can benefit from the information in this chapter include: Department of Public Works (DPW), public officials, engineers, architects, landscape architects, and site design planners responsible for land use planning and decision making in watershed management.

The technical contents of this chapter are based on, and derived from, materials almost entirely in the public domain, published by federal or state agencies or public educational institutions. It must be noted that this chapter provides general technical guidance on LID BMP design and construction specifications. Since every site is unique - locally, geographically, and regionally, the soil type and topographic characteristics may differ even from site to site at the same installation. As such, the chapter is developed primarily to educate Army installation personnel (especially those responsible for policy making and engaged in stormwater management) in areas such as: (1) Role and significance of LID in addressing watershed stormwater management, and (2) Providing technically-sound knowledge and background information on design, construction and maintenance for their use in making intelligent policy and management decisions in planning, budgeting, project management, field implementation, and the monitoring of LID practices and procedures.

Therefore, the materials presented in this chapter are not intended to substitute formal project design and construction drawings which must be prepared and obtained from licensed industry

professionals. It is recommended that the following guidance should be used while developing formal design and construction drawings and specifications for LID projects.

- Use the information presented in this chapter primarily for planning and initial design and construction purposes.

- Adapt the information provided in the chapter to specific conditions at your site.

- Prior to construction of any practice described in this chapter, all permits must be obtained, including approval of erosion and sediment control plans and stormwater management plans from local permitting authority.

- It is extremely important to obtain professional services and have a licensed surveyor site stake to locate underground utilities. If in doubt, the identification and location of underground utilities must be performed early on during planning and design processes to avoid "work stop orders" and added costs later encountered during construction.

- Consult the local USDA NRCS Extension Service Office on your project development, especially regarding site-specific soil types and establishing and maintaining vegetation. Use boring logs and geotech report information as available.

- Final "Design and Construction Drawings" must be prepared by licensed engineering professionals in accordance with existing land use conditions and current site surveys.

5.2 BIORETENTION

5.2.1 Description

Bioretention is a stormwater infiltration and/or filtration practice used to reduce site stormwater runoff volume and pollutant loading. Bioretention systems are flexible in design and can be used to help fulfill the landscape requirements of a site. Bioretention systems are commonly located in or adjacent to parking lots or within small pockets in residential neighborhoods or commercial developments and have wide applicability.

Bioretention systems are flat-bottomed, shallow landscaped depressions used to collect and hold stormwater runoff, allowing pollutants to settle and filter out as the water infiltrates into the ground or to an underdrain. Stormwater runoff from the contributing drainage area (e.g., parking lot) enters as sheet or concentrated flow into the bioretention system, where it temporarily ponds within the shallow depression and subsequently filters down through the various layers in the bioretention area: plants, mulch or ground cover, engineered soil media, a gravel base layer with a possible underdrain, until it infiltrates into the underlying soils. Runoff from larger storms is generally diverted through or around the bioretention system to the storm drain system via a yard inlet or overland relief via a spillway. Bioretention systems often provide complete on-site infiltration for small storm events (the "first flush"). Bioretention systems can be sized to infiltrate large storms in areas where soils are sandy, highly permeable, and drain well or bypass

to an approved discharge point. Bioretention systems reduce peak runoff rates and increase stormwater infiltration for volume reduction when designed to a larger capacity.

The bioretention system components make use of the chemical, biological and physical properties of soil, water, and plants to remove pollutants from stormwater runoff. Processes that take place within the soil-plant media of a bioretention system include sedimentation, adsorption, evapo-transpiration, physical filtration, infiltration, decomposition, phyto-remediation, bioremediation, storage, and pollutant uptake by plants. Bioretention systems remove a wide range of pollutants, such as suspended solids, nutrients, heavy metals, hydrocarbons, and bacteria from stormwater runoff. Bioretention systems encourage biologic, microbial and physical processes to occur and to self-perpetuate. This self-perpetuation represents a significant difference between bioretention and other stormwater treatment strategies. The components are intended to blend over time with soil, water, plant and root growth to produce organic decomposition and the development of a macro and microorganism community for removal of runoff pollutants. This microbial community in turn helps develop a natural soil horizon and structure that lengthens the bioretention systems' life span and reduces the need for maintenance.

5.2.2 Types of Bioretention

There are three main types of bioretention systems based on their scale and size of constructed area: bioretention, micro-bioretention, or rain gardens.

5.2.2.1 Bioretention Cell

Bioretention cells are systems that generally treat larger areas such as parking lots, commercial rooftops and areas in commercial, institutional or industrial settings (Photo 5-1). When constructed in residential areas, they may be distributed throughout the subdivision, but mostly they are located in common areas or within the drainage easements to treat a combination of roadway or parking lot runoff.

Contributing drainage areas to a bioretention cell should not exceed 5 acres. Pretreatment is often required to avoid sediment and debris clogging the filter bed. Forms of pretreatment include a forebay, stone diaphragm or vegetative filter strip.

Photo 5-1. Bioretention Cell
(Source: Low Impact Development Center, Inc., XXXX)

5.2.2.2 Micro-Bioretention Cell

Micro-bioretention cells are structurally and functionally the same as the bioretention cells described above. The only difference between the two is merely the size, wherein micro-bioretention cells are smaller than traditional bioretention cells. Since these practices are smaller, they do not require the same pretreatment techniques as traditional bioretention cells. Micro-bioretention cells have contributing drainage areas between approximately 10,000 square feet and 1/2 acre. Pretreatment is not usually required, except where concentrated flows, such as roof drain outfalls, are entering the filter bed.

5.2.2.3 Rain Gardens

Rain gardens have contributing drainage areas less than 10,000 square feet. Contrary to the common use of bioretention cells and micro-bioretention cells in commercial, industrial, and institutional applications, rain gardens are essentially small, distributed practices designed to treat runoff from small areas. Rain gardens are typically used to treat runoff from individual rooftops, driveways, and other on-lot features mostly in single family detached residential developments, as shown in Photo 5-2. Because of their small size and location, rain gardens often do not require an underdrain system or overflow inlet.

Table 5-1. Bioretention Types

Bioretention Type	Contributing Drainage Area	Infiltration or Underdrain?
Bioretention	1/2 to 5 acres	Could have one or both
Micro-Bioretention	10,000 sf to 1/2 acre	Could have one or both
Rain Garden	Less than 10,000 sf	Infiltration, no underdrain

Photo 5-2. Rain Garden

5.2.3 Planning Considerations

Bioretention systems are suitable for many types and sizes of new construction and redevelopment projects, including single-family residential as well as commercial, industrial, and institutional settings.

5.2.3.1 Applications

Bioretention systems can be used to filter the runoff from both residential and nonresidential developments. They are most effective when they receive runoff as close to its source as possible. They can vary in size and can receive and treat runoff from a variety of drainage areas within a land development site. They can be installed in lawns, median strips, parking lot islands, unused lot areas, and certain easements. They are intended to receive and filter storm runoff from both pervious and impervious areas.

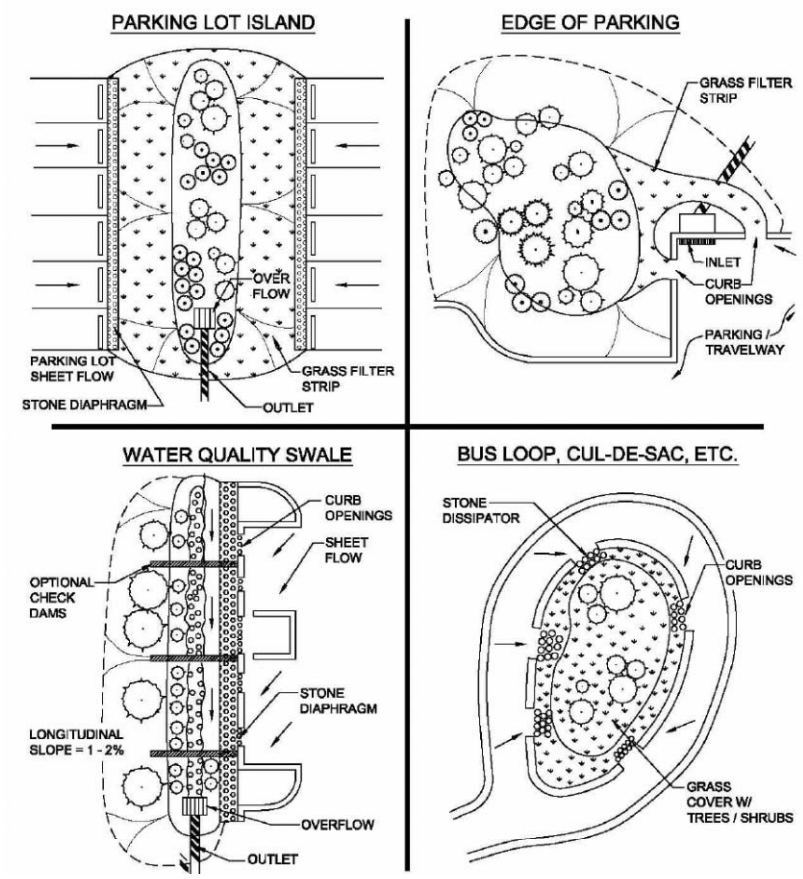

Figure 5-1. Typical Bioretention Applications

Typical residential, commercial and industrial applications for bioretention systems are shown in Figure 5-1, and are described below:

- Parking lots, parking lot edge, road medians, roundabouts, interchanges, cul-de-sacs, public right-of-way, commercial setbacks, courtyards, individual residential lots, etc. are the prime areas where bioretention can be successfully applied to enhance stormwater quality and aesthetics.

- Commercial/Industrial: Bioretention can be designed to treat runoff commercial parking lots, roads, rooftops, pervious areas, and/or pervious areas such as managed lawns.

- Institutional (*e.g.,* schools, government buildings, and parks): Bioretention features can be incorporated into bus loops, parking lot islands, roof downspout areas and access road shoulders, etc.

- Residential: Bioretention applications are most appropriate for residential settings. In this regard, they should be designed as distributed practices within areas designated as open space and covered by drainage easements. For example, roof or driveway runoff can be directed to rain gardens located at the front, side, or rear of a home. In

residential applications, bioretention features increase property values and enhance aesthetics.

- Retrofitting: Numerous options are available to retrofit an existing stormwater system or impervious area with bioretention applications in urban landscape.

5.2.3.2 Constraints

One of the most advantageous qualities of bioretention systems is that they can be installed independent of soil conditions (sandy, clayey, or in between) because stormwater infiltration and filtration is made artificially possible using engineered soil percolation media where soil conditions are not favorable. Nevertheless, there are several site constraints that must be considered in the designing and construction of bioretention facilities and practices.

Drainage Area
Ideally, the bioretention systems are used on small drainage areas, *i.e.,* less than 5 acres.

Site Location and Topography
The practice is best applied in areas with relatively gradual slopes, of the order of less than 5 percent but greater than 1 percent. Bioretention should not be constructed in areas where mature trees would have to be removed or within a floodplain.

Available Hydraulic Head
Hydraulic head is the difference in elevation between the runoff inflow point and the outflow point at the underdrain outlet where it meets the storm sewer system or overflows to downstream swale or a stream. The bioretention system is fundamentally and functionally constrained by the invert of the existing outlet to which the practice discharges (i.e., the bottom elevation needed to tie the underdrain from the bioretention system into the storm drain/sewer system or the downstream open channel). In general, a minimum of 4 to 5 feet of elevation above this invert is needed to create a hydraulic head needed to overcome friction losses through the proposed filter and gravel bed. For the bioretention facility to function properly and adequately, it must be capable of emptying the percolating runoff at a considerably faster rate than that of the infiltration rate of soil media above.

Groundwater Table
In order to avoid possible groundwater contamination, a minimum separation distance of 2 feet is required between the bottom of the excavated bioretention section and the seasonally high groundwater table.

Soils
As stated above, the soil conditions do not constrain the use of bioretention, although they do determine whether an underdrain or impermeable liner is needed. Clay soils, with low infiltration rates, often necessitate an underdrain pipe, which may not be required in loamy sand soils where infiltration is higher. If the site has karst (limestone) topography and is susceptible to sinkholes, the geotechnical engineer may require an impermeable liner to prevent any infiltration into the underlying soils that could cause instability or groundwater contamination.

Hotspot Land Uses

Hotspot land uses (gas stations, auto repair shops, motor pools, etc.) generate high concentrations of petroleum-base hydrocarbons and chemical contaminant loads. These areas should not be treated using infiltration bioretention systems but instead with bioretention systems that drain to an underdrain that is directed to the stormwater infrastructure. In addition to an underdrain, an impermeable bottom liner must be employed where bioretention is to receive and treat hotspot runoff to prevent aquifer contamination.

Root Barrier

The use of a vegetation root barrier should be considered when there are susceptible services or utilities nearby, such as water or sewer lines that are likely to be at risk from root penetration. The root barrier should be placed adjacent to the utilities which require protection.

Tail Water

The hydraulic design of the underdrain and overflow systems, as well as any stormwater quantity control outlets, must consider any significant tail water effects of downstream waterways, conveyance systems, or other stormwater management facilities. This includes instances where the lowest invert in the outlet or overflow structure is below the flooding or tide elevation in a downstream waterway or storm sewer system.

5.2.4 Design Criteria & Specifications

The major design goal for a bioretention is to maximize volume reduction and removal of stormwater suspended solids and other pollutants/contaminants. The basic design parameters of a bioretention systems is its storage volume, the thickness, character, and permeability or infiltration rate of its planting soil bed, and either the hydraulic capacity of its underdrain or the permeability of its subsoil (whichever is applicable). The system must have sufficient storage volume, if possible, above the surface of the soil bed to contain the design storm runoff volume without overflow. The thickness and character of the soil bed itself must provide adequate pollutant removal, while the soil bed permeability must be sufficient to drain the stored runoff. In addition, depending upon the type of bioretention system (i.e., infiltration or non-infiltration), either the capacity of the underdrain or the infiltration rate of the existing subsoil must also be sufficient to allow the system to drain preferably within 48 hours. Details of these and other design parameters and system components are presented in the following sections.

5.2.4.1 General

An important design factor to consider when designing a bioretention system is the size and scale of the practice at which it will be applied, as well as the existing site (i.e., soil texture) conditions where the bioretention facility will be constructed. The location and scale will determine the physical characteristics of the facility and whether it will require pretreatment measures. The soil characteristics of the site will further determine if the system can achieve full or partial on-site infiltration or if it will require an underdrain system connected to a conventional storm drain system.

Since the geology and soil conditions vary with the site location, bioretention design specifications will vary accordingly. The source of contributing drainage area and the resulting pollutant loading and its characteristics generated from within the drainage area will be another important factor in the design of a bioretention system. If the source is a high traffic area that generates large pollutant loads, such as a parking lot, the depth of filter bed or soil bed media will have to be greater than if the contributing drainage area is a residential lot producing relatively low pollutant loads.

5.2.4.2 Infiltration versus Underdrain

Bioretention systems can be designed to fully infiltrate the required volume, or can have an underdrain to convey treated stormwater to a storm drain system, or a combination of the two.

Non-Infiltration with Underdrain

Bioretention systems accept runoff from the contributing area (such as parking lot), filter runoff to remove and treat pollutants in the soil media, and then temporarily store runoff in a gravel storage layer. If the system includes an underdrain, the treated runoff is returned to the traditional storm drain system or daylights to the surface downstream. The underdrain consists of a perforated pipe buried within the gravel layer. A bioretention facility with an underdrain system is commonly referred to as an off-line bioretention practice. Typical details of an offline practice, with limited infiltration capability, are shown in Figure 5-2.

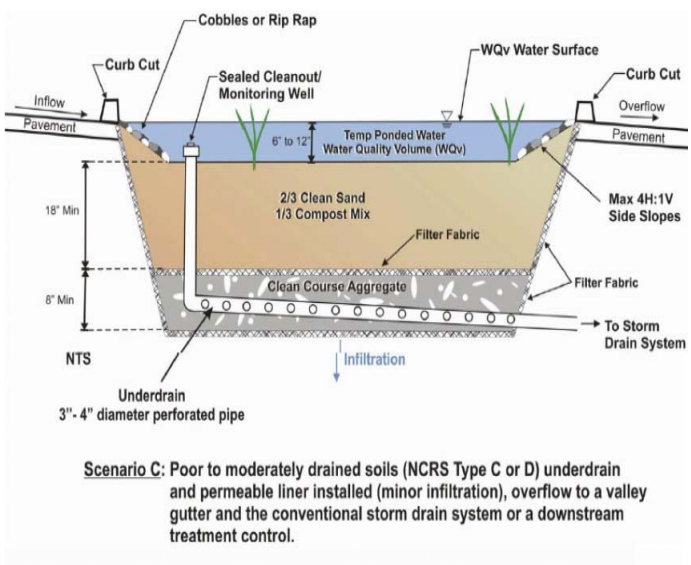

Figure 5-2. Design Components of an "Offline" Bioretention with Limited Infiltration

Infiltration without Underdrain

A bioretention system without an underdrain will allow the treated runoff to infiltrate directly into the native soils underneath. Infiltration (also called "online") bioretention systems require permeable, sandy loam or loamy sand underlying soils (USDA Hydrologic Soil Group A or B) to function properly; these soils have infiltration rates in excess of 1 to 2 inch per hour. Typical details of an online practice are shown in Figure 5-3. Infiltration bioretention systems are

designed for sites where soils are highly permeable, groundwater table is low, and there is no risk for groundwater contamination.

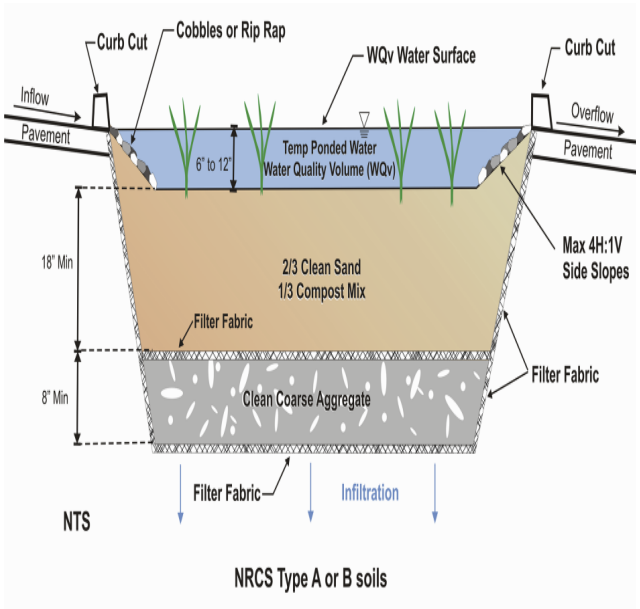

Figure 5-3. Design Componenets of an "Online" Infiltration Bioretention

Combination Infiltration and Underdrain

A combination of offline and online systems can be used where the underdrain is installed near the top of the gravel storage layer with a few inches of gravel over the top of the pipe, leaving a gravel "sump" that temporarily stores water for infiltration (Figure 5-4). This type of system will infiltrate runoff until the gravel layer fills up to the underdrain elevation, and then the underdrain will convey runoff to the storm drain system before it saturates the soil media layer.

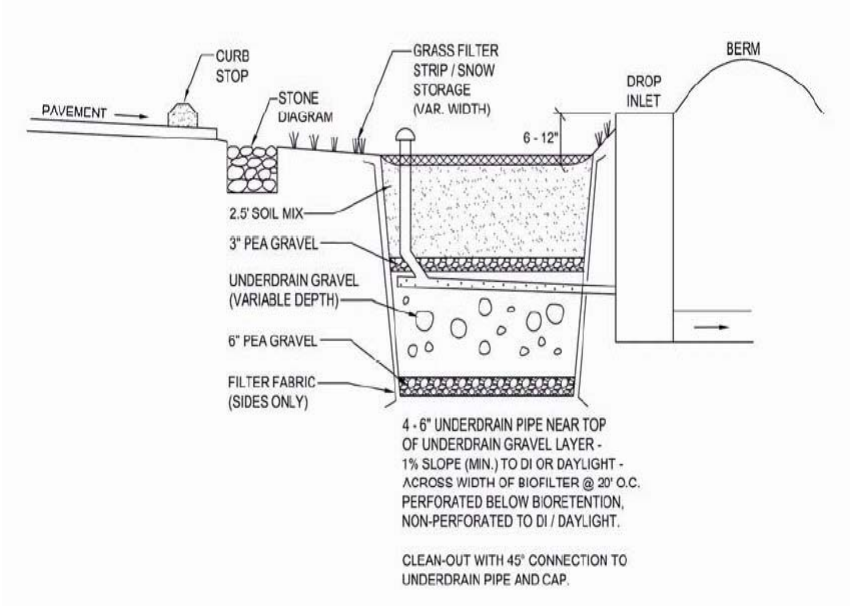

Figure 5-4. Combination Infiltration and Underdrain Bioretention System

5.2.4.3 Storage Volume, Depth, and Duration

Bioretention systems shall be designed to manage the volume of stormwater runoff required by EISA Section 438 through the EPA Technical Guidance Manual for the project site. Techniques to compute the stormwater runoff volume to be managed are discussed in Chapter 4, Hydrologic Modeling and Simulation; these techniques should be used as a guideline to determine the maximum water depth for managing the required runoff volume for the design storm. For more detailed information about sizing criteria, see the local permitting authority's stormwater design manual.

5.2.4.4 Contributing Drainage Area

Generally, the bioretention systems are constructed on sites that are disconnected by impervious area and consist of small contributing areas (i.e., two acres or less for impervious and less than 5 acres where the contributing drainage area is pervious). The cell size is designed to treat the first flush of runoff generated from approximately 1 inch of rainfall. The bioretention filter bed surface area may range between 3 percent to 12 percent of the contributing area depending on the imperviousness and desired bioretention type (bioretention cell, micro-bioretention cell, or rain garden).

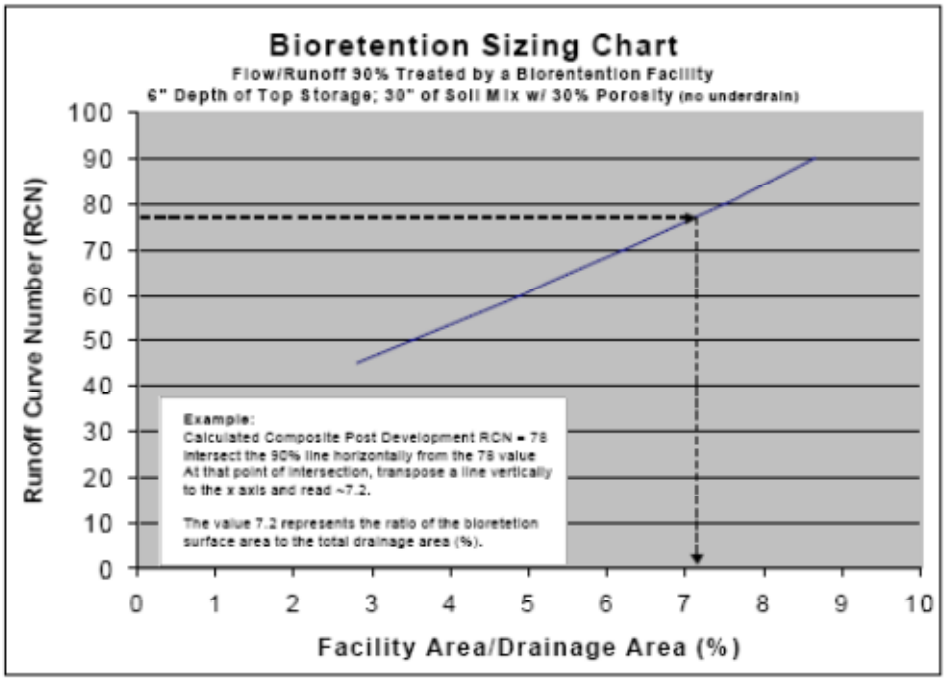

Figure 5-5. Bioretention Sizing Chart

Prince George's County, Maryland has developed a simplified criteria for sizing bioretention surface area (Figure 5-5) based on design drainage area and the post development curve number (that can be estimated using methods presented in Chapter 4, Hydrologic Modeling and Simulation). The graph presented in Figure 5-5 is applicable only for "online" infiltration-specific applications, and assumes surface ponding depth of 6 inches and soil storage capacity of 2.5 feet depth with 30 percent soil porosity.

5.2.4.5 Components of a Typical Bioretention

Bioretention is flexible in design and can be designed either as an infiltration or non-infiltration practice. The key elements of a bioretention are:

- Inflow Entrance
- Pretreatment
- Surface Ponding
- Mulch Layer
- Vegetation
- Soil Media
- Pea Gravel Choking Layer
- Gravel Storage Layer
- Underdrain
- Filter Fabric
- Liner
- Overflow or Drop Inlet

The system components of a bioretention are illustrated in Figure 5-6, and briefly described below.

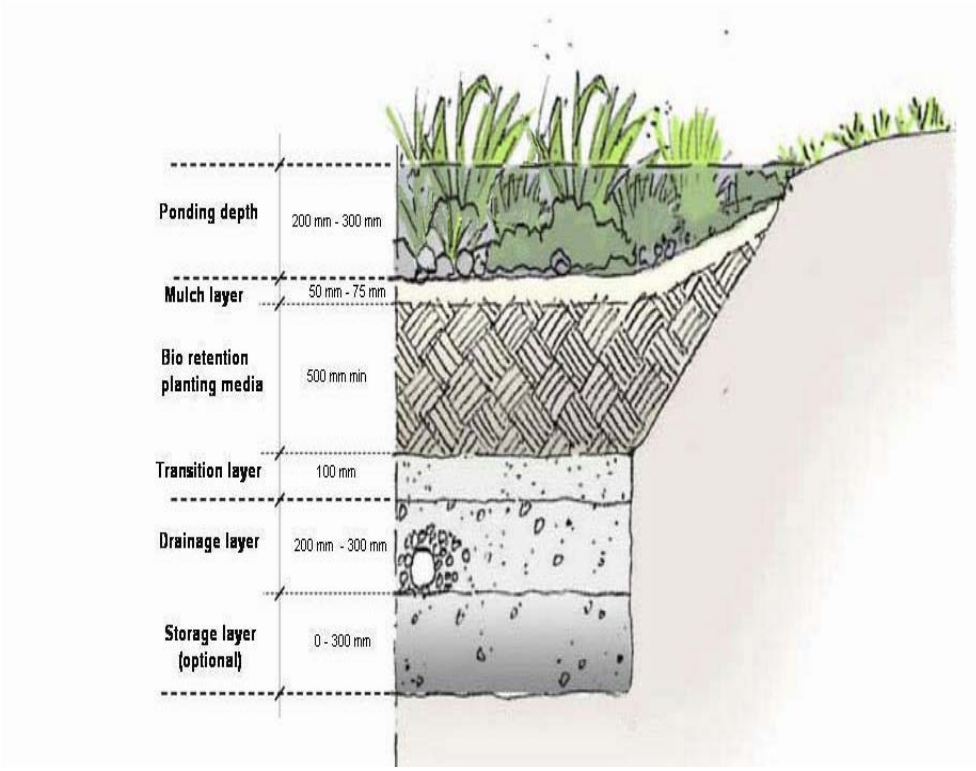

Figure 5-6. Typical Components of a Bioretention System

Inflow Entrance

The inflow entrance of a bioretention system is an important component as this is where the stormwater runoff will enter the system. The best method of capturing and treating runoff is to allow the water from contributing drainage area to sheet flow into the bioretention over grassed areas. This is not always possible, especially where site constraints or space limitations impede such an approach. A remedy to this problem is to provide flow entrances that can reduce the velocity of the water, such as riprap channels. In the case of parking lot landscape islands, curb cuts protected with energy dissipaters (such as landscape or surge stone or riprap) can be used. The curb cuts for the inflow entrance can be designed as a weir or flume, to regulate and allow defined flow volume directly from a contributing area into the bioretention. The design engineer will determine how many curb cuts are necessary (i.e., one curb cut every 20 linear feet of curb). Photos 5-3 and 5-4 show examples of curb cut inflow entrances with riprap and stone channels.

It is important to note that entrances of this type may become obstructed with sediment and trash that settles out at lower velocities. The accumulated sediment and debris should be removed from the inflow entrance area regularly.

Photo 5-3. Inflow Entrance - Curb Cut with Riprap

Photo 5-4. Inflow Entrance – Stone Channel

Pretreatment

To prevent premature clogging and possible failure of bioretention cells, incorporation of a pretreatment system is strongly recommended, and often required by the local stormwater management permitting authority. Pretreatment is a fundamental component of any bioretention in order to reduce incoming velocities and capture suspended sediment particles before runoff enters the bioretention facility. Pretreatment also extends the life of the bioretention. Sediments deposited in the pretreatment device must be periodically removed to maintain the system performance and functionality.

Several pretreatement options are listed below:

- Forebay, an excavated depression that collects runoff prior to the bioretention cell
- Grass filter strip between impervious area and bioretention cell
- Pea gravel diaphragm
- Riprap channel
- Level spreader

The most commonly used form of pretreatment is achieved through the use of a simple grass strip, which filters out most of the suspended sediment in the first 10 to 15 feet of the strip. Which pretreatment method to use depends on on the scale of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deep concentrated flows. For example, grass filter strips are appropriate for sheet flow whereas a gravel or stone diaphragm is recommended both for sheet flow and concentrated flow.

Surface Ponding Area

The surface storage ponding area is the area above the mulch layer that provides temporary storage for stormwater runoff and an environment for the settlement of suspended sediment and fine particles before infiltration, filtration, evaporation, and uptake processes can occur within the bioretention system. Ponding time provides water quality benefits by allowing larger debris and sediment to settle out from the runoff. The bioretention area should have a design depth of approximately one foot above the mulch layer, but may vary between 6-18 inches. Ponding time should not exceed 48 hours.

A convenient way to determine design ponding depth is simply to multiply the desired ponding time with infiltration rate of the planting soil. Conversely, the design ponding time (in hours) can be determined simply dividing ponding depth (in inches) by soil infiltrate rate (inches/hour).

Vegetation

Vegetation is an important component of a bioretention system. Plants uptake water and release it into the atmosphere through evapotranspiration and also uptake pollutants and nutrients; this contributes to the management of the stormwater runoff volume and quality. Plant roots enhance the infiltration capacity of the soil, creating pathways for percolation and infiltration of runoff through the soil. The plants species selected for bioretention planting should be native and designed to survive stresses such as frequent periods of inundation, ponding fluctuations and drought.

Root growth provides a media that fosters bacteriologic growth, which in turn develops a healthy soil structure. A variable plant community structure is preferred to avoid monoculture susceptibility to insect and disease infestation and to create a microclimate, which ameliorates

urban environmental stresses including heat and drying winds. Bioretention systems in parking lot islands are particularly susceptible to extended dry conditions because of urban heat effects. A layered planting scheme will help discourage weeds as well as creating suitable microclimates. There are many potential side benefits to the use of planting systems other than water quality and quantity treatment. Planting systems, if designed properly, can improve the property value of the site, provide shade and wind breaks, improve aesthetics, support wildlife, and absorb noise.

Native plants are preferable. Planting soil, mulch and plants selected will be appropriate for the local climatic conditions. The use of wetland plants is not recommended for bioretention planting, as these plants are not well suited to free draining soils or dry conditions. Plant materials should conform to the American Standard Nursery Stock as well as meet local requirements.

Organic Layer or Mulch

The mulch layer plays a vitally important role in the overall bioretention design and has several functions:

- Protects the soil bed from erosion
- Retains soil moisture to the benefit of plants
- Provides a medium for biological growth and decomposition
- Prevents evaporation, thus protects the soil surface from excessive drying
- Enhances plant survival
- Suppresses weed groth
- Provides runoff pretreatment by filtering sediment and fines before they enter the soil media

The mulch layer may consist of either a standard landscape shredded hardwood or hardwood chips (Figure 5-5). Other mulch materials include: organic materials such as compost, bark mulch, leaves, as well as small river gravel, pumice, or other inert materials. The mulch should be uniformly applied at approximately 3 to 4 inches in depth and replenished as necessary. If aged mulch is used, select the shredded type over the chip variety to minimize floatation and washouts. Mulch should be free of weed seeds, soil, roots, or any other substance not consisting of either branch wood or bark. Stone or gravel are not recommended in parking lot applications, since they increase soil temperature and have little or no water holding capacity.

As an alternative, if a dense herbaceous cover or 70 to 80 percent of tree canopy is established, a mulch layer is no longer necessary. While mulching provides an important function in the bioretention process, the establishment of an herbaceous layer or groundcover may be preferred over mulching for several reasons. First, the mulch material has the ability to float up-and-out during heavy rain events. Second, the herbaceous layer provides more opportunities to capture

and hold water through interception and evapotranspiration. Finally, providing thick, lush groundcover increases the aesthetic appeal and adds to the landscape character. A combination of groundcover and mulch is an equally preferable option.

Photo 5-5. Mulch Layer in Bioretention

Planting Soil Media

The planting soil media (also called soil media, filter media, planting growth media, soil mix, etc.) is the crucial component, and may be considered the "heart", of the bioretention providing several important functions, including:

- Provides media for infiltration and runoff volume reduction
- Support plant growth
- Provides home for soil microbial activity
- Provides environment for removal of pollutants
- Acts as a storage reservoir for moisture for plants

The planting soil is the region that provides water and nutrients for the plants to sustain growth. The upper soil zones are designed to enhance biological activity and encourage root growth. The macro-fauna breaks up organic matter into smaller parts, preparing it for the next stage of decomposition. In addition, as these microbes move through the soil, they provide aeration and redistribute soil components. This change in soil texture also allows more infiltration. The microbes (i.e., bacteria and fungi) break down complex organic compounds and transform nutrients into forms usable to plants. Symbiotic microbes living within plant roots enhance nutrient uptake and water retention. Clay particles also can adsorb heavy metals, nutrients, hydrocarbons, and other pollutants. The soil particles can also absorb some additional pollutants

through chemical processes, and the pore space (porosity) within soil particles can temporarily store a portion of runoff volume and dampen downstream peak flow from increased time of concentration.

The soil media composition will vary depending on design goals, available media (native soil or manufactured), targeted pollutants and the type of vegetation selected for the design bioretention practice. The soil media composition usually consists of sand and organic materials. The soil media should have a small amount of fines (silt and clay) to support plant growth and remove and treat pollutants and heavy metals. The soil media also must be permeable enough to allow water to pass at rates greater than 2 inches per hour. This balance is best achieved by using sandy loam or loamy sand soil, provided additional leaf compost or similar organic matter is added to increase soil pore space and, thus, the permeability. Leaf compost is essentially composed of aged leaf mulch and provides added organic matter to improve the health of the soil and ensure adequate soil structure. The soil must be a uniform mix, free of stones, stumps, roots, or other similar objects larger than two inches. No other materials or substances should be mixed or dumped within the bioretention that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The planting soil must be free of plant or seed material of non-native, invasive species, or noxious weeds.

Use of the native soil if it belongs to the USDA Hydrologic Soil Group A category (sandy loam) is acceptable to save costs and resources. The approach should simply consist of excavating the bioretention site to the design depth, save the excavated soil, and mix into it a 4 to 6 inch of well-aged organic matter, such as composted leaf mulch, double shredded mulch or pine fines, and planted with vegetation.

If soil conditions necessitate the use of manufactured media, make sure its characteristics conform to or exceed sandy loam soil characteristics in terms of structure, permeability, water holding capacity, the capability to support plant growth as well as water quality treatment characteristics such as the capability to remove suspended sediment and pollutants carried by runoff.

Soil bed depth will vary from site to site and depend on the type and function of bioretention.
The types of vegetation expected to grow in the bioretention cell also affect the depth of media selected. Grasses do not need more than 15 to 18 inches to survive, while certain small trees require a minimum of 4 to 5 feet soil depth. Most bioretention shrubs can survive and even flourish with a minimum of 24 inches, whereas bulbs may only need 12 inches to 18 inches. Most stormwater permitting authorities required a minimum 24 inches of soil media.

<u>Pea Gravel Choking Layer</u>
A pea gravel (No. 7, 8, or 89 stone) layer serves as a transition layer between the soil media and the underdrain gravel storage layer. This layer prevents fines from the soil media layer from migrating into open-graded gravel storage layer below.

<u>Sand Layer</u>
Sometimes the local permitting authority prefers a sand layer to serve as a transition between the planting soil bed and the gravel/underdrain layer in lieu of pea gravel. It must have a minimum

thickness of 9 to 12 inches and consist of pure washed sand or that of clean medium aggregate concrete sand. To ensure proper system operation, the sand layer must have a permeability rate at least twice as fast as the design permeability rate of the planting soil bed. The infiltration rate of sand is greater than 4 inches per hour compared with 1 to 2 inches per hour design permeability of soil media above.

Gravel "Sump" Storage Layer

The gravel layer is the bedding material and conveyance medium for the underdrain pipes. Thickness of the gravel layer will depend on the size of the perforated drain pipe and should be no less than 12 inches and consist of of clean, double washed No. 57 stone or equivalent. The design rule for gravel layer is that it must have sufficient thickness to provide a minimum of 3 inches or more of gravel above the underdrain pipe.

Depending on the placement of the underdrain, the gravel layer can provide some or no infiltration to the underlying soils. If the bioretention system does not require an underdrain, the gravel provides temporary storage for runoff before it infiltrates into the underlying soils. If some infiltration is desired, the underdrain can be placed within the gravel layer so there is additional gravel below the underdrain invert. The depth of the storage layer will depend on the target treatment and storage volume needed to meet EISA Section 438 and other stormwater volume and water quality or channel protection criteria, and should be a minimum of 12 inches deep. If no infiltration is desired, the underdrain should be placed at the bottom of the gravel layer. The bottom of the gravel layer must be at least 2 feet above the seasonally high water table to prevent the potential for groundwater contamination.

Underdrain

An underdrain is a perforated pipe (typically 4 to 6 inch diameter) installed within the gravel storage layer that conveys filtered runoff to the storm drain system (or daylights to a suitable, non-erosive outfall on the downstream slope). Bioretention systems may or may not incorporate an underdrain in their design depending on treatment goals and site conditions.

The role of an underdrain in the bioretention facility is to ensure proper drainage for the vegetation and to keep the soil at an adequate aerobic state, allowing plants to thrive and flourish. Underdrains are configured in many different ways and typically include a gravel/stone "blanket" encompassing a horizontal, perforated discharge pipe (Figure 5-7). The underdrain piping must connect to a downstream storm sewer manhole, catch basin, channel, swale, or ground surface at a location that is not subject to blockage by debris or sediment and is readily accessible for inspection and maintenance.

Underdrains are sometimes not necessary for in-situ soils with high infiltration rates (e.g. greater than 1 to 2 inches per hour) and where seasonally high water table depths are known to be greater than 2 feet below the proposed invert of the bioretention facility.

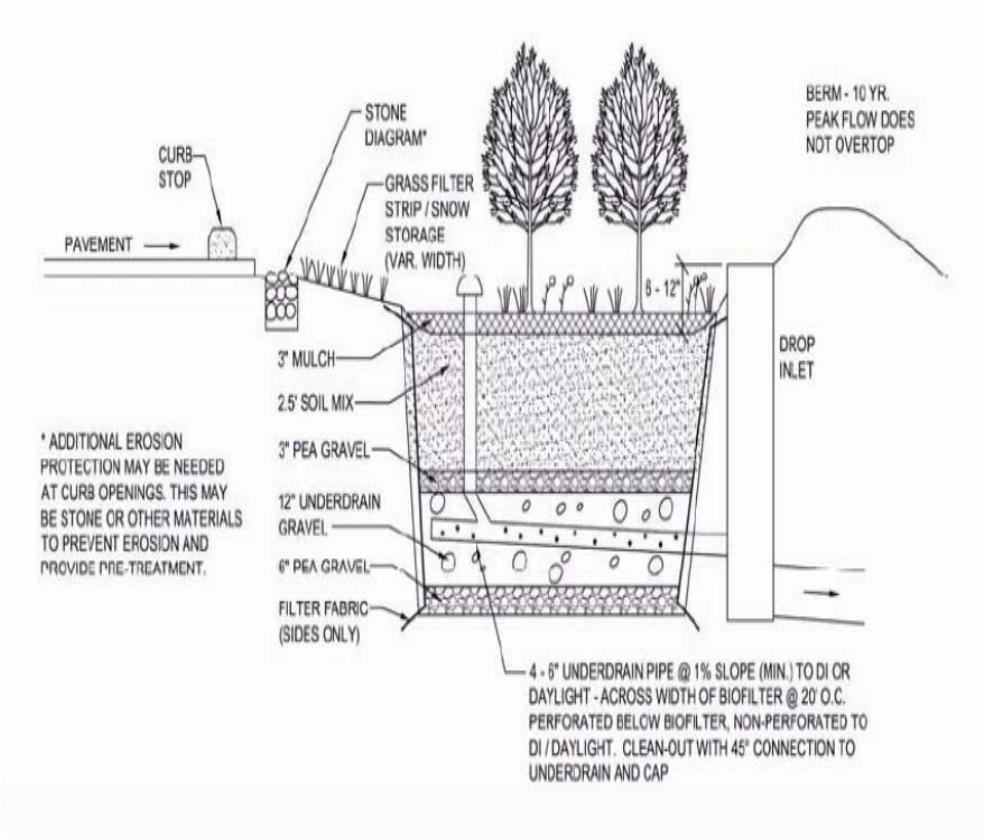

Figure 5-7. Use of Underdrain for Bioretention with Little or No Infiltration

Filter Fabric – Geotextile

The filter fabric is used to control silt and sediment migration and to control the direction of flow. There is a debate whether to use a permeable filter fabric between the gravel layer and the overlying soil growth media – this is on the premise that filter fabric does not adequately prevent the migration of finer soil as intended for bioretention applications. Preferably, in lieu of permeable fabric, pure sand and/or choking stone may be used as a separation layer between the underdrain gravel and the soil above.

Filter fabric should be placed along the sidewalls of the bioretention facility to help direct the water flow downward and to reduce lateral flows.

Liner – Impermeable Layer

In applications where bioretention is used for areas that require groundwater protection (karst topography, hotspot land uses, or source water protection), an appropriate impervious liner should be specified, provided, and installed. Clay liner should be of an appropriate impervious material, whereas synthetic liners, such as HDPE or PVC of appropriate thickness (at least 30 millimeters) can also be used. Any underdrain system shall be placed above the liner with a provision to cap the underdrain discharge pipe to confine drainage if needed. Care during placement of the liner is necessary to avoid puncture. To avoid compaction, soil medium placed over the liner should be placed by hand shovel rather than construction equipment.

Overflow/Outlet

As in the case of any impoundment, overflow of storm events that exceed the storage capacity of the facility should be addressed appropriately. An evaluation of overflow risks should always be performed when designing a stormwater facility.

In a residential setting where a rain garden is used, overflow may not present a problem if the system is located within a grassy area that provides a safe, non-erosive surface for any overflow conditions that may arise. Even in these cases, downstream conveyance must also be considered and designed appropriately.

For bioretention cells and micro-bioretention cells, it is important to design an overflow system to safely convey heavier, less frequent storms either through or around the bioretention facility. In commercial and industrial settings, a spillway or overflow yard inlet is often installed within the bioretention cell, as shown in Photo 5-6. The top of the outlet or overflow box is set at the desired maximum ponding depth. The overflow can outfall to the storm drain system or may "daylight" to a suitable, non-erosive outfall such as a swale or downslope area.

Photo 5-6. An Overflow within Bioretention

One common approach is to 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 bypassed or diverted past the bioretention facility to the storm drain system. In this case, the higher flows do not enter the bioretention area, and low flows are able to enter as the ponding water filtrates through the soil media.

Observation Well/Cleanout

An observation/cleanout standpipe should be installed in every bioretention facility that has a depth greater than 2 feet and/or an underdrain system. The standpipe will indicate how quickly

the bioretention facility dewaters following a storm, provides a maintenance cleanout port, and it will be connected to the underdrain system to facilitate cleanout. It should be located in the center of the structure and be capped flush with the ground elevation of the facility. The top of the well should be capped with a screw, or flange type cover.

5.2.5 Materials

Table 5-2 provides a summary of the typical material requirements for the bioretention components described in previous pages. Designers should follow their local stormwater management requirements when specifying materials.

Table 5-2. Typical Bioretention Material Specifications

Material	Specification	Notes
Surface Ponding	6 to 12 inches	Not to exceed 18 inches
Plantings	Natives trees, shrubs, or grasses: Plant 1 tree per 250 sq. ft. Plant shrubs that are a minimum of 30 inch high at 10-ft on-center. Plant ground cover plugs at 12 to 18 inch on-center. Plant container grown plants at 18 to 24 inch on-center; depending on the initial plant height and how large it will grow	Plants are site-specific. Establish plant material as specified in the local landscaping plan and recommended plant list. In general, plant species must be native and spacing must be sufficient to ensure the plant material achieve 80% cover in the proposed planting areas within a 3-year period. If seed mix is used, they should be free of weed and from an approved supplier' should be appropriate for stormwater basin applications.
Mulch Surface Layer	Shredded hardwood mulch 3 to 4 inch thick	Spread layer on the surface of soil filter bed. Alternative is native groundcover, such as seedums, in which case topsoil would replace mulch layer
Soil Filter Media	2 to 4 feet, to consist of: Sand = 85% to 88% Soil Fines = 8% to 12% Organic Matter = 3% to 5% ASTM C33	Use soil filter media 10% extra than computed value to account for settling or compaction. pH to range from 5.5 to 7.0. USDA soil types loamy sand or sandy loam with infiltration rate of 1 to 2 inches/ hour Soil media layer thickness depends on vegetation type: shrubs and trees require thicker layer than grasses and flowers
Pea Gravel Choking Layer	Minimum 4 inches No. 7, No. 8, or No. 9 washed stone	Transition between soil media and underdrain gravel.
Underdrain Gravel/ Storage Layer	Minimum 12 inches No. 57 or No. 6, double washed stone (3/8 to 3/4 inch) AASHTO M-43	Can exceed 12 inches for additional storage

Material	Specification	Notes
Underdrain Pipe, Cleanouts, and Observation Wells	4 to 6 inch rigid schedule 40 PVC or equivalent. 3/8 inch perforations at 6 inches on center on underdrain (non-perforated on cleanout) Minimum 3 inches gravel over pipe Wrap pipe with 1/4 inch galvanized hardware cloth Space 20 feet on-center.	Lay the perforated pipe under the length of the bioretention cell; and install non-perforated pipe as needed to connect with storm drain or daylight to ground surface Install T's and Y's as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps. Not required for Rain Garden application.
Stone Diaphragm or Curtain Drain	River washed cobbles 2 to 5 inch	Depends on inlet flow velocity; engineer will design
Sand (if required)	AASHTO M6 or ASTM C-33	Clean, concrete sand, free of deleterious materials, grain size range 0.02 to 0.04 inch
Geotextile	ASTM D751 (puncture strength 125 lb), ASTM D 1117 (Mullen burst 400 PSI), and ASTM D 1682 (Tensile strength – 300 lb) PE Type 1 Non-woven	Fabric should have 0.08 inch thick, and maintain 120gal/ft^2 flow rate
Overflow Conveyance	Overflow yard inlet or Spillway	Not required for Rain Garden application

5.2.6 Construction Considerations

5.2.6.1 General

The construction phase of a bioretention is critical and must be phased to avoid soil media compaction or inflow of sediment laden runoff from disturbed areas during construction. All contributing drainage areas must be stabilized before the bioretention section is constructed. In this case, stabilization means having all pervious areas either fully landscaped (with mulch installed) or having well established grass or other stabilizing ground cover. If this is not possible, sediment laden runoff should be diverted around the bioretention and treated with erosion and sediment control practices. If sediment from disturbed areas is introduced to the bioretention cell during construction, the Contractor must remove the section and reconstruct it with new materials.

5.2.6.2 Excavation

The bioretention facility should be excavated to the dimensions, side slopes, and elevations indicated on the design plans. The method of excavation should minimize the compaction of the soils on the bottom of the bioretention facility. Excavators and backhoes, operating on the ground adjacent to the bioretention facility, should be used to excavate the facility if possible. Low ground-contact pressure equipment may also be used for excavation. Use of equipment with narrow tracks or narrow tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction resulting in reduced infiltration rates and storage volumes, which should be avoided. Compaction of the base and the side walls of the bioretention area should be minimized. Excavation should not occur during wet or saturated conditions.

The bottom of the bioretention area should be tilled at least to an additional depth of 12 inch to promote infiltration for basins that allow for limited or full infiltration.

5.2.6.3 Soil Media Placement

The bioretention area should be prepared for soil media placement by scarifying the invert area of the bioretention facility in lifts of 12 to 18 inches. The preparation of the area should include light to minimal compaction to allow for adequate filtration; minimal compaction effort can be applied to the soil by tamping with a bucket from a dozer or backhoe. Excessive compaction will result in reduced infiltration rates, which reduces storage volumes and contributes to design failure.

The soil media should be placed and graded using excavators and/or backhoes operating on the ground adjacent to the bioretention facility or spread by hand, in order to avoid compaction and maintain the porosity of the media. If equipment must operate within the filter area itself, it must be light equipment that will not compact the soil to any appreciable degree (e.g., small loader with wide tracks or marsh tracks). No heavy equipment and/or equipment with narrow tracks, narrow tires, rubber tires, or high pressure tires should be used within the immediate filter area during or after the placement of the soil mix. The media should be overfilled above the proposed surface elevation, as needed, to allow for natural settling. After the final lift is placed, the soil media should be raked (to level it), saturated and allowed to settle for at least one week prior to installation of plant materials.

5.2.6.4 Watering

Once plant materials are planted, the bioretention area must be watered frequently to ensure establishment of the plants. Watering the plants is critical during establishment, especially during dry periods. Regular and frequent watering will reduce plant loss and provide the new plant materials with a chance to establish root growth.

5.2.6.5 Construction Sequence

The following is a typical construction sequence to properly install a bioretention facility. These steps may be modified to reflect different bioretention applications or site conditions:

1. The owner and the contractor should have a pre-construction conference and check the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

2. 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 curbs or other inlets while the bioretention area is being constructed.

3. Temporary erosion and sediment controls 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. Construction runoff should be directed away from the proposed bioretention location using erosion and seiment control protection. Proposed bioretention areas may only be used as sediment traps during construction if at least two feet of soil are removed and replaced.

4. Excavate bioretention area to proposed invert depth and manually scarify the existing soil surfaces. Do not compact in-situ soils. It may be necessary to scarify the bottom soils to a depth of 6 to 12 inches to promote greater infiltration.

5. Place geotextile fabric on the sides of the bioretention area as per manufacturer specifications. If a stone storage layer will be used, place the appropriate depth of gravel on the bottom, install the perforated underdrain pipe, and place gravel to a minimum of 3 inches above the underdrain pipe.

6. Place choker stone/pea gravel as a transition between gravel layer and the soil media.

7. Place soil 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.

8. Prepare planting holes for any trees and shrubs, install the vegetation, and water accordingly. Install any temporary irrigation.

9. Place the surface cover in both cells (mulch, river stone or groundcover), 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, and holes or slits will have to be cut in the matting to install the plants.

10. Seed and plant vegetation as indicated on the plans and specifications.

11. Place mulch and hand grade to final elevations.

12. Water vegetation regularly during first year to ensure successful establishment.

5.2.7 Maintenance

5.2.7.1 General

Maintenance for bioretention systems is similar to the routine maintenance for any landscaped area. Routine repair and maintenance tasks specific for bioretention systems are presented in Table 5-3. Repair and maintenance inside the cell should not be conducted if its soil surface is wet or saturated to prevent compaction. Perform maintenance tasks when the soil is dry.

All bioretention system components expected to receive and/or trap debris and sediment must be inspected for clogging and excessive debris build up and sediment accumulation at least once

after each storm event exceeding one inch rain. Besides the surface ponding area above the facility, such components may include trash racks, low flow channels, outlet structures, riprap or gabion aprons, and cleanouts.

Sediment removal should take place when the basin is thoroughly dry. Disposal of debris, trash, sediment, and other waste material should be done at suitable disposal/recycling sites and in compliance with all applicable local, state, and federal waste regulations.

5.2.7.2 Vegetative Maintenance

Mowing and/or trimming of vegetation must be performed on a regular schedule based on specific site conditions. Grass outside of the bioretention system should be mowed at least once a month during the growing season. Vegetation within the bioretention system must be carefully maintained so as not to compact the soil, and by using hand-held tools, such as a hand held line trimmer. Vegetated areas must be inspected at least annually for erosion and scour. Vegetated areas should also be inspected at least annually for unwanted growth, which should be removed with minimum disruption to the planting soil bed and remaining vegetation.

When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. Once established, inspections of vegetation health, density, and diversity should be performed at least twice annually during both the growing and non-growing seasons. All use of fertilizers, mechanical treatments, pesticides and other means to assure optimum vegetation health should not compromise the intended purpose of the bioretention system. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides whenever possible.

5.2.7.3 Watering Requirements

Water is needed once a week during the first 2 months of planting, and then as needed during the entire growing period (April – October). Watering the vegetation on an “as needed basis” helps ensure a healthy condition and pleasing appearance. During dry periods the underdrain may cause the planting soil to dry out, resulting in plant stress.

5.2.7.4 Removal of Debris and Dead Plants

Experience has shown that up to 10 percent of the plants may die off in the first year. The 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. The typical thresholds below which replacement is required are 85 to 90 percent survival of plants and 100 percent survival for trees.

5.2.7.5 Inspection

It is highly recommended that a spring maintenance inspection and cleanup plan be in place and conducted for each bioretention area. The following is a list of some of key maintenance problems to look for and take care of them accordingly.

- Check to see if 75 to 90 percent cover of mulch and vegetation has been achieved in the soil bed

- Check the bioretention bed for evidence of mulch floatation, excessive ponding, dead plants or concentrated flows

- Check for accumulated sediment and trash at filter strips, curb cuts, gravel diaphragms, pavement edges that may prevent flow from entering the bed, and check for other signs of stormwater bypassing.

- Check for clogged or slow-draining soil media or a crust formed on the top of soil bed layer

The most common non-routine maintenance problem involves standing water inside the basin. If water remains on the surface for more than 72 hours after a storm, it is an alarm that the soil bed and/or the underdrain perforated pipe is not functioning properly and may have become clogged. This is a serious problem and a precursor to practice failure and, thus, be addressed promptly. 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 snaked.

5.2.8 Benefits

The use of bioretention not only has the potential for quantity control and water quality, it also improves aesthetics and can increase property value.

- Can be very effective for removing fine sediment, trace metals, nutrients, bacteria, and organic
- Layout of bioretention facilities can be very flexible, and selection of plant species can provide a wide variety of landscape designs
- Can be applied in many different climates and geologic environments, with some minor design modifications
- Ideally suited for many highly impervious areas, such as parking lots, commercial roofs, and within public right of way
- Reduces the size and cost of downstream stormwater control facility and/or storm drain systems by runoff reductions *via* infiltration and evapotranspiration in upland areas.
- Reduces downstream flooding and protects streambank integrity by dampening flow peaks.
- Can be applied as stormwater retrofit, by modifying existing landscaped areas

Table 5-3. Suggested Maintenance Activities for Bioretention

	Task	Frequency	Maintenance Notes
1	Mowing of grass filter strips and bioretention turf cover	As needed	At least three times a year
2	Spot weeding, erosion repair, sediment, trash and debris removal, and mulch raking	Twice each year	
3	Replant vegetation to maintain desired planting density, remove invasive plants, stabilize the contributing area to prevent concentrated flow and erosion	As needed	Vegetative cover should be maintained at 75 to 90%. When vegetation falls below 50%, replant area in accordance with original specifications.
4	Spring inspection and clean up	Annually	
5	Remove sediment in pre-treatment cells and inflow/outflow points	Annually	
6	Pruning of Plants	1 to 2 times/yr	Nutrients cause vegetation to flourish and thus need pruning
7	Mulching	Biannually	Use hard wood to suppress weeds and retain moisture
8	Watering	As needed	Initially more frequently
9	Inspect inflow/overflow	After each storm	Check for clogging, rubbish, and debris

5.3 VEGETATED SWALES

5.3.1 Description

Vegetative swales are stormwater runoff conveyance systems that provide surface flow as an alternative to underground storm sewer systems. Vegetated swales are shallow in depth and configured as linear channels, with parabolic or trapezoidal cross sections (Photo 5-7 and Photo 5-8). Vegetated swales are densely planted with a variety of trees, shrubs, grasses, and other herbaceous plants. They can infiltrate entire stormwater runoff from low flows or carry runoff from heavy rains to storm drains or directly to surface waters.

Vegetative swales provide reduction in peak flow by increasing time of concentration and reducing runoff volume through infiltration and evapotranspiration. Vegetated swales provide improved water quality through settling, filtering, infiltration and plant uptake of pollutants from stormwater runoff. Swales can also provide pre-treatment for other stormwater treatment practices.

Vegetated swales are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography and soils permit. Contrary to a concrete or riprap lined drainage channel or ditch, vegetated swales are aesthetically pleasing and can be landscaped similar to bioretention. Vegetated swales are generally less expensive to construct and maintain than concrete/riprap lined channels.

Photo 5-7. Vegetated Swale Adjacent to Impervious Parking Lot

Photo 5-8. Vegetated Swale in a Commercial Setting

5.3.2 Types of Vegetated Swales

There are three types of grass swales: grass swale, wet swale, and bio-swale. Brief descriptions of each are provided below.

5.3.2.1 Grass Swale

Grass swale (also known as grass channel) is quite similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design

velocity for water quality treatment of small storm events (Figure 5-9). Grass swales are the least expensive option because they are constructed in native soils without the use of manufactured soil media. A common application of a grass swale is as a pretreatment to other structural stormwater treatment practices, such as bioretention (as described in Section 5.1).

The length of the swale is generally equivalent to the contributing impervious area. The runoff enters the grass swale as lateral sheet flow and the total contributing drainage area cumulatively increases along the length of the swale. The treatment component of the swale can extend to a greater length for additional storage.

Grass swales can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system. The performance of grass swales will vary depending on the underlying soil permeability. Grass swales, however, are not capable of providing the same stormwater functions as bio-swales as they lack the storage volume associated with the bio-swale's cross section (engineered soil media and gravel layers). Their runoff reduction performance can be boosted when compost amendments are added to the bottom of the swale. Grass swales can also be used to treat runoff from the managed turf areas of turf-intensive land uses, such as sports fields and golf courses, and drainage areas with combined impervious and turf cover (e.g., roads and yards).

Photo 5-9. Grass Swale

5.3.2.2 Wet Swale

Wet swales are similar to grass swales but intersect the groundwater table, and behave almost like a linear wetland cell. This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment.

These linear wetland cells often intercept shallow groundwater to maintain a wetland plant community. The saturated soil and wetland vegetation provide an ideal environment for gravitational settling, biological uptake, and microbial activity. The cells are formed within the

channel to create saturated soil or shallow standing water conditions (typically less than 6 inches deep).

5.3.2.3 Bio-Swale

A bio-swale is a linear adaptation of a bioretention system that lines the edge of a contributing impervious area such as a roadway or parking lot (Figure 5-10). The cross section of a bio-swale is similar in design to traditional bioretention areas (see Section 5.1, *Bioretention*). The design incorporates a manufactured/engineered soil media and gravel layer under the channel. The gravel layer may or may not have an underdrain system (perforated pipe along the length of the swale).

The bio-swale is a soil bio-filtering system that filters and temporarily stores the stormwater runoff. If the underlying soils are very permeable, runoff infiltrates and the system functions exactly like a bioretention system without an underdrain. If the bio-swale has an underdrain, the runoff treated by the soil media flows into the underdrain, which conveys treated runoff back to the storm drain system further downstream (or daylights to surface flow), functioning like an off-line bioretention. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale beneath the filter media.

Photo 5-10. Typical Bio-Swale

5.3.3 Planning Considerations

5.3.3.1 Applications

The linear nature of vegetative swales makes them well-suited to treat roadway, low- and medium-density residential roadway runoff, or commercial applications where there is real estate to grade a swale. Typical applications of vegetative swales include the following:

- Within a roadway right-of-way, along roads and highways
- At roof downspout discharge points
- Along edges of paved areas (roads, parking lots), parking lot islands, intermediary common areas, open spaces, or adjacent to buildings.
- Within residential developments and commercial properties
- Pre-treatment for other LID practices
- Alternative to conventional curb/gutter and storm sewer

5.3.3.2 Constraints

Vegetated swales have some limitations, including:

- Individual grass swales cannot treat a very large drainage area
- Wet swales may become a nuisance due to mosquito breeding
- A thick vegetative cover must be maintained for proper function
- Vegetated swales are not recommended when residential density exceeds more than 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel
- Runoff from hotspot land uses, such as gas stations and auto repair shops, should not be treated with infiltrating dry swales – an impermeable liner should be used when hotspot runoff is filtered

5.3.4 Design Criteria and Specifications

Vegetated swales can be designed to be simple, such as a grass swale, or more complex, such as the bio-swales, but all types require space and the appropriate topography or grading to convey water. The key to designing a vegetated swale is to ensure the conveyance of stormwater runoff from the impervious surface to either a receiving waterbody, a stormwater system, or to infiltrate

to groundwater while slowing the velocity of the runoff and increasing the time of concentration. Design criteria and specifications are discussed below and presented in Table 5-4 for all three types of vegetated swales.

5.3.4.1 Available Space

Vegetative swale footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Dry swales should be approximately 3 to 10 percent of the size of the contributing drainage area, depending on the amount of impervious cover.

5.3.4.2 Site Topography

Vegetative swales should have longitudinal slopes of less than 4 percent, but preferably less than 2 percent. The gradual slope helps to reduce the velocity of flow in the channel.

5.3.4.3 Contributing Drainage Area

The maximum contributing drainage area to a bio-swale should be 5 acres, but preferably not more than two acres. When bio-swales or vegetated swales treat larger drainage areas, the velocity of flow through the surface channel often becomes too great to treat runoff or prevent erosion in the channel. Similarly, the longitudinal flow of runoff through the soil, stone, and underdrain may cause hydraulic overloading at the downstream sections of the swale. An alternative is to provide a series of inlets or diversions that convey the treated water to an outlet location.

5.3.4.4 Soils

Soil conditions do not constrain the use of vegetated swales, although they normally determine whether an underdrain is needed. Low-permeability soils with an infiltration rate of less than 1/2 inch per hour, such as those classified in Hydrologic Soil Groups (HSG) C and D, will require an underdrain.

5.3.4.5 Depth to Water Table

Restrictions on the depth to groundwater depend on the type of swale used. The bottom of a grass swale or bio-swale should be at least 2 feet above the seasonally high groundwater table, to ensure that groundwater does not intersect the swale bottom, since this could lead to groundwater contamination or practice failure. In a wet swale it is permissive to intersect the groundwater table since treatment is enhanced by the saturated conditions.

5.3.4.6 Hydraulic Capacity and Swale Size

Vegetated swales are usually sized to temporarily store and infiltrate the “first flush” (one inch) storm event. In addition to treating runoff for water quality, grass swales need to convey larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales

should also have the capacity to pass larger storms (typically a 10-year storm) safely**.** This means the swale should contain the 10-year design flow within its banks, so the swale's surface dimensions are more often determined by the need to pass the 10-year storm events, which can be a constraint in the siting of vegetated swales within existing rights-of-way (e.g., constrained by sidewalks or roads). The maximum ponding time is 48 hours, though 24 hours is more desirable. Studies have shown that the maximum amount of swale filtering occurs for water depths below 6 inches.

A major difference between vegetated swales and other stormwater treatment practices is the method used to size the practice. Most stormwater treatment practices are sized by volume of runoff. That is, the practice captures and treats a defined water quality volume, or the volume of water. The grass swale, on the other hand, is based on flow rate (i.e., a peak flow from the water quality storm; this varies from region to region but a typical value is the one inch storm), grass swales should be designed to ensure that runoff takes an average of ten minutes to flow from the top to the bottom of the channel. Bio-swales use a combination of this sizing method but also incorporate storage in the soil media and gravel layers.

5.3.4.7 Available Hydraulic Head

A minimum amount of hydraulic head is needed for effective bio-swales, measured as the elevation difference in elevation between the inflow point and the downstream underdrain invert. Bio-swales typically require 3 to 5 feet of hydraulic head since they have both a filter bed and an underdrain layer.

5.3.4.8 Vegetation

The dense vegetation helps reduce flow velocities, protect the swale from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel of the swale before the turf has been established, either with a temporary grass cover, or the use of natural or synthetic erosion control products.

5.3.4.9 Channel Geometry

Although there are different design variations of the vegetated swales *(*e.g., grass, wet, and bio-swale), several design considerations are common to all. For example, the cross-sectional geometry of all three options is similar. Channels should generally have a trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter). Designing the channel with flat side slopes also maximizes the wetted perimeter. The wetted perimeter is the length along the edge of the channel cross section where runoff flowing through the channel is in contact with the vegetated sides and bottom of the swale. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage filtering and infiltration. Another advantage of flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope. The flat channel for each type of vegetated swale should be between two and eight feet wide. The minimum width ensures filtration for water quality treatment, and the maximum width prevents braiding, the formation of small channels within the swale bottom.

Table 5-4 summarizes design guidance for vegetated swales.

Table 5-4. Vegetated Swale Design Guidance

Design Criteria	Grass Swale	Wet Swale	Bio-Swale
Bottom Width	4 to 8 feet	4 to 8 feet	4 to 8 feet
Side Slope	3H:1V or flatter	3H:1V or flatter	3H:1V or flatter
Longitudinal Slope	2 to 4%	2 to 4%	2 to 4%
Water Quality Treatment	Sized for 1 inch (first flush)	Sized for 1 inch (first flush)	Sized for 1 inch (first flush)
Maximum Contributing Drainage Area	5 acres	5 acres	5 acres
Flow Capacity: 2-year storm	Convey at non-erosive velocity	Convey at non-erosive velocity	Convey at non-erosive velocity
Flow Capacity: 10-year storm	Convey within banks at minimum 6 inches freeboard	Convey within banks at minimum 6 inches freeboard	Convey within banks at minimum 6 inches freeboard
Vegetation	Grass	Wetlands plants	Native vegetation that can handle ponding or drought
Depth from Channel Bottom to Water Table	Minimum 2 feet	Water table intersects channel	Minimum 2 feet
Gravel Layer/Underdrain	No	No	Yes
Engineered Filter Media	No	No	Yes

5.3.5 Components of a Vegetated Swale

The design components of vegetated swales vary between the grass swale, wet swale and bio-swale. The key elements of a vegetated swale are:

- Pretreatment
- Conveyance and Overflow
- Landscaping and Planting Plan
- Soil Media (for bio-swale sonly)
- Underdrain and Gravel Storage Layer (for bio-swales only)

5.3.5.1 Pretreatment

No matter which swale type is chosen, pre-treatment is recommended to allow for removal of sediments from the stormwater runoff. Pre-treatment could be in the form of a small forebay upstream of the channel to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river run gravel) can also be used to pretreat runoff that enters the sides of the channel. In addition, a grass filter strip (minimum 10 feet wide) along the length of the contributing impervious drainage area, such as parking lot, could be used.

5.3.5.2 Conveyance and Overflow

The bottom width and slope of a vegetative swale should be designed such that the velocity of flow from a 1-inch rainfall will not exceed 3 feet per second. Gravel check dams may be used to achieve the needed runoff reduction volume and flow velocity. Check dams should be spaced based on channel slope and ponding requirements. Use non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric, and include weep holes. Wood used for check dams should consist of pressure-treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.

5.3.5.3 Landscaping and Planting Plan

Designers should choose grasses, herbaceous plants, or trees that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Salt tolerant grass species should be chosen for vegetative swales located along roads. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover. Grass species should have the following characteristics: a deep root system to resist scouring, high stem density with well-branched top growth, water-tolerance, resistance to being flattened by runoff, and an ability to recover growth following inundation. Photo 5-11 illustrates the thick vegetation of a dry swale. To find a list of plant species suitable for your area, consult the local USDA NRCS office.

Photo 5-11. Dry Swale

5.3.5.4 Soil Media (for bio-swales only)

Bio-swales require replacement of native soils with an engineered soil media. The soil media provides adequate drainage, supports plant growth, and facilitates pollutant removal within the swale. The soil media for bio-swales is identical to that used for bioretention systems. The soil media should be obtained from an approved vendor to create a consistent, homogeneous fill media.

5.3.5.5 Underdrain and Gravel Storage Layer (for bio-swales only)

Where the underlying soil infiltration rates meet applicable requirements, bio-swale design would not need an underdrain. In case of impermeable soils (infiltration rates less than 0.50 inches per hour), a gravel storage layer will surround a perforated underdrain pipe to ensure proper drainage after storms. The underdrain should be encased within a gravel bed. The depth of the gravel storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria. Typical construction details of a bio-swale with an underdrain and gravel storage layer are given in Figure 5-8.

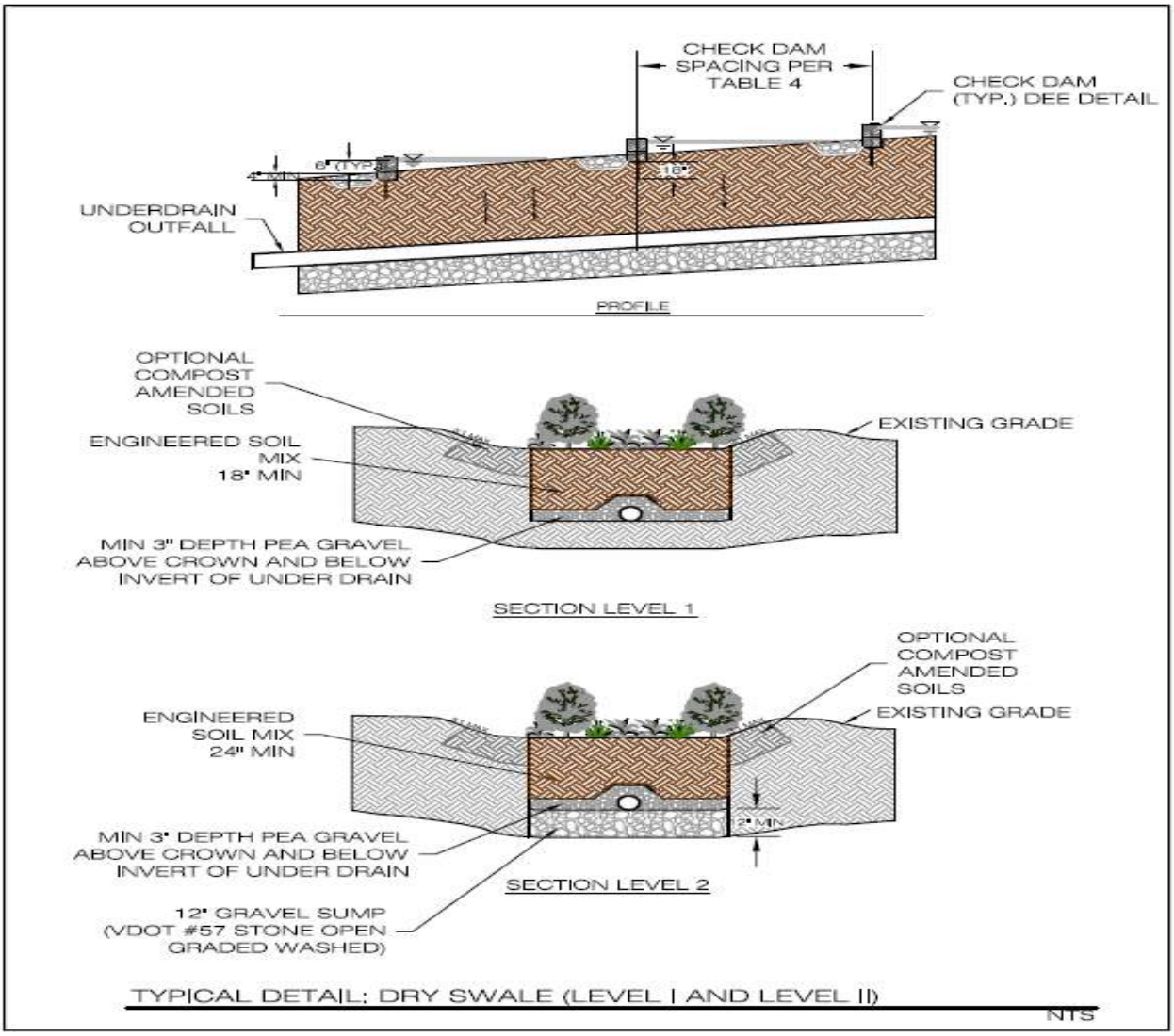

Figure 5-8. Typical Design Details of a Bio-Swale

5.3.6 Materials

Bio-swales are the only swale type that involves manufactured materials. See the materials specifications in Table 5-2 in Section 5.2.5 for bioretention materials. Designers should follow their local stormwater management requirements when specifying materials.

5.3.7 Construction Considerations

5.3.7.1 General

Construction of the vegetated swale should begin when the up-gradient site has been sufficiently stabilized and state-approved temporary erosion and sediment control measures are in place. Use light equipment and avoid excessive compaction and/or land disturbance during construction of the vegetated swale. Excavating equipment should operate from the sides of the swale and never on the bottom. If excavation leads to substantial compaction of the subgrade, excavate 18 inches

and replace with a blend of topsoil and sand to promote infiltration and biological growth. Vegetative swales should be fully protected by silt fence or construction fencing, particularly if they will provide an infiltration function (i.e., have no underdrains) during construction within the immediate area.

Vegetative swales should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical given that swales are a key part of the drainage system at most sites. In these cases, temporary erosion and sediment controls such as dikes, silt fences and other similar measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, erosion control fabric should be used to protect the channel, and excavation should be no deeper than 2 feet above the proposed invert of the bottom of the planned underdrain. Vegetative swales without an underdrain that provide for infiltration must be fully protected by silt fence or construction fencing to prevent compaction by heavy equipment during construction within the immediate area.

5.3.7.2 Construction Sequence

The following is a typical construction sequence to properly install a vegetated swale, although the steps may be modified to adapt to different site conditions.

1. Installation may only begin after the entire contributing drainage area has been stabilized.

2. Excavators or backhoes should work from the sides to excavate the vegetative swale area to the 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 project area.

3. The bottom of the swale should be ripped, roto-tilled or otherwise scarified to promote greater infiltration.

4. Rough grade the swale. For bio-swale, continue to Step 5. For grass and wet swale, skip to Step 7.

5. Place filter fabric on the excavated sides of the vegetated swale with a minimum overlap as specificed by manufacturer. Place the stone needed for storage layer. Lay the perforated underdrain pipe. Add the remaining stone jacket, ensuring a minimum 3 inches of gravel above the top of the underdrain, and then add pea gravel choker layer.

6. Place the engineered soil media in 12-inch lifts until the desired top elevation of the swale is achieved. Wait a few days to check for settlement, and add additional media as needed.

7. Install check dams, driveway culverts and internal pre-treatment features, as specified in the plan.

8. Fine grade the swale.

9. Prepare planting holes for specified trees and shrubs, install erosion control fabric where needed, spread seed or lay sod, and install any temporary irrigation.

10. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

5.3.7.3 Final Inspection

A final construction inspection should be conducted and a punch list developed for facility acceptance. Items to inspect are as follows:

- Check elevations such as the invert of the underdrain, inverts for the inflow and outflow points, and the ponding depth provided between the surface of the filter bed and the overflow structure.

- Check the filter media to confirm that it meets specifications and is installed to the correct depth.

- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.

- Make sure the desired coverage of turf or erosion control fabric has been achieved following construction, both on the filter beds and their contributing side-slopes.

- Inspect check dams and pre-treatment structures to make sure they are properly installed and working effectively.

- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of a vegetative swale occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Also, inspectors should check that the swale drains completely within the minimum 6-hour drawdown period. Minor adjustments are normally needed as a result of this post-storm inspection (e.g., spot reseeding, gully repair, added armoring at inlets or outfalls, and check dam realignment).

5.3.8 Maintenance

Once established, vegetated swales have minimal maintenance needs outside of the spring cleanup, regular mowing, and pruning and management of trees and shrubs. Additional effort

may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pre-treatment cells.

In a bio-swale, the surface of the filter bed can become clogged with fine sediment over time, but this can be alleviated through core aeration or deep tilling of the filter bed. Additional effort may be needed to repair check dams, stabilize inlet points, and remove deposited sediment from pre-treatment cells. Maintenance activities are similar to that of bioretention; refer to Section 5.1.7 for bioretention maintenance.

Table 5-5 is a schedule of inspection and maintenance activities recommended for vegetated swales.

Table 5-5. Suggested Maintenance Activities for Vegetated Swales

	Task	Frequency	Maintenance Notes
1	Re-mulch /re-plant void areas	As needed	
2	Replace diseased trees, shrubs, vegetation	As needed	
3	Clean Overflow	Monthly	Clear leaves and debris
4	Inspect soil and repair eroded areas	Monthly	
5	Remove litter and debris from swale	Monthly	
6	Inspect for sediment buildup, vegetative condtions, etc.	Annually	
7	Inspect all trees and shrubs to evaluate helath	Biannually	

5.3.9 Benefits

Vegetative swales provide reduction in peak flow by increasing time of concentration and runoff volume reduction by infiltration and evapotranspiration. Vegetated swales also provide improved water quality via filtering polluted runoff. They are more aesthetically pleasing than concrete/riprap lined drainage ditch. Vegetated swales are generally less expensive to construct and maintain than lined channels. Vegetated swales protect local and regional water quality by reducing sediment and nutrients; and increase community character and aesthetics. Some benefits are summarized below.

- Can be used in residential and commercial settings
- Inexpensive
- Combines water quality treatment with runoff conveyance
- Reduces runoff velocities
- Low maintenance

5.4 VEGETATED FILTER STRIP

5.4.1 Description

A vegetated filter strip is a densely vegetated strip of land designed to receive stormwater runoff from an impervious area, such as a road or parking lot. These systems function by slowing stormwater runoff and filtering out sediment and other pollutants as the stormwater runoff passes through the filter strip or infiltrates to groundwater. Stormwater runoff is absorbed by the soils and is taken up by plants and transpired or may infiltrate into the ground if the soil is well drained. A properly designed and operating filter strip reduces overland flow velocity and provides water quality treatment by reducing the amount of sediment, organic matter, nutrients, and metals carried in stormwater runoff.

The main purpose of a VFS is to reduce the velocity of the stormwater runoff through the surface roughness of the vegetation and to encourage filtration, sediment deposition, infiltration, absorption, and plant uptake of nutrients from the stormwater runoff. Usually, a vegetated filter strip is used as a pretreatment component in conjunction with a primary stormwater BMP (such as bioretention, vegetated swale, etc.) for slowing runoff velocity and reducing sediment and particulate pollutant load that could otherwise reach the primary BMP and impact its effectiveness.

Vegetated filter strips have historically been used and proven effective on agricultural lands, usually downslope along field crops (Grimser, 2006). In urban settings, vegetated filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, parking lots, and small impervious areas. Sheet flow access from upslope paved areas to the filter strip is a mandatory requirement for its proper function and effectiveness. One challenge associated with filter strips, therefore, is that it is difficult to maintain sheet flow over longer flow paths, so the practice may be "short circuited" by concentrated flows, receiving little or no treatment.

5.4.2 Planning Considerations

5.4.2.1 Applications

The vegetated filter strips are suitable for many types of development projects in residential, commercial and industrial settings. They are usually recommended for use as a pretreatment component for other stormwater BMPs as they slow runoff velocities and can direct stormwater runoff to another BMP, though they do not provide adequate pollutant removal benefits while acting as a standalone practice. As stated above, vegetated filter strips are generally not recommended as “stand alone” features, but as pretreatment systems for other BMPs, such as infiltration trenches, vegetated swales, or bioretention areas. They are generally a poor stormwater retrofit option because they consume a relatively large amount of space and cannot treat large drainage areas (PA DEP, 2006).

Vegetated filter strips rely on their relatively flat cross slope, mild downslope, and dense vegetation to slow and remove stormwater runoff pollutants. These design features ensure that runoff remains as sheet flow while passing through the strip. The Virginia Departement of Conservation and Recreation (2011) recommends that vegetated filter strip systems are effective only where the runoff enters the filter strip, from above the contributing drainage area, as sheet flow and remains in sheet flow condition while flowing through the strip. This requirement limits flow length over impervious surfaces not to exceed 75 feet (Claytor and Schueler, 1996).

The proper planning and construction of a filter strip should consider factors such as: soil characteristics (texture, soil type, hydrologic soil group, infiltration rate, and permeability); the slope, shape, length, and size of the contributing area; and the designed quantity of pollutant removal from runoff (sediment, nutrient, organic matter, metals and hydrocarbons, etc.). The type of vegetation applicable to local climatic conditions, and time of the year to properly establish that vegetation (by seed or sod) are also important considerations. Although, the type of vegetation used can be very broad, the best performance is associated with native plant species having deep, fibrous roots and dense ground patterns such as turf-forming grasses.

5.4.2.2 Constraints

Vegetated filter strips require runoff to enter as sheet flow to work effectively, therefore, they should not receive large volumes of runoff since such flows tend to concentrate and form channels. Channels within a filter strip allow runoff to short-circuit the BMP, rendering it ineffective.

Vegetated filter strips have several other limitations related to their performance and space consumption such as:

- VFSs are not intended to treat concentrated flow and are only effective when runoff flows as sheet flow
- Not recommended for soils with high clay content because VFSs require some infiltration for proper treatment
- Very poor soils that cannot sustain a grass cover are also a limiting factor
- Filter strips require a large amount of space, making them often infeasible in urban environments where land space is limited
- Vegetated filter strips should not receive “hot spot” runoff for potential aquifer contamination, because the practice encourages infiltration
- Sheet flow is the mandatory requirement for proper functioning of the BMP which is difficult to achieve and maintain, especially for longer flow reaches

5.4.3 Design Criteria & Specifications

Vegetated filter strips require minimal design as they essentially a grassed landscape with a gentle to flat slope. Thus, the design and construction criteria are not much different than seeding/sodding a residential lawn. However, some design features are critical to ensure that a vegetated filter strip properly slows stormwater runoff and provides intended water quality treatment. These features include its slope, length, width, and type of surface cover. To be effective, vegetated filter strips require the stormwater runoff to sheet flow across the entire strip.

Key vegetated filter strip design elements are described in several state Stormwater BMP Manuals, such as New Jersey BMP Manual (2003), PA DEP (2006), Virginia DCR (2011), etc., and are also discussed on the USEPA Website: EPA Menu of Stormwater BMPs (http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm) under "Management Measures for Vegetated Treatment Systems. These elements are briefly described in the following sections.

5.4.3.1 General

The basic design parameters for a vegetative filter strip are its longitudinal slope and length (i.e., parallel to flow) and the type of vegetative cover. The vegetation in the filter strip will slow the stormwater runoff; the degree to which the vegetation slows the runoff is associated with the roughness of the vegetation. Different types of vegetation have different roughness coefficients called the Manning's roughness coefficient, n, which refers to the resistance of the bed of a channel to the flow of water. The vegetation is selected to have a certain roughness for slowing runoff velocity which, in combination with vegetated filter strip slope, is used to determine the required filter strip length parallel to flow through the strip. In addition, since runoff from upslope contributing drainage area must enter as sheet flow into the vegetated filter strip, the peak runoff rate originating from the contributing drainage area (such as from a parking lot) must be sufficiently low and uniformly distributed to ensure sheet flow conditions over the entire area. The sheet-flow length limitation, in turn, limits the size of the contributing drainage area to the filter strip and, consequently the peak runoff rate. Details of these and other design parameters are presented in the following sections. The components of a typical vegetated filter strip are shown in Figure 5-9.

5.4.3.2 *Contributing Drainage Area and Runoff Characteristics*

Typically, vegetated filter strips are used to treat very small drainage areas. The limiting design factor, however, is not the drainage area but the sheet flow requirement for the runoff to travel over the impervious area, which limits the length of flow not to exceed 75 feet over the paved area (CWP, 1996). As noted above, the maximum sheet flow travel length over an impervious, paved surface is 75 feet (CWP, 1996). Therefore, the maximum contributing drainage area to a VFS will be limited to an area 75 feet long measured perpendicular to the upslope edge of the filter strip. If the width of the drainage is equal to the width of the vegetated filter strip, then the contributing drainage area is essentially equal to length multiplied by width.

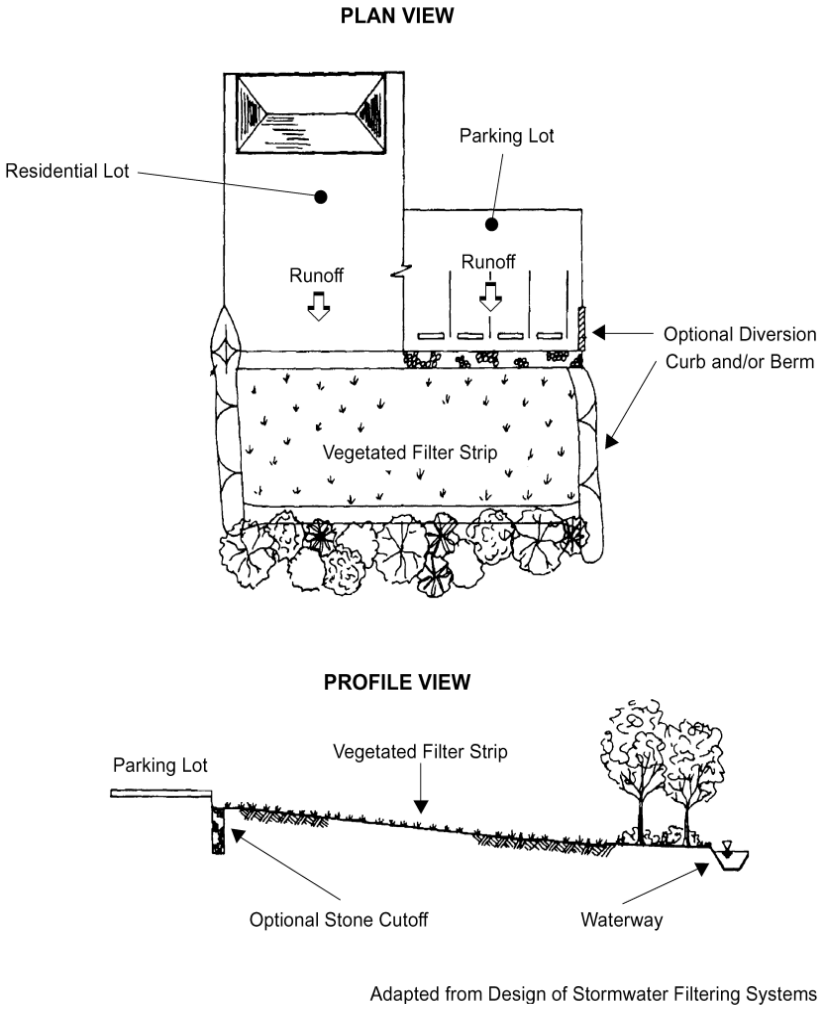

Figure 5-9. Vegetated Filter Strip Components
(Source: CWP, 1996)

5.4.3.3 *Vegetation Cover and Manning's Roughness Coefficient, n*

Vegetation for filter strips may be comprised of turf grasses, meadow grasses, shrubs, and native vegetation. Native vegetation helps to minimize erosion by stabilizing the soil with deep root structure common in native plants. A vegetated filter strip should be densely vegetated with a mix of erosion resistant species that have fibrous root system to effectively bind the soils. The selection of plants should be based on their compatibility with local climatic conditions, soils, topography; and their ability to tolerate urban thermal stress, variable soil moisture conditions, drought, and ponding conditions.

Table 5-6 below presents Manning's roughness coefficient, n, values for various surface covers. These Manning's "n" values, in combination with respective slopes may be used to determine maximum filter strip lengths for VFS systems (New Jersey BMP Manual, 2003).

Table 5-6. Manning's Roughness Coefficients (n)

Vegetation Cover in Filter Strip	Manning's N
Dense Grass	0.25
Sod	0.35
Meadow or Woods with Dense Vegetation	0.35
Natural Woods with Dense Vegetation	0.40

(Source: New Jersey BMP Manual, 2003)

5.4.3.4 Filter Strip Slope

The vegetated filter strips should, in general, be designed for slopes, parallel to flow length, between 2 and 6 percent. The maximum slope should not be more than 8 percent, whereas the minimum should be not less than 2 percent to promote positive drainage. Steeper slopes will increase flow velocity and lead to concentration of runoff and likelihood of erosion and gullying. In addition, as the slope increases, the treatment effectiveness decreases. Slopes flatter than 2 percent may be appropriate in some geographic regions, but are discouraged in residential areas due to the tendency for surface ponding that creates potential nuisance conditions. The recommended cross slope for a vegetated filter strip is 1 percent or flatter.

The maximum filter strip slopes for various vegetation covers and soil types for a vegetated filter strip are shown in Table 5-7. Except for coarse sandy soils, the recommended slopes for other soils types and hydrologic soil groups (HSG) are mostly in the range of 8 percent. County soil surveys can help determine the soil type and HSG within a vegetated filter strip, although site soil testing may be necessary for accurate design.

Table 5-7. Maimum Vegetated Filter Strip Slopes for Various Soil Types

Soil Type	HSG	Maximum Slope, %	Maximum Slope, %
		Dense Grass, Sod, and Bermuda Grass	Woods with Dense Underbrush
Sand	A	7	5
Sandy Loam	A	8	7
Loam, Silt Loam	B	8	8
Sandy Clay Loam	C	8	8
Clay Loam, Silty Clay, Clay	D	8	8

(Source: New Jersey Stormwater BMP Manual, 2003)

5.4.3.5 *Filter Strip Length*

In vegetated filter strip systems, the limiting design factor is the length of the flow both over the contributing drainage area, as well as, through the vegetated filter strip itself; sheetflow needs to be maintained across the contributing drainage area and the vegetated filter strip (PA DEP, 2006). Vegetated filter strip length (the dimension parallel to flow path) is a function of slope, vegetation type, soil type, and the desired amount of pretreatment. Figure 5-10 provides vegetated filter strip lengths as a function of various vegetation types (Manning's roughness, n, Table 5-6) and slopes, Table 5-7. It should be noted that that linear interpolation may be used for Manning's n values not specifically plotted in the figure. As shown in the figure, the minimum filter strip length is 20 feet regardless of slope or Manning's n value**.**

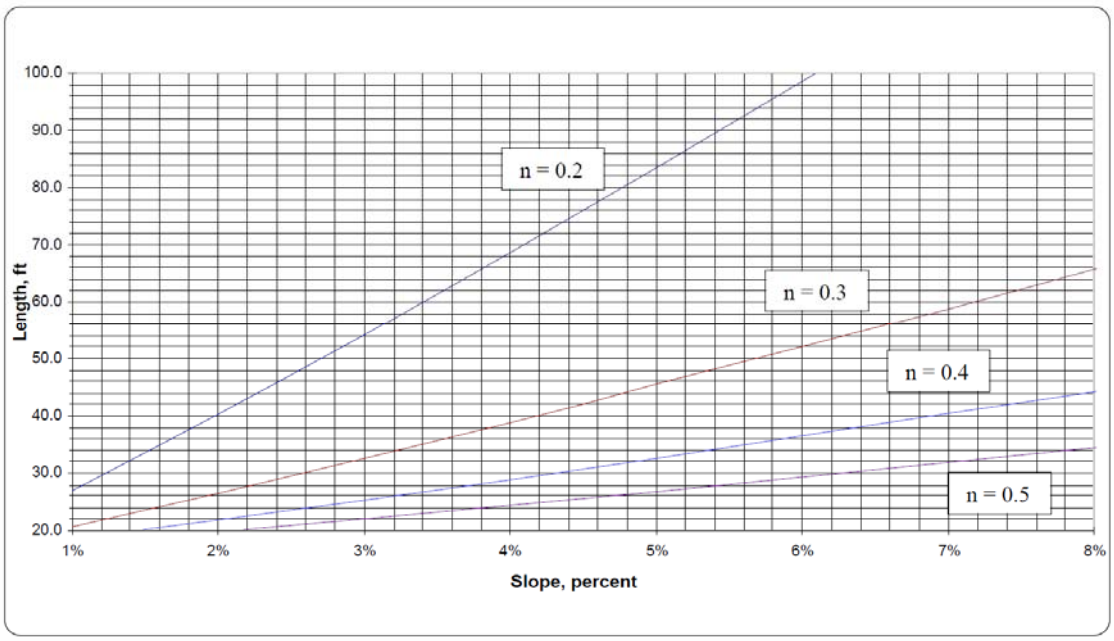

Figure 5-10. Vegetated Filter Strip Length Determination

(Source: New Jersey BMP Manual, 2003)

It is also important to note that the lengths shown in Figure 5-10 are applicable only for filter strips with coarse soils, such as sands. For filter strip areas with less coarse soils, such as silt and clays, the length shown in the Figure 5-10 must be multiplied by the factors shown in Table 5-8.

Table 5-8. Filter Strip Length Correction Factors

Soil Type	HSG	Correction Factor
Sand	A	1.0
Sandy Loam	A	1.1
Loam, Silt Loam	B	1.3
Sandy Clay Loam	C	1.5
Clay Loam, Silty Clay, Clay	D	1.8

(Source: New Jersey BMP Manual, 2003)

5.4.3.6 Filter Strip Width and Travel (Contact) Time

The vegetated filter strip should be designed to provide a 20-minute travel time (contact time) for runoff passing through the filter strip. The Iowa SUDAS (2000) recommends that this 20-minute level of contact time with vegetation would provide approximately 85 percent removal of total suspended solids.

The width of the VFS, perpendicular to flow length, should be sized according to Manning's equation to limit the flow depth to one half inch or less. As a general rule, the width should be equal to the width of the contributing drainage area above. When this is not possible, a pea gravel diaphragm or a level spreader should be provided to reduce the flow width to that of the filter strip. CWP (1996) and Virginia DCR (2011) guidelines suggest a minimum vegetated filter strip width of 25 feet at 1 percent or flatter cross slope.

5.4.3.7 Pea Gravel or Gravel Trench

A pea gravel diaphragm should be installed along the entire up-gradient edge of the strip. The pea gravel diaphragm serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader or energy dissipater for maintaining sheet flow as runoff flows over the filter strip. The pea gravel diaphragm is created by excavating a 2-foot wide and 1-foot deep trench that runs on the same contour as the top of the filter strip. A layer of geotextile filter fabric should be placed between gravel and underlying soil trench. When placed directly adjacent to an impervious surface (parking lot), a drop (between the paved edge and the trench) of 2-3 inches is recommended.

5.4.3.8 Permeable Berm

Filter strip effectiveness may be enhanced through the addition of a pervious berm at the toe of the slope for providing a temporary ponded area. The filter strip should be designed with a permeable berm of sand and pea gravel at toe of the vegetated filter strip. The runoff volume ponded behind the berm should be equal to the water quality volume. The water quality volume is the amount of runoff that will be treated for pollutant removal inside the filter strip. Typical water quality volume is the runoff from a 1-inch storm or ½-inch of runoff over the entire

contributing drainage area to the filter strip. The permeable berm should have the following design characteristics:

- A wide and shallow trench, 6-12 inches deep, should be excavated at the upstream toe of the berm
- Media for the berm should consist of 40 percent excavated soils, 40 percent coarse sand, and, and 20 percent pea gravel
- The berm, 6 to 12 inches high, should be located down gradient of the excavated trench and should have gentle side slopes to promote easy mowing
- Stone may be used to armor the top of the berm to handle runoff overtopping

A permeable berm is not needed when a VFS is used as a pretreatment to another stormwater practice.

5.4.4 Materials

Vegetation selected for filter strips should have dense growth to provide good, uniform soil cover, and a fibrous root system for stability. In addition, the type of vegetation selected should be adapted to local soil and climatic conditions, and have good regrowth characteristics following dormancy and mowing. Common materials used in filter strips are outlined in Table 5-9.

Table 5-9. Vegetated Filter Strip Material Specifications

Material	Specification
Gravel Diaphragm	Pea gravel ASTM D 448, size #6 or #8 (1/8-nch to 3/8-inch dia); DOT stone #57: Diaphragm should be 2 feet wide, 1 feet deep, and at least 3 inches below the edge of pavement
Permeable Berm	Not required when VFS is used as a pretreatment practice; otherwise use 40% topsoil, 40% sand, and 20% gravel
Geotextile	Non-woven, ASTM D4491
Compost	Compost shall be derived from plant material

(Source: Virginia DCR, 2011)

5.4.5 Construction Considerations

In general, the same considerations apply for the installation of a filter strip as for the establishment of lawns and other landscaped areas. Land grading and other soil surface preparation is necessary to ensure establishing vegetation and that the runoff will enter the strip in the form of sheet flow.

Begin vegetated filter strip construction only when the up-gradient site has been sufficiently stabilized and “state-approved” temporary erosion and sediment control measures are in place.

Construction should be initiated, if possible, at a time of the year when successful establishment without irrigation is most likely. However, irrigation may be needed in periods of little or no rain.

5.4.5.1 Construction Sequence

The following procedures should be followed during construction.

1. Rough grade the site using light equipment to avoid compaction.

2. If existing topsoil is stripped during grading, it should be stockpiled for later use.

3. Prepare a firm seedbed by plowing and cultivating to a depth of 6-12 inches.

4. Plant the seed shallow (1/4-inch) with a seed drill or by broadcast. Make sure the seed is on a firm seedbed to obtain good seed-to-soil contact.

5. Before seeding, apply soil amendments that would ordinarily be used for turf grasses including fertilizer, lime, compost or gypsum per soil tests.

6. Use native vegetation as recommended by your local USDA NRCS Extension Office.

7. Must use wheat straw or blanket mulch over seeded area to ensure germination and early plant establishment.

8. Irrigate after seeding. During periods of dry weather, germination of seed and plant establishment may require subsequent irrigations.

5.4.6 Maintenance

Vegetated filter strips require regular maintenance. Inspections are critical during the first few years to ensure that the VFS becomes adequately established. Once a VFS is established and is functioning, as intended, periodic maintenance such as watering, fertilizing and spot repair may still be necessary. Overseeing and replanting should be limited to those species which have exhibited the ability to thrive.

Maintenance for grassed filter strips may consist of the following simple steps and as summarized in Table 5-10.

Table 5-10. Suggested Maintenance Activities for Vegetated Filter Strips

Activity	Frequency
Inspect pea gravel diaphragm for clogging and remove build-up sediment	Annually
Inspect vegetation for rills and gullies and correct	Annually
Seed or sod bare areas	Annually
Ensure that grass has established. If not, replace with an alternate species	Annually
Mow during growing season	As needed
Remove weeds and invasive species	As needed

5.4.7 Benefits

Vegetated filter strips are agricultural BMPs and their effectiveness in urban settings, especially as a pretreatment practice, has not been widely investigated and established (Yu et al., 1992). However, some significant benefits and limitations of vegetated filter strip systems include:

- Water quality treatment via filtering of suspended sediments and NPS pollutant control
- Provides pretreatment control to capture coarse sediments before they reach main stormwater BMP such as a bioretention or vegetated swale
- Can be used to treat runoff along residential streets, stream corridors, and parking lots
- Provides an aesthetically pleasing appearance

5.5 PERMEABLE PAVEMENTS

Pervious or permeable pavements consist of a permeable surface course underlain by a uniformly graded stone-bed laid on uncompacted soil. The surface course consists of porous asphalt, porous concrete, or various porous pavers. Stormwater drains through the permeable surface course to the stone bed, where it is temporarily stored to provide peak flow reduction and promote infiltration to the underlying soils. A layer of geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The application of permeable pavement allows stormwater runoff to infiltrate the surface more evenly, resulting in a reduction of runoff and minimizes concentrated flows. Permeable pavements and pavers provide water quantity and quality benefits by promoting infiltration, while still providing a stable load-bearing surface without increasing the project impervious area.

5.5.1 Types of Permeable Pavement

There are several types of permeable pavements and pavers. For the purposes of the Army LID Technical User Guide, the four main categories of permeable pavements and pavers will be discussed: porous asphalt, pervious concrete, permeable concrete pavers, reinforced turf.

5.5.1.1 Porous Asphalt

Porous asphalt is similar to conventional asphalt in structure and form, except that the fines (sand and finer material) from parent asphalt mix have been removed. The same mixing and application is used for porous or pervious asphalt as the impervious asphalty; only the formula for the asphalt is different.

Porous asphalt is appropriate for only pedestrian-use areas and for very low-volume, low-speed vehicular areas such as overflow parking areas, residential driveways, alleys, and parking stalls. Photo 5-12 shows porous asphalt use on a playground and basketball court.

Photo 5-12. Porous Asphalt in Playground

5.5.1.2 Pervious Concrete

Pervious concrete can be used in place of conventional concrete in most situations. Smaller amounts of fines, larger pea gravel, and a lower water-to-cement ratio are used to achieve a pebbled, open surface that is roller compacted. In northern and mid-Atlantic climates, such as Pennsylvania, pervious concrete should always be underlain by a stone subbase designed for stormwater management and should never be placed directly onto a soil subbase. Pervious concrete has a coarser appearance than its conventional counterpart, as seen in Photo 5-13. Care must be taken during placement to avoid working the surface and creating an impervious layer.

Photo 5-13. Standard and Porous Concrete

5.5.1.3 Permeable Concrete Pavers

Permeable pavers consist of interlocking units (often concrete or brick) that have pervious pea gravel, vegetation or mulch in the spaces between the units to form a grid system. The pervious spaces between the pavers allow for filtration of stormwater through layers of open-graded aggregated and infiltration into the underlying soils. Permeable pavers provide pervious surfaces throughout the otherwise impervious surface and also enhance the aesthetic appeal of the area. They are most often used for driveways, small parking areas, entryways, walkways, plazas, patios or terraces to achieve a more aesthetically pleasing appearance. Photo 5-14 illustrates the use of two colors of permeable pavers to outline parking spots within a larger parking lot.

Photo 5-14. Permeable Pavers at Multnomah Art Center
(Source: Portland Philadelphia Stormwater Manual)

5.5.1.4 Reinforced Turf

Reinforced turf and gravel are highly permeable as they have voids where, once installed, grass, flowers, or vegetation are planted inside and allowed to grow through the paver. The pavers themselves can be made from plastic, concrete, or gravel, and can be used in high traffic areas (Photo 5-15).

Reinforced turf consists of interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking. The reinforce turf is underlain by a stone and/or sand layer to filter pollutants and temporarily store runoff. There are also products available that provide a fully permeable surface through the use of high strength plastic geogrids (often made from recycled materials) filled with gravel or grass. After heavy rains, the grids act as mini holding-ponds, and allow water to gradually absorb into the soil below.

Reinforced turf applications work well for fire access roads, overflow parking, and occasional use parking. Reinforced turf application allows for the reduction of the required standard pavement width for paths and driveways that must occasionally provide for emergency vehicle access.

The reinforced turf grides provide a support structure for heavy vehicles, and prevent erosion. While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic

will not absorb water and diminish soil moisture conditions. A number of products (e.g., Grasspave, Geoblock, GravelPave, Grassy Pave, Geoweb) are available and the designer is encouraged to evaluate and select a product suitable to the design in question.

Photo 5-15. Examples of Reinforced Turf

5.5.2 Planning Considerations

Permeable pavements can be used as a substitute for impervious pavements in most land use areas to reduce stormwater runoff. However, as there are many opportunities to employ permeable pavers, there are also many constraints. Permeable pavements work well in parking lots and some roads but the may be limited in supported the weight of heavy vehicles or heavy traffic. There are also human safety concerns, such as use in handicap parking areas, where pavers can be a hazard if the surface is uneven.

5.5.2.1 Applications

There are several opportunities to incorporate permeable pavements into many types of land uses. Such applications include:

- Ultra urban, commercial, industrial, retrofit, highway/roadway(limited use), and residential streets and driveways
- Public play grounds, tennis courts, parking lots, plazas, and similar uses
- Areas adjacent to tree islands in parking lots (Photo 5-16)
- Service drives and emergency vehicle access lanes and fire lanes
- Pedestrian sidewalks (Photo 5-17 and Photo 5-18)

Photo 5-16. Permeable Pavers in Parking Lots Adjacent Tree Island

Photo 5-17. Porous Asphalt Along Pedestrian Walkways

Photo 5-18. Pervious Concrete Along Roads and Streets

5.5.2.2 Constraints

Permeable pavements are not suitable in areas where the underlying soils do not drain well. Permeable pavements should be laid on uncompacted, level soil. Compacting the subgrade will prevent runoff from being able to infiltrate. If new fill is required, it should consist of additional stone and not compacted soil.

Permeable pavements/pavers are not recommended where:

- Excessive sediment could be deposited on the surface
- Steep erosion prone areas that are likely to deliver sediment and clog pavement
- Underlying soils are composed of fill material, which can become unstable when saturated
- Maintenance is unlikely to be performed at appropriate intervals
- Porous asphalt is not recommended for slopes exceeding 5%

- Pervious concrete is not recommended on slopes exceeding 6%

- Porous asphalt not ideal for high traffic/high speed areas because it has lower load-bearing capacity than conventional asphalt.

- Areas where requirements under the Americans with Disabilities Act apply, such as handicap parking spaces

- Permeable pavement should not be used on stormwater "hotspot land use" (such as gas stations) applications with high pollutant loads because the rain falling directly on the paved surface cannot be pretreated prior to filtering through the pavement section and infiltrating into the subgrade.

5.5.3 Design Criteria & Specifications

Permeable pavements can be used in place of conventional pavements, though additional factors must be considered in the placement and design as there are some structural differences. Design considerations include the permeability of underlying soils, risk of contaminating groundwater in hotspots, and the type of permeable pavement to be used.

5.5.3.1 Site Investigation

The overall site should be evaluated for potential pervious pavement/infiltration areas early in the design process. Pervious pavement and infiltration beds should not be placed on areas of recent fill or compacted fill. Any grading that requires fill should be done using the gravel subbase material.

5.5.4 Components of Permeable Pavement Section

A permeable pavement section consists of a pervious surface course (porous asphalt, pervious concrete, permeable concrete pavers or reinforced turf) underlain by layers uniformly graded and clean-washed coarse aggregate with a void space of at least 40 percent. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, site grading, and anticipated loading. Stormwater drains through the surface, is temporarily held in the voids of the stone bed, and then slowly drains into the underlying, uncompacted soil mantle. The stone bed can be designed with an overflow control structure or subdrain so that during large storm events peak rates are controlled, and at no time does the water level rise to the surface course. A layer of geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. Figure 5-11 shows an example of a permeable concrete paver section without an underdrain.

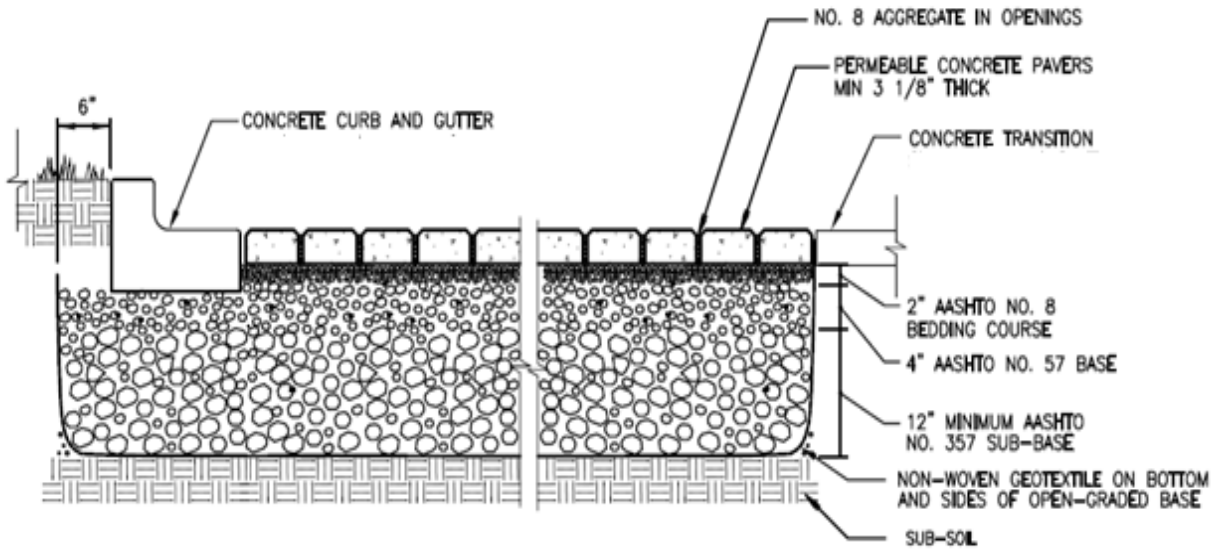

Figure 5-11. Cross Section of Permeable Concrete Paver
(Source: USACE, 2011)

5.5.4.1 Drainage/Overflow

All systems should be designed with an overflow system. Water within the subsurface stone bed should never rise to the level of the pavement surface.

While infiltration beds are typically sized to handle the increased volume from a storm, they should also be able to convey and mitigate the peak of the less-frequent, more intense storms (such as the 10 or 100-year). The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, the need for a detention basin may be eliminated or reduced in size. Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal weir and low-flow orifice is a common type of control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always should include positive overflow from the system.

All pervious pavement installations should have a backup method for water to enter the stone storage bed in the event that the pavement fails or is altered. In uncurbed lots, this backup drainage may consist of an unpaved stone edge or curtain drain connected directly to the bed. In curbed lots, inlets with water quality devices may be required at low spots. Backup drainage elements will ensure the functionality of the infiltration system, if the pervious pavement is compromised.

In areas with poorly draining soils, infiltration beds below pervious pavement may be designed to slowly discharge to adjacent wetlands or bioretention areas. Only in extreme cases (i.e., industrial sites with contaminated soils or karst topography) will the aggregate bed need to be lined to prevent infiltration.

5.5.5 Materials

Table 5-11 provides a summary of the typical material requirements for the permeable pavement components described in previous pages. Designers should follow their local stormwater management requirements when specifying materials.

Table 5-11. Typical Permeable Pavement Material Specifications

Material	Specification	Notes
PERMEABLE PAVER		
Interlocking Concrete Paver	Min. 3-1/4 in. thick meeting ASTM C 396 or CSA A231.2	20% or more surface area open
Pea Gravel Bedding Course	2-inch layer 1/8 to 3/8 – inch aggregate (AASHTO No. 8 stone)	
Open Graded Base Course	4-inch layer AASHTO No. 57 stone	
Subbase Course	AASHTO No. 2 stone	40% voids Thickness varies, minimum 6 inches
Non-woven Geotextile	ASTM-D4632 ASTM-D3786 ASTM-D4491 ASTM D-4355 Nonwoven polypropylene fibers	
REINFORCED TURF		
Plastic Geogrid	Minimum 1-3/4 inch thick	
Subbase Course	AASHTO No. 2 stone	Minimum 30% voids Thickness varies, minimum 6 inches
POROUS ASPHALT AND PERVIOUS CONCRETE		
Cement	Portland Cement Type I or II conforming to ASTM C 150 Portland Cement Type IP or IS conforming to ASTM C 595	Cement content shall not be less than 600 lbs/cy for pavement subjected to vehicle loads
Air Entraining Agent	ASTM C 260	
Admixture	Type D Water Reducing – ASTM D 494	
Mixing Water	Potable	
Aggregate/Cement Ratio	4:1 to 4.5:1	
Water/Cement Ratio	0.34 to 0.40	
Asphalt and Concrete Mix Design	Consult pavement designer	Pavement shall have load capacity cable of supporting applicable traffic and vehicle loads

Material	Specification	Notes
Asphalt and Concrete	Minimum 15 percent air voids in the completed top lift. Concrete strength 2400 to 2500 psi after 28 days curing period.	
ALL PERMEABLE PAVEMENT TYPES		
Subgrade (Existing Subsoil)	Subgrade shall not be compacted	
Aggregate Layers	Aggregates shall be washed and free of fines	
Underdrain	Minimum 6-inch perforated pipe PVC Schedule 40 HDPE to meet AASHTO M252, Type S or AASHTO M294, Type S.	

5.5.6 Construction Considerations

5.5.6.1 General

Due to the nature of construction sites, permeable pavement and other infiltration measures should be installed toward the end of the construction period, when the surrounding areas are stabilized. If this is not possible, sediment laden runoff during construction shall be diverted around the permeable pavement. Sediment on the pervious surface or in the constructed gravel bed can clog the pores and lead to system malfunction.

During construction, the excavated bed may serve as a temporary sediment basin or trap. This will reduce overall site disturbance. The bed should be excavated to within one foot of the final bed bottom elevation for use as a sediment trap or basin. Following construction and site stabilization, sediment should be removed and final grades established.

5.5.6.2 Construction Sequence

Installation techniques vary for the type of permeable material chosen, but the sequence is in general similar. The installation and construction of permeable pavement should be done in accordance with designer of record specifications and standards. However the following construction sequence should be followed.

1. Bed bottoms should be level. Sloping bed bottoms will lead to areas of ponding and reduced distribution.

2. Excavate the project area to the depth of the entire pavement section.

3. Cover the uncompacted subsoil with geotextile fabric to reduct migration of fines into the gravel reservoir. Place geotextile in accordance with manufacturer's specifications.

4. Install clean, washed gravel subbase (and perforated underdrain if required). Place gravel in lifts and lightly compact according to specifications.

5. Install gravel base course (to transition bedding course to subbase).

6. Install the bedding course (pea gravel or sand depending on permeable pavement type).

7. Lay the surface course (set in place concrete pavers or open grid units, plastic geogrid, or cast in place asphalt/concrete).

8. If using permeable concrete pavers fill the voids between pavers with pea gravel. For reinforced turf, fill spaces or voids with planting soil, sand or gravel. Follow manufacturer's specifications.

9. Seed, fertilize, and mulch the entire surface for grass applications.

10. Water immediately and then every couple of days until the grass is established.

5.5.7 Maintenance

5.5.7.1 General

The primary goal of permeable pavement maintenance is to prevent the pavement surface and/or the underlying infiltration-bed from being clogged with fine sediments. To keep the system clean throughout the year and its lifespan, the pavement surface should be swept with a street sweeper and vacuumed once every two years with a commercial vacuum unit. Use of conventional pavement washing and/or compressed systems is not recommended.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement surface. If any washout does occur it should be cleaned off the pavement immediately to prevent future clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted or reseeded to stabilize the area. All trash and other litter that is observed during routine inspections should be removed. Soil particles that become ground from repeatedly traffic use leads to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking and spilling sediment onto the permeable pavement.

Maintenance agreements should clearly specify how to conduct maintenance activities. See Table 5-12 for suggested maintenance activities and frequency.

5.5.7.2 Winter Maintenance

Winter maintenance for a permeable pavement parking lot may be necessary but is usually less intensive than that required for a standard impervious surface. By its very nature, a permeable pavement system with subsurface aggregate has superior snow melting characteristics compared to standard pavements. The underlying stone bed tends to absorb and retain heat so that freezing

rain and snow melt faster on pervious surfaces. However, snow will accumulate during heavier snowstorms. Snow plow blades should be set slightly higher than usual by approximately one inch. Salt is acceptable for use as a deicer on the pervious surface; though nontoxic, organic deicers, applied either as blended, magnesium chloride-based liquid products or as pre-treated salt, are preferable. Sand should never be used.

5.5.7.3 Repairs

Potholes in porous asphalt and pervious concrete are unlikely; though settling might occur if a soft spot in the subgrade is not removed during construction. Small damaged area can be patched by any suitable means. Under no circumstances should the pavement surface ever be seal coated.

Table 5-12. Suggested Maintenace Activities for Permeable Pavement

	Task	Frequency	Maintenance Notes
1	Sweep and Vacuum Pavement	2 to 3 times / yr	Commercial sweeper/vacuum unit
2	Clean Inlets, Drainage Pipe, Stone Edge Drains, etc.	2 times /yr	Remove sediment and debris
3	Water Reinforced Turf and Grass-filled Open Grid Pavement	Regularly	
4	Clean Up Soil Deposited on Pavement	Immediately	
5	Maintain Planted Areas adjacent to Permable Pavement	Regularly	Prevent mulch and soil washout onto pavement surface
6	Snow Removal	As Needed	Raise plow blade 1 inch higher Do not use sand

5.5.8 Benefits

There are numerous advantages to permeable pavement systems, including:

- Reduces drainage infrastructure costs
- Reduces stormwater runoff by infiltration
- Contributes to good water quality
- Volume and Peak flow reduction
- Landscaping for aesthetics
- Promote stormwater infiltration and groundwater recharge
- Improved water quality through pollutant reduction by processes such as filtration/infiltration
- Minimizes “urban heat island” effects

5.6 RAINWATER HARVESTING

5.6.1 Description

Rainwater harvesting is the process of collecting water from roof surfaces and impervious surfaces, such as parking lots, during rain events and storing it in tanks, barrels, or cisterns for non-potable use. Potential uses include indoor non-potable applications (*i.e.,* toilet flushing, laundry) and outdoor applications such as landscape irrigation.

Rainwater harvesting follows ecologically sound principles as it promotes water conservation, reduces peak flows and runoff volumes, and provides irrigation water for landscaping during dry periods. Runoff collected from rooftops is sodium and chlorine free, low in salt content, and high in nitrogen, and relatively clean that can be used for irrigation and for flushing toilets and urinals. Capturing and using rainwater runoff also reduces site discharge and erosion, and the potential for stormwater pollutants.

5.6.2 Types of Rainwater Harvesting Systems

Rain barrels and cisterns are the most common water storage tanks for capturing and storing rooftop rainwater or runoff from other impervious surfaces.

5.6.2.1 Rain Barrels

Rain barrels are 50-150 gallon covered plastic tanks with a hole at the top for downspout discharge, an overflow outlet, and a valve and hose adapter at the bottom. They are used almost exclusively on residential properties. Since rain barrels rely on gravity flow, they should be placed near, and slightly higher than, the point of use (whether a garden, flower bed, or lawn.) A hose is attached to a faucet at the bottom of the barrel and water is distributed by gravity pressure. The overflow outlet should be routed to a dry well, bioretention area, or rain garden. It is important for property owners to use the water in rain barrels on a regular basis, or else they fill up and no additional roof runoff can be stored. It is recommended that each house have at least two rain barrels; a one inch storm produces over 500 gallons of water on a 1000 square foot roof.

For residential applications, a typical rain barrel design will include a hole at the top to allow for flow from a downspout, a sealed lid, an overflow pipe (to divert excess water once the barrel is full), and a spigot at or near the bottom of the barrel (Photo 5-19). A screen is often included to control mosquitoes and other insects. The water can then be used for lawn and garden watering or other uses such as supplemental domestic water supply. Rain barrels can be connected in a series to provide larger volumes of storage

Some commercially available rain barrels are manufactured with upper and lower ports linking the primary barrel to a second barrel (and potentially others) linked together in series. Screening at any orifice or entry point to the tank discourages vectors such as mosquitoes. A food grade plastic barrel used for bulk liquid storage in restaurants and grocery stores can be fitted with a

bulkhead fitting and spigot for garden watering. However those that are not opaque must be screened from sunlight. Standard tanks must be installed above ground.

Photo 5-19. Residential Rain Barrel

5.6.2.2 Cisterns

Surface tanks and cisterns may be larger than rain barrels but serve the same function. They can be integrated into sites where a significant water need exists or rain harvesting and reuse is desired. They may drain by gravity or be pumped. Unlike rain barrels, cisterns and tanks typically need design professional assistance for more complex water collection and delivery system design. Also, they typically need to be installed to local code by a certified and bonded plumbing or construction contractor.

Cistern capacities range from 250 to over 30,000 gallons (Virginia Department of Conservation and Recreation Stormwater Design Specification No. 6, 2011). Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage as needed.

Cisterns are partially or fully buried tanks with a secure cover and a discharge pump; they provide considerably more storage than barrels as well as pressurized distribution. Cisterns can collect water from multiple downspouts or even multiple roofs, and then distribute this water wherever it needs to go through an electric pump. Property owners may use one large tank or multiple tanks in series. Either way, the overflow for the systems should be a drywell or other infiltration mechanism, so that if the cistern is full, excess roof runoff is infiltrated, and not discharged to the stormwater system. Some cisterns are designed to continuously discharge water

at a very slow rate into the infiltration mechanism, so that the tank slowly empties after a storm event.

5.6.3 Planning Considerations

Rainwater harvesting and reuse is a direct way to reduce stormwater runoff volume. The harvesting barrels, tanks or cisterns should be sized for the climate and ranges of rainfall events, and relate to the amount of impervious area, reuse applications and consideration of the downstream effects. There are opportunities to collect rainwater in all land use situation with minimal constraints. Rain barrels and cisterns can be retro-fitted to existing buildings or integrated into new building design. Rainwater harvesting systems can range from a simple 55-gallon rain barrel to a complex multimillion-gallon cistern with electronic pumps and controls. It is important to evaluate existing site conditions of the project to ensure compliance with state and local requirements during the planning phase. Identify opportunities and areas where water can be reused for irrigation, released to an infiltration area, or meet indoor use needs. Estimate the rate at which water can be reused.

5.6.3.1 Applications

Rainwater harvesting systems can be as simple as a rain barrel for garden irrigation at the end of a downspout, or as complex as a domestic potable water supply system or a multiple end-use system at a larger scale. The rainwater harvesting systems may be above or below ground, and they may drain by gravity or be pumped. Stored water may be slowly released to a pervious, grass area, used for landscape irrigation, or used indoors for non-potable purposes such as toilet flushing.

Rain barrel design and construction is simple where the rain barrels are available commercially in almost “ready to install” configurations. The only consideration is that there must be enough room near the downspout for the installation of rain barrels. Also, a rain barrel will need a flat, stable surface to sit upon. On the contrary, cisterns are large and require careful planning in terms of site topography, water table, and soil conditions. However, they do not need to be located adjacent to the building since piping and pumps will convey the rainwater.

Underground utilities, high water tables or shallow bedrock may limit the sites available for tank planned for underground installation. Locate utilities, and investigate groundwater and geological restrictions during the planning phase. Buoyant forces can act on an empty underground and cause it to float out of ground. Careful consideration should be given to manufacturer’s installation guides and instructions in order to correctly site and protect tanks against negative impacts of soils with a high water table.

General planning considerations include:

- Existing topography will influence storage locations, site layout, rainwater harvesting design and layout, and types of rainwater harvesting features.

- Capture as much runoff as possible without depriving adjacent or downstream vegetation of water, and without violating downstream water rights (applicable in the western United States). If all runoff cannot be permanently captured, then slow the flow of the remaining volume to increase percolation and on-site infiltration.

- Design for overflow from large rainfall events with erosion controls and overflow conveyance to useful and safe discharge locations.

- Above-ground tanks maintain head pressure to allow some gravity flow. Below-ground tanks take less space above-ground but usually require pumps. The higher on the site above-ground tanks are located, the more gravity-feed pressure will be available. Water can be distributed by gravity flow or by a booster pump via hoses, irrigation systems, channels, or perforated pipes.

- For all tanks, install a tank overflow and route it to a logical location in the landscape where it will be put to beneficial use. The overflow capacity must be equal to or greater than the inflow capacity.

- Screen inflow from roof to tank to keep debris out. Screen tank outflow before it enters the irrigation system to prevent clogging.

- Select roofing surface based on planned uses of tank water (metal or tile roofing provides high quality runoff water).

- Evaluate the potential to use tank water in site cooling towers or for wash water uses; design location and piping accordingly.

- Carefully plan roof slopes to direct water to specific downspouts based on tank capacity.

5.6.3.2 Constraints

The stormwater volume/peak discharge rate benefits of cisterns and rain barrels depend on the amount of storage available at the beginning of each storm. One rain barrel may provide a useful amount of water for garden irrigation, but it will have little effect on overall runoff volumes, especially if the entire tank is not drained in between storms. Greater effectiveness can be achieved by having more storage volume and by designing the system with a continuous discharge to an infiltration mechanism, so that there is always available volume for retention.

When selecting a location for cistern installation, note that roofs constructed with tar, gravel, treated cedar shakes, or old asbestos shingle roofs may produce too much contamination for rainwater harvesting. Similarly, rainwater should not be harvested if it is conveyed via gutters with lead soldering or lead-based paints. Roofs exposed to air borne particles originating from cement kilns, gravel quarries, crop dusting, or concentrated automobile emissions will create runoff that could adversely affect the rainwater quality.

One concern that must be considered is mosquitoes. In some situations, poorly designed rainwater systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other vector insects from entering the tanks and vicinity if water is intended for landscaping use.

The water collected is for non-potable uses only and its use for potable (drinking) purpose is not cost-effective.

Storage tank and cisterns may have permit requirements.

5.6.4 Design Criteria & Specification

5.6.4.1 Sizing Criteria

For the purposes of meeting the requirements of EISA Section 438, rainwater harvesting systems should be sized with respect to the stormwater runoff volumes required to be managed onsite (refer to Chapter 4), and also considering the possible use of other BMPs. As a general rule of thumb, one square foot rooftop area will yield approximately 0.62 gallons of water per one inch of rainfall can be collected during a rain event. The volume of water that can be collected from a given rain event can be calculated as:

$$V_{collect} = 0.62 * A_{roof} * \text{Rainfall}$$

Where:

$V_{collect}$ = Volume of rainwater collected, gallons
A_{roof} = Roof surface area, ft^2
Rainfall = Design rainfall, inch (such as 95th percentile or 2-year, 24 hour)

The basic rule for sizing any rainwater harvesting system is that the volume of water that can be captured and stored (the supply) must equal or exceed the volume of water used (the demand). Storage capacity needs to be sufficient to store water collected during heavy rain events to last through dry periods. Some residences might be constrained by the size of the collection surfaces and/or the volume of storage capacity that can be installed due to space or costs. The following section describe ways to determine the amount of rainfall, the estimated demand, and how much storage capacity is needed to provide enough rainwater to meet the demand. A much more in-depth analysis of how to calculate potential harvested rainwater is available through the American Rainwater Catchment Systems Associated website (http://www.arcsa.org) in their guidelines publication.

Cisterns can vary in size and may consist of several thousand gallons of storage capacity. It is important to gauge what size and storage capacity is right for the site and facility. Low storage capacities will limit rainwater harvesting so that the system may not be able to provide water in a low rainfall period, and increased storage capacities add to construction and operating costs. A factor that will assist in determining the size of the cistern is the volume of water available for capture. An analysis of precipitation records should be performed to determine the amount,

frequency, and seasonal variation of rainfall for the area. Including several years of data is recommended in order to account for dry and wet years. The anticipated daily or monthly demand for the harvested rainwater should also be determined. This will first require determining what the end use of the collected water will be, and then predicting the amount needed. Toilet and urinal flushing impart a consistent daily demand on a water system while outdoor irrigation may be somewhat more episodic. The total surface area of the roof is another factor in determining cistern size.

5.6.4.2 Components of Rainwater Harvesting

Cistern tanks should have three openings where pipes will be placed: an inlet, outlet/outflow (or faucet), and overflow. Overflows should be directed away from structures and toward pervious areas to allow for infiltration.

Generally all rainwater tank/cistern designs should include the components below. More information on some of the components is provided in this section.

- A solid secure cover
- A leaf / mosquito screen at cistern entrance
- A coarse inlet filter with clean-out valve
- An overflow pipe
- A manhole, sump, and drain to facilitate cleaning
- An extraction system that does not contaminate the water (e.g. a tap or pump)
- A soak-away to prevent spilled water from forming puddles near the tank

Additional features might include:

- A device to indicate the amount of water in the tank
- A sediment trap, tipping bucket, or other "foul flush" mechanism
- A lock on the tap

<u>Screen</u>
A screen keeps leaves and other debris from entering and clogging the rain barrel/cistern. A screen also prevents mosquitoes from breeding in the storage element. A screen is typically placed at the end of the roof leader, before flow enters the rain barrel or cistern. A leaf strainer may also be placed where the gutter connects to the roof leader.

Storage Element

The storage element is the barrel, cistern, or tank itself (Photo 5-20). Rain barrels are typically made of plastic. Underground cisterns may be poured concrete or prefabricated plastic tanks similar to septic tanks. Proprietary products that store water in a variety of structures are also available. Tanks larger than rain barrels may be used above or below ground.

The selection of tank is based on three main criteria: size, location, and material.

All systems consist of the same basic components: a collection surface (roof top – only roof surfaces are addressed in this practice), a conveyance system, pre-tank treatment, water storage, and distribution.

Photo 5-20. Rainwater Harvesting Storage Element

Slow Release Mechanism or Pump

For the storage element to serve its stormwater control function, it must be partially or completely drained between most wet weather events. Rain barrels are typically drained in one of two ways: manually by means of a spigot similar to ordinary outside water faucets; and, the continual, slow release using a soaker hose to a garden or infiltration area. Larger surface tanks may drain by gravity or may be pumped. Subsurface systems and systems where stormwater is reused for needs other than irrigation (toilet flushing, car wash) are typically pumped.

Overflow Mechanism

The storage capacity of rain barrels, cisterns, and other tanks may be exceeded in large storms. In rain barrels, a flexible hose is provided at an elevation near the top of the barrel. The diameter of the hose is at least equal in size to the roof leader to allow runoff to flow unimpeded during large events. The overflow from cisterns and larger tanks can occur through a weir, pipe, or other mechanism.

A design consideration involving the overflow pipe is to connect it to the inlet of a second cistern tank (Figure 5-12 and Photo 5-21). This would be appropriate for areas with heavy rainfall or large facilities with a high demand for non-potable water.

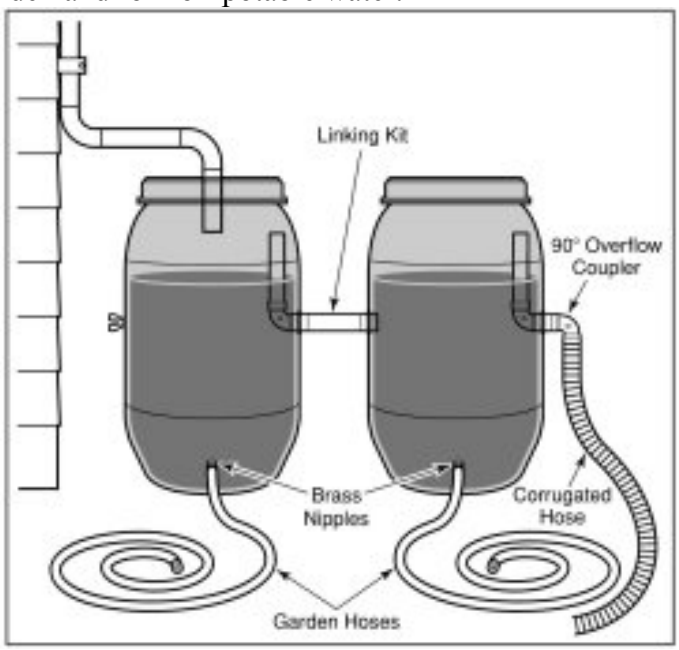

Figure 5-12. Linked Rainwater Harvesting Cisterns

Photo 5-21. Linked Rainwater Harvesting Cisterns

First Flush Diverter

A diverter at the cistern inlet can redirect the "first flush" of runoff which is more likely to have particulates, leaves, and air-deposited contaminants washed off the roof. Direct the first flush to an infiltration trench, bioretention area, or grassed swale sized to infiltrate the required volume.

Make-Up Water

When make-up water is required to be provided to the cistern from the municipal system, steps must be taken to prevent cross-contamination. Pipes connected to the outflow (or any part of the harvesting system) should never connect to potable water piping. The make-up supply to the cistern is the point of greatest risk for cross-contamination of the potable supply. A backflow prevention assembly on the potable water supply line, an air gap, or both must be provided to prevent collected rainwater from entering the potable supply. Dedicated piping should be color-coded and labeled as harvested rainwater, not for consumption. Faucets supplied with non-potable rainwater should also contain signage identifying the water source as non-potable and not for consumption. The designated dual piping system is also part of the cross-contamination prevention measures. Specific requirements can be obtained by local water system authorities.

Vent

All tanks (aboveground and belowground) must have a vent to expel air as rainwater enters the tank and draw air in as rainwater is pumped out of the tank. If the tank overflow does not have a water trap, air can be displaced through the overflow as rainwater enters the tank. In these cases, the vent only needs to be as big in diameter as the water supply line leaving the tank. If air cannot leave the tank through the overflow, the vent diameter should be 1.5 times the diameter of the inlet pipe.

5.6.4.3 Design Considerations

Cistern design should be conducted by a licensed professional engineer experienced in rainwater harvesting design. Licensed plumbers are required by law to install any plumbing systems. Only licensed contractors should install any rainwater harvesting system, but special rainwater harvesting installers are not required.

The following list includes basic guidelines that should be followed when designing and installing rain barrels and cisterns.

- Only rooftop rainwater should be collected.
- The roof materials should be selected carefully.
- Systems must be equipped with overflow pipes that direct water to another tank, stormwater pipes, pervious, grass surface.
- Storage tanks should be accessible for maintenance and cleaning. Underground systems should have a standard size manhole or equivalent opening to allow access for cleaning,

inspection, and maintenance. This access point should be secured/locked to prevent unwanted access.

- Storage tank openings must be covered and screened.
- Gutters and roof drains should be designed in accordance with local code.
- Above ground storage tanks should be UV resistant or otherwise protected from direct sunlight to inhibit algae growth and should be screened to prevent mosquito breeding and reproduction.
- Underground storage tanks must be designed to support the overlying soil burden and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
- For gravity-fed systems, a minimum of 6 inches of dead storage should be provided for sedimentation.
- Tanks should be sized to adequately capture runoff based on local precipitation patterns, roof area, and anticipated demand.
- Water should be drained between rainfall events (for irrigation) to maximize effectiveness.
- Rain barrels are most effective when they are designed to help meet demands for non-potable water, such as irrigation.

Tank size is always dependent on the roof area and the anticipated use of the water. However, size decisions may also be based on availability of space on the site, stormwater or LEED requirements, and the availability of a back-up water supply. Tank size selection will affect possible tank locations and location and size will then help in the selection of tank materials.
American Rainwater Catchment System Association has published guidelines for rainwater harvesting systems, and the Association has developed national standards for the rainwater harvesting industry which are available on their web site (www.arcsa.org). Currently Rainwater Catchment Design and Installation Standards are being developed by a joint effort of ARCSA and the American Society of Plumbing Engineers (ASPE). The purpose of these standards is to assist engineers, designers, plumbers, builders, developers, local government, and end users in successfully implementing rainwater catchment systems.

Residential Design

Residential rainwater harvesting systems in residential settings primarily collect rainwater from the rooftops and downspouts. They can be designed for reuse for non-potable needs such as toilet flushing, laundry washing, and landscape irrigation. These non-potable uses account for 78 percent of total household water use, with outdoor use alone accounting for 59 percent of

household use (VA Rainwater Harvesting Manual, 2009) Because outdoor use is more than half of residential use, bringing harvested rainwater indoors for potable or non-potable uses is often not cost-effective, particularly in retrofit situations.

Commercial, Industrial, Institutional

Rainwater harvesting systems in commercial, industrial and institutional settings can vary from rooftop collection to collection from large impervious surfaces in underground cisterns. Collected rainwater can serve non-potable needs in these settings. For example, 87 percent of water use in an office building is for restrooms alone (Huston, et al., 2004). Huston (2004) reported that 34 percent of all water use in the United States for landscape irrigation.

Roof Considerations

Roof materials should be non-porous and smooth. Copper roofs and roofs with lead components (for example, flashing or solder) should not be used in any application with a potential for human ingestion (for example, vegetable gardens). Aluminum and rubber membrane are recommended roof materials for rainwater harvesting. Green roofs should be used with caution in rainwater harvesting and rainwater harvested from green roofs with soil bases should only be used for irrigation.

Roof Drains

While rain barrels and cisterns can be integrated with any roof drain system, siphonic roof drains (Photo 5-22) present a number of advantages. When siphonic roof drains are used, the downpipes can be located near the cistern. When conventional roof drains are used instead of siphonic, pipes often have to be brought longer distances (often either around or under the building).

Photo 5-22: Roof Drain

5.6.5 Materials

5.6.5.1 Roofs

Metal roofs, with the exception of copper and lead components, are recommended for rainwater harvesting. Because of a low runoff coefficient and many of the products used to treat wood, wood shingles are not recommended for rainwater harvesting as well. Membrane roofs create an ideal surface for rainwater harvesting. These roofs have a high runoff coefficient and have not been shown to add harmful contaminants to the harvested water.

5.6.5.2 Material Specifications

Cisterns can be constructed of nearly any impervious, water retaining material. However, it is generally advisable to select a material that is rated for potable water use by the National Sanitation Foundation to prevent the introduction of any additional contaminants into the harvested rainwater. Commercially available systems are typically constructed of high density plastics. They can also be made of metal or concrete and can be cast-in-place. Outdoor tanks should be constructed of opaque materials or otherwise shaded or buried to prevent damage from sunlight. They should also contain adequate screening at each opening to prevent insects from entering the tank.

Other materials utilized for the construction of cisterns can include redwood, polyethylene, fiberglass, metal, concrete, plaster (on walls), ferro-cement and impervious rock such as slate and granite.

The basic specifications for rain water harvesting systems are presented in Table 5-13. Designers should consult with experienced irrigation installers on the choice of recommended manufacturers of fabricated tanks and other system components.

Table 5-13. Rain Water Harvesting System Material Specifications

Material	Specification
Gutters and Downspout	• Materials commonly used for gutters and downspouts include polyvinylchloride (PVC), pipe, vinyl, aluminum and galvanized steel. Lead should 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 storage tanks. • Be sure to include needed bends and tees
Pre-Treatment	• Provide pretreatment by installing screens to remove debris for all collected rainwater
Storage Tanks	• Materials used to construct storage tanks should be structurally sound • Tanks should be constructed in areas of the site where native soils can support the load associated with design stored water • Tanks should be water tight and sealed using a water-safe, non-toxic substance • Tanks should be opaque to prevent the growth of algae • Underground tanks should be installed below local frost line • Rain barrels commonly plastic, wood or steel • Cisterns commonly fiberglass, concrete, plastic, brick or other materials

(Source: Virginia DCR Stormwater Design Specification No. 6, 2011)

Table 5-14 compares the advantages and disadvantages of different cistern materials.

Table 5-14. Advantages and Disadvantages of Various Cistern Materials

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available; durable; light weight; integral fitting; no leaks	Must be installed on smooth, solid, level footing; expensive in small sizes
Polyethylene	Commercially available; alterable; 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
Modular Storage	Can modify to topography; can alter foot-print and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic	Commercially available; inexpensive	Low storage capacity (20-50 gals.; limited application
Galvanized steel	Commercially available, available in 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
Steel	Commercially available	Small storage capacity; prone to corrosion and rust can lead to leaching of metals; water and soil pH my also limit applications
Ferro Concrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak
Cast in Place Concrete	Durable; immoveable; 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

(Source: Cabell Brand, 2009)

5.6.6 Construction Considerations

5.6.6.1 General

Prefabricated rainwater harvesting cisterns or rain barrels can be purchased and installed professionally. The interior of tanks should be accessible for periodic inspection and maintenance. Position outlet pipes several inches above the bottom of the tank to allow sediment to settle in the bottom. All tanks need an overflow pipe of equal or greater capacity than the fill pipe. Overflow pipes should be able to operate passively (i.e. not dependent on a pump). Water in aboveground tanks can be delivered by gravity flow alone to low-pressure uses nearby. Below-ground tanks save land area, but require substantially more construction. A booster pump can be added to hook tanks into an irrigation system. Tank water should be filtered as it enters irrigation lines to keep debris from plugging the irrigation system. The tank should be installed somewhat angled upward to protect settled sediment and inlet installed above tank bottom to provide for sediment sedimentation. The tank should have an overflow of at least the same diameter as the inlet pipe to prevent backup in gutters and downspouts. This overflow should be directed to a pervious area such as nearby landscape grass area.

5.6.6.2 Construction Sequence

Commercially available aboveground and belowground tanks should always be installed in compliance with manufacturers' recommendations. Depending on the type and purpose of the system, the installation can be involved. Cisterns must be installed by licensed professional contractor. When constructing underground cisterns, local utility companies should be contacted in order to locate any underground pipes or cables that may be in the installation site.

It is advisable to have a single contractor install the rainwater harvesting system, outdoor irrigation system and secondary runoff reduction 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. Check with local jurisdiction if a permit is required to install a rain barrel and/or cistern for non-potable water use.

2. Excavate the hole to the required dimensions (for underground) or prepare platform for above ground system. Ensure smooth stable surface for cistern or rain barrel.

3. Install the pre-fabricated cistern or rain barrel as per manufacturer's specifications.

4. Seal the inside of the cistern.

5. Install the pump (if needed) and piping to end-uses (indoor re-use, outdoor irrigation, or tank dewatering release)

6. Install the lid, screens and hatches.

7. Route all downspouts or roof drains to pre-screening devices and first flush diverters. Stormwater should not be diverted to the rainwater harvesting system until the overflow filter.

5.6.6.3 Final Inspection

Inspections during construction are needed to ensure that the cistern is built in accordance with manufacturer's specifications. The following items should be inspected prior to final sign-off and acceptance of a rainwater harvesting system.

- Rooftop area matches design plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Screens and seals are installed on all openings
- Overflow device is directed as shown on design plans
- Tank foundation or platform is constructed as shown on plans
- Catchment area and overflow area are stabilized

5.6.7 Maintenance

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 5-15).

Rainwater harvesting systems, including all their components and accessories, should undergo regular inspection at least twice a year. An example maintenance inspection checklist for Rainwater Harvesting can be accessed in Appendix C of Chapter 9 of the *Virginia Stormwater Management Handbook* (2010). Replacement or repair of the unit as a whole, and any of its constituent parts and accessories should subsequently be undertaken if needed. Tanks must be "winterized" or drained prior to winter to prevent damage if freezing conditions prevail.

Table 5-15: Suggested Maintenance Tasks for Rainwater Harvesting Systems

Activity	Frequency
Clean gutters and downspouts of leaves and other debris and check for leaks.	Twice a year
Inspect overflow that it is draining in non-erosive manner	Twice a year
Inspect and clean pre-screening devices and first flush diverters.	Four times per year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately.	Once per year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices.	Once per year
Inspect tank for sediment buildup and seal leaks.	Every third year
Clear overhanging vegetation and trees over roof surface.	Every third year
Inspect structural integrity of tank, pump, pipe, over flow preventer and electrical system. Replace damaged or defective system components.	Every third year
If mosquitoes become a problem, mosquito dunks (floating donut-shaped briquettes containing the biological insecticide) can be used.	As needed

(Source: Virginia DCR Stormwater Design Specification No. 6, 2011)

5.6.8 Benefits

When properly installed, cisterns reduce the peak discharge rate and runoff volume through detention. However, when compared to other stormwater BMP options, the peak discharge is minimally impacted by the use of rain barrels or cisterns. However, if many rainwater barrels or large capacity tanks are installed, then benefits may be seen in terms of reduced peak flows and volumes entering sewers and streams.

- Reduces stormwater runoff volume and flow rates
- Reduces erosion in urban environments
- Reduce on-site flooding
- Water conservation and supplemental water supply
- Increase water availability for non-potable uses
- Meet LEED Credit

5.7 GREEN ROOFS

5.7.1 Description

Green roofs (also known as vegetative roofs, living roofs, bio-roofs, or eco-roofs) are thin layers of living vegetation installed on top of conventional roofs (Photo 5-23). Green roofs typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth.

The purpose of green roofs is to maximize nutrient and pollutant removal and runoff volume reduction. A portion of the captured stormwater evaporates or is taken up by plants and transpired, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

Photo 5-23. Green Roof – Washington, DC
(Source: Healthy Roofs for Healthy Cities (Photo by US DOT))

Green roofs filter particulate matter from the air, retain and cleanse stormwater and provide new opportunities for biodiversity preservation and habitat creation. They generate aesthetic benefits and help to reduce the urban heat island effect (the over-heating of cities in summer from dark roof surfaces, which contributes to air pollution and increased energy consumption).

5.7.2 Types of Green Roofs

There are two types of green roof systems: extensive and intensive green roofs. The variation in each type is the depth of growing media, which relates to the volume of stormwater that can be absorbed by the vegetation and soils.

5.7.2.1 Extensive Green Roof

Extensive roofs typically have much shallower growing media (3 to 8 inches) that is planted with carefully selected drought tolerant vegetation (Photo 5-24 and Photo 5-25). With shallower growing media, this type of green roof is lightweight and relatively easy to construct and maintain. Extensive roofs can be easily applied to Army construction.

The most common vegetated roof cover in temperate climates at Army facilities may in the future be a single un-irrigated 4 to 6 inch layer of lightweight soil growth media planted with succulent plants and herbs. In Germany, this simple design has demonstrated the highest benefit-to-cost ratio (Virginia Department of Conservation and Recreation, Stormwater Design Specification No. 5, 2011).

Photo 5-24. Green Roof – Washington, DC
(Source: Healthy Roofs for Healthy Cities (Photo by US DOT))

Photo 5-25. Hamilton Building Green Roof
(Source: Portland Stormwater Management Manual)

5.7.2.2 Intensive Green Roof

Intensive green roofs have a deeper growing media layer that ranges from 6 inches to 4 feet thick. These deep layer roofs are planted with a wider variety of aesthetically pleasing plants, including shrubs and shallow-rooted trees. The thick growing media and dense vegetation makes these green roofs heavy, which can put strain on the roof and building structure. Design must consider building structure, possibility of roof leaks, weight of the green roof, and high maintenance requirements. Intensive green roofs may not always be applicable on Army facilities nor cost effective for the volume of stormwater they may manage, thus, only the details for extensive green roofs are provided below. The extensive green roofs are much lighter and less expensive than intensive green roofs and are recommended on most development and redevelopment sites.

5.7.3 Planning Considerations

5.7.3.1 Applications

Green roofs are ideal for use on commercial, industrial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites to reduce/prevent "urban heat island" effects.

5.7.3.2 Constraints

Green Roofs have several limitations, including:

- Structural Capacity – Consider structural capacity to support live and dead weight, including additional (15 to 30 psf) weight of stormwater for an extensive green roof.

- Roof Access – adequate access to the roof must be provided to deliver construction materials and perform routine repair and maintenance.

- Roof Type – can be applied to most conventional surfaces, although concrete roof decks are preferred.

- Setbacks – Green roofs should not be located near rooftop electrical and HVAC systems.

- Local Building Codes – Building codes often differ in each municipality and local planning and zoning authorities should be consulted to obtain proper permits.

- Leaky Roofs – Research on green roofs has demonstrated that a well designed and installed green roof would have fewer problems with roof leaks than that of with a traditional roof. A waterproof liner is recommended to prevent leaks.

5.7.4 Design Criteria & Specifications

In the United States, green roof designs are generally regulated using existing standards for ballasted roofs. In general, the municipalities follow "The International Code Council (ICC), formerly the BOCA, construction code that requires that "wet weight" of the green roof be treated as an additional dead load.

Specific design considerations may include energy efficiency, green building or LEED points, architectural considerations, visual amenities and landscaping features for human enjoyment.

5.7.4.1 General

All well-designed green roof focus on three main design criteria:

Drainage
Provision for drainage from the rooftop must be provided for stormwater not absorbed by the green roof. The drainage layer may include filter fabric, gravel, or it can be the growing (soil) media itself. An approved discharge location must be identified for every green roof and drain(s) provided. Design must both maintain optimum growing conditions in the plant soil growth media and manage heavy rainfall without sustaining damage due to erosion or ponding of water.

Plant Nourishment and Support
The engineered or manufactured soil growth media must meet requirements for void (porosity or open) ratio, moisture retention, and plant material containing adequate nutrients for sustainable plant establishment and continued growth. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

Protection of Underlying Water Proofing Systems
The green roof design must provide protection measures for the underlying waterproofing system from human activities (including impacts of maintenance) and biological, weather, climatic and

other environmental impacts to prevent leaks from the roof into the building that could compromise the building.

5.7.4.2 Sizing Requirements

Green roofs should be sized to capture a portion of the stormwater runoff volume from the project site as required to be treated for compliance with EISA Section 438, called the treatment volume. The Treatment Volume (Tv) is estimated as below:

$$Tv = (RA * D * P)$$

Where:

- Tv = Required storage volume capacity, ft^3
- RA = Vegetated roof surface area, ft^2
- D = Soil media depth, ft
- P = Soil media porosity (usually 0.30, but may be higher, consult manufacturer)

Details are provided in Chapter 4, Hydrologic Modeling and Simulation, regarding estimating of water quantity runoff volumes to comply with EISA Section 438. The methods described in this section may be used to determine water quality requirements for use in designing of green roofs.

5.7.4.3 Structural Capacity

Green roofs can be limited by additional weight of the fully saturated soil and plants, in terms of physical/structural capacity to bear additional (15 to 30 lbs/sft) structural loads, a condition that may preclude retrofit applications.

5.7.5 Components of Green Roofs

As shown in the Figure 5-13, a green roof is composed of several different systems or layers. The generic cut-away shows common types of green roofs that utilize a lower granular drainage layer in combination with an upper growth medium or substrate.

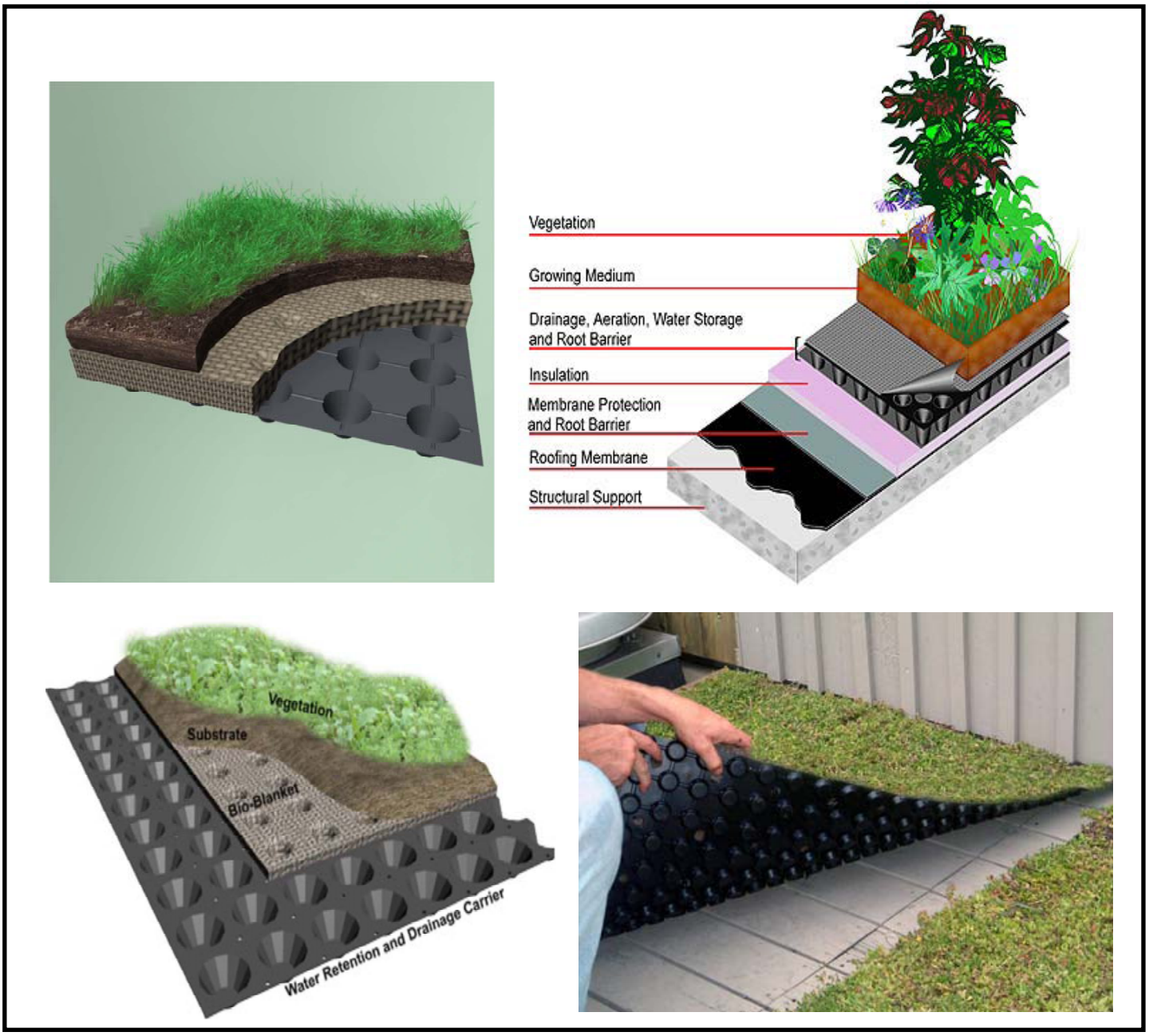

Figure 5-13. Various Layers of a Green Roof

Typical components of a green roof, as illustrated in Figure 5-14, include:

- Plant – Perennials and shrubs
- Erosion control blanket
- Plant Growth Media – 3” to 6” for Extensive and 6” to 4 feet for Intensive roofs
- Filter Fabric
- Drain: 4” to 6”
- Filter Fabric
- Aluminum Curbing
- Gravel (Optional)
- Vegetation-free strip gravel

- Thermal Insulation
- Leak Detection System
- Protection Layer
- Root Barrier
- Water Proof Membrane
- Root Deck with vapor Barrier and Root Structure
- Perforated aluminum Curb w/Drainage Fabric
- Roof Drain w/parapet well
- Emergency Overflow

Sizing

Green roofs replace impervious area at a 1:1 ratio. They are not allowed to receive runoff from other impervious areas.

Slope

Maximum roof slope shall be 25 percent, unless the designer provides documentation of runoff control on steeper slopes.

Waterproofing and Roofing Membrane

A good-quality waterproofing material, such as modified asphalt, synthetic rubber, or reinforced thermal plastics, shall be used on the roof surface. Some waterproofing materials also act as a root barrier. A roofing membrane covers the natural roof to protect the structural supports of the roof. The membrane protection and root barrier protects the roof membrane and prevents roots from penetrating the roof. Insulation helps insulate the building, keeping it cooler during the summer and warmer in the winter. The drainage section to insure the proper range of water content in the growing medium, aeration section is essential to promote optimal vegetation growth; the water storage section will provide more successful growth of vegetation.

Protection Boards or Materials (optional)

These materials protect the waterproof membrane from damage during construction and over the life of the system and are usually made of soft fibrous materials. They often are not needed, depending on the membrane selected.

Ballast (optional)

Gravel ballast is sometimes placed along the perimeter of the roof and at air vents or other vertical elements. The need for ballast depends on operational and structural design issues. It is sometimes used to provide maintenance access, especially to vertical elements that require regular, periodic maintenance. In many cases, very little, if any, ballast is needed.

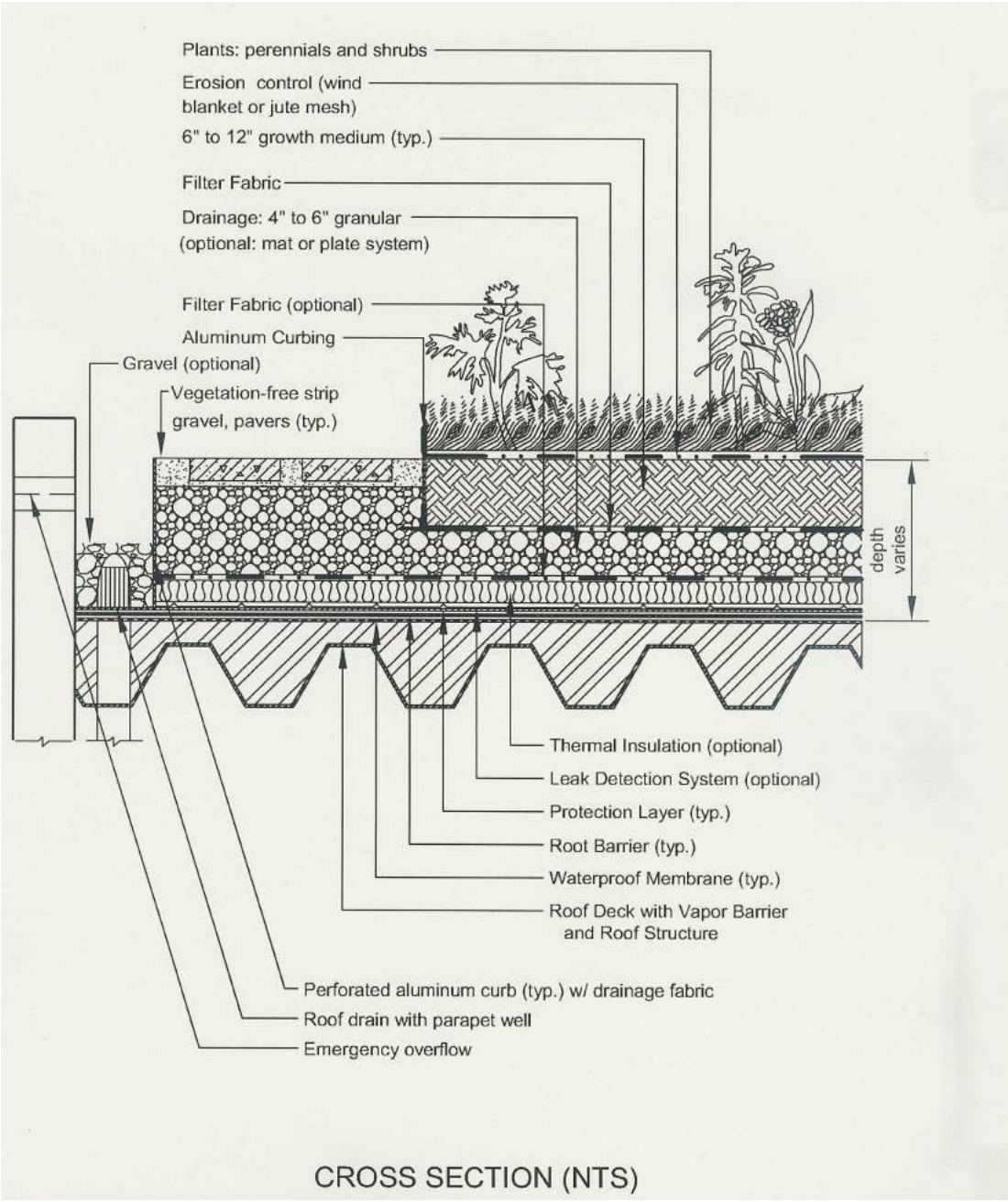

Figure 5-14. Cross Section of an Intensive Green Roof
(Source: Northern Virginia Regional Commission)

Header/Separation board (optional)
In some situations, a header or separation board may be placed between gravel ballast and adjacent elements (such as soil or drains), but pressure-treated lumber is prohibited. In many cases, a header is not needed, and designers are encouraged to use one only when necessary.

Root Barrier
A root barrier is sometimes required in addition to waterproofing material, depending on the type used and the types of vegetation proposed. Root barriers impregnated with pesticides, metals, or

other chemicals that may leach into stormwater are not permitted, unless the applicant can provide documentation that leaching would not occur. If a root barrier is used, it must extend under any gravel ballast and the growing medium and up the side of any vertical elements.

5.7.6 Materials

Table 5-16 provides guidelines for typical material specifications used for extensive green roofs. Always follow manufacturer's specifications.

Table 5-16. Extensive Green Roof Material Specification

Material	Specification	Notes
Roof	-Structural Capacity should conform to ASTM E-2397-05, Practice for Determination of Live Loads and Dead Loads Associated with Green Roof Systems. -ASTM E2398-05 for Water Capture and Media Retention of Geo-composite Drain Layers for Green Roof Systems -ASTM E 2399-05 for Maximum Media Density for Dead Load Analysis.	Architect, structural engineer, and civil engineer must coordinate design criteria
Vegetation	-Drought tolerant plants must achieve 90% coverage within 2 years. -Minimum 50% green roof must be composed of evergreen species -Maximum 10% green roof area may be non-vegetated (gravel ballast, pavers for maintenance access, etc.)	-Vegetation must be recommended by professional landscape architect, horticulturist, or the local USDA Natural Resources office -Succulent, herbaceous plants and perennial grasses that are shallow-rooted, self-sustaining, 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*.
Waterproof Membrane	In accordance with local county ordinances and laws	
Root Barrier	In accordance with local county ordinances and laws	
Drainage Layer	1 to 2 inch layer of clean washed granular material, such as ASTM D 448 size No. 8 stone.	Roof drains and emergency overflow should be designed in accordance with local county ordinances and laws.

Material	Specification	Notes
Filter Fabric	Needled, non-woven, polypropylene geotextile. -Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. -Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.	
Growth Media	-80% lightweight inorganic materials and 20% organic matter (well-aged compost). -Determine acceptable saturated water permeability using ASTM E2396-05.	Inorganic materials include expanded slates, shales or clays, pumic, scoria or similar.

5.7.7 Construction Considerations

5.7.7.1 Construction Sequence

Given the wide diversity of green roof designs, there is no typical step-by-step construction sequence for green roof installation that would cover all situations. The green roof manufacturer's instructions should always be followed. The following is a general construction sequence:

1. Construct the roof deck with the appropriate slope and material.

2. Install the waterproofing method, according to manufacturer's specifications.

3. Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.

4. Add additional system components (*e.g.,* insulation, root barrier, drainage layer, interior drainage system, and filter fabric, etc.), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.

5. The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. 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.

6. 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 so during initial establishment

7. Generally it takes 12 to 18 months for the vegetation to establish fully on the roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support and promote plant growth and dense establishment. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years.

8. All construction contracts should contain a "Care and Replacement Warranty" from the contractor that specifies a 75 percent minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75 percent for flat roofs and 90 percent for pitched roofs.

5.7.7.2 Inspections

Inspections during construction are needed to ensure that the vegetated roof is built in accordance with the designer of record specifications. Also, 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 is needed during several steps of vegetated roof installation, 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
- Upon installation of plants, to ensure they conform to the planting plan
- Before issuing use and occupancy approvals; and
- 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.

5.7.8 Maintenance

Vegetated roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established. Table 5-17 lists suggested maintenance activities for extensive green roofs.

A vegetated roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns. In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and soil media

should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first five years after the vegetated roof is installed.

If a roof leak is suspected, it is advisable to perform an electric leak survey (*i.e.,* Electrical Field Vector Mapping) 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 the waterproof membrane. Only non-chemical fertilizers may be used. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.

Green roof maintenance may include watering, fertilizing and weeding, and is typically greatest in the first two years as plants become established. Maintenance largely depends on the type of green roof system installed and the type of vegetation planted. The use of native vegetation cannot be overemphasized in planting vegetation on roofs and is highly recommended in order to reduce plant maintenance in both extensive and intensive systems.

A green roof should be monitored after completion for plant establishment, leaks and other functional or structural concerns. Vegetation should be monitored for establishment and viability, particularly in the first two years.

Table 5-17. Suggested Maintenance Activities for Extensive Green Roofs

	Task	Frequency	Maintenance Notes
1	Inspect Vegetation	Twice during growing season	
2	Inspect for Leaks, Drainage Problems, Structural Concerns and Repair	Inspect Biannually Repair As Needed	
3	Remove Weeds and Replant Bare Areas	Regularly	
4	Watering for plant establishment	Regularly	In first two years

5.7.9 Benefits

Benefits of green roofs include:

- Controlling stormwater runoff peak flow and volume. Vegetative roofs are particularly effective at controlling runoff on large roofs typical of commercial and institutional buildings.

- Improving stormwater quality by mechanisms of bio-filtration and plant uptake.

- Mitigating unban heat-island effects and energy conservation (see Figure below).

- Green roofs may reduce cooling energy demands in summer and heating bills in winter because of up-roof insulation; they be less important in multi-story buildings.

- Prolonging the service life of roofing materials. Studies have shown that a roof assembly that is covered with a green roof is expected to outlast a comparable roof without a green roof by a factor of at least two, and often three.

- In urban areas, up to 30 percent of nitrogen and phosphorous released into receiving streams originates from dust that accumulated on rooftops. Acting on natural bio-filtration devices, green roofs reduce this nutrient contamination carried by roof-top runoff.

Figure 5-15 exhibits the stormwater runoff reduction benefits of a green roof.

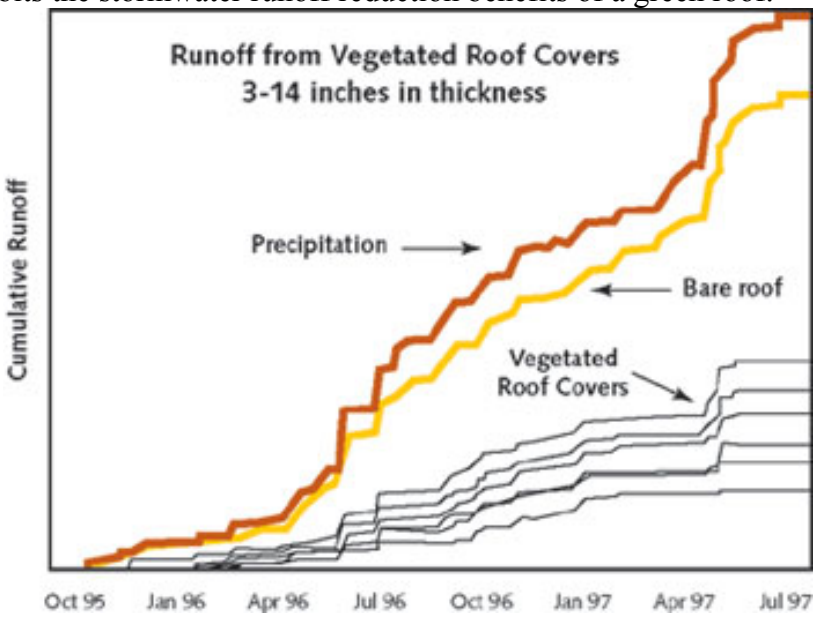

Figure 5-15. Runoff Reduction Benefits from Green Roods