CHAPTER 18
POST-CONSTRUCTION WATER QUALITY BEST MANAGEMENT PRACTICES

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18.1 INTRODUCTION AND PURPOSE

The Post-Construction Water Quality Best Management Practices chapter of the Design Manual was originally published in 2013 pursuant to Louisville Metro's Municipal Separate Storm Sewer System permit requirements and Article 6 of the MSD Wastewater/Stormwater Discharge Regulations to establish and enforce a water quality treatment standard and to promote clean, safe waterways in our community. Post-construction water quality best management practices (BMPs) improve water quality by treating stormwater that flows through drainage conveyances and storm sewers into streams by capturing, filtering and/or infiltrating stormwater.

Rain Garden at the Northeast Library

Planning strategies must meet the minimum requirements identified in this section to comply with MSD's post-construction water quality requirements. However, as part of the planning process, additional benefits should be considered such as over-sizing BMPs for flood reduction benefits and ancillary benefits of BMPs, such as reduction in heat island effects.

Federal and local regulatory programs can impact water quality and quantity. This section provides an overview of the basic regulatory programs. The regulatory programs outlined should not be considered static, as requirements of regulatory programs frequently change over time. Therefore, the designer should always consult pertinent statutes and ordinances when developing a project. Where regulations are in conflict, the more restrictive requirements shall be applied.

18.1.1 Acronyms

ASTM American Society of Testing and Materials

BMP Best Management Practice

CFR Code of Federal Regulations

CFS Cubic Feet per Second

CSO Combined Sewer Overflow

CSS Combined Sewer System

EPA Environmental Protection Agency

EPSC Erosion Prevention & Sediment Control

ESAL Equivalent Single Axle Load

FPS Feet per second

H:V Horizontal: Vertical

IOAP Integrated Overflow Abatement Plan

KDOW Kentucky Division of Water

KPDES Kentucky Pollutant Discharge Elimination System

KRS Kentucky Revised Statutes

KYTC Kentucky Transportation Cabinet

MS4 Municipal Separate Storm Sewer System

O&M Operation & Maintenance

PVC Polyvinyl Chloride

RE Required Water Quality Volume Rain Event

SSO Sanitary Sewer Overflow

TSS Total Suspended Solids

USACE United States Army Corps of Engineers

VP Water Quality Volume Provided

VR Water Quality Volume Required

WQV Water Quality Volume

18.1.2 Definitions

Aquatic Bench Shallow areas around the edge of a wet basin that sustains vegetation and that provide water quality benefits.

Best Management Practice Schedules of activities, prohibitions of practices, treatment requirements, operating (BMP) procedures, and other various protocols used to prevent or reduce the discharge of pollutants to the Waters of the United States.

Bioswale Stormwater conveyance features that mimic ecological function of a landscape, often serving as replacements to open ditches or underground pipes.

Catch Basin Insert Device added to catch basins for the purpose of capturing or retaining stormwater pollutants including sediment, debris, oils or metal.

Check Dam Small stone dam built across minor channels, swales, bioswales, or drainage ditches; used to reduce erosion and allow pollutants/sediments to settle.

Choker Course a finer aggregate layer placed above more course the base aggregate layer in permeable pavement design for leveling of the surface material.

Class V Injection Well Defined by EPA as a bored, drilled or driven shaft or a dug hole that is deeper than it is wide, an improved sinkhole or a subsurface fluid distribution system.

Clean Water Act An act by which congress mandated that the EPA address non-point source pollution in stormwater runoff.

Combined Sewer Overflow An outfall which MSD is authorized to discharge during wet weather, as defined by MSD's KPDES permit for the Morris Forman WWTP.

Combined Sewer System (CSS) The portion of MSD's Sewer System designed to convey municipal sewage (domestic, commercial, and industrial wastewaters) and stormwater runoff through a single-pipe system to MSD's Morris Forman WWTP or CSOs.

Compost Organic residue or a mixture of organic residues and soil, that has undergone biological decomposition until it has become relatively stable humus.

Constructed Wetland Stormwater management practices that are generally shallow, except for pool areas and contain dense native aquatic vegetation. Constructed wetlands temporarily store stormwater runoff, treat pollutants and create habitat.

Cultivar A plant cultivated for its desirable characteristics and often used in ornamental or landscaped gardens.

Detention Managing stormwater runoff or sewer flows through a temporary holding and controlled release.

Dry Well See Class V Injection Well.

Emergency Spillway Gates or structures that regulate the passage of flood flows around the dam or containment structure.

Energy Dissipater A mechanism to break up and slow the flow of water.

Erosion Detachment and movement of soil or rock fragments by water, wind, ice or gravity.

Evapotranspiration The combined loss of water from a given area and during a specific period of time, by evaporation from the soil and by transpiration from plants.

Exfiltration A method for managing stormwater runoff whereby stormwater enters and travels through green infrastructure from the surface and drains into subsurface soils.

Extensive Green Roof A stormwater management practice comprised of a roofing system consisting of the following layers: a waterproof layer, drainage system, engineered soils and vegetation. Extensive roofs have soil depths of six inches or less that is designed to support dense, low growing, drought tolerant vegetation.

Filter Fabric A woven, water-permeable material generally made of synthetic products such as polypropylene and used in stormwater management and erosion and sediment control applications to trap sediment or prevent the clogging of aggregates by fine soil particles.

First flush The first portion of runoff generated by rainfall event and containing the main portion of the pollutant load resulting from the rainfall.

Floatable A type of litter pollution that floats on the surface of stormwater, typically bottles, cans, styrofoam containers or other trash.

Forebay A manmade pool of water in front of a larger body of water, often used for energy dissipation and debris collection.

Freeboard A vertical distance between the elevation of the design high water and the top of a dam, levee or diversion ridge.

Frost Heave Uplift of soil or pavement surface due to expansion of groundwater upon freezing.

Geogrid Manufactured soil reinforcement products that stabilize subsurface conditions through a multi-directional load distribution grid.

Gray Infrastructure Constructed structures such as treatment facilities, sewer systems, stormwater systems, or storage basins. The term "gray" refers to the fact that such structures are typically made of, or involve the use of concrete.

Green Dry Basin Stormwater management practices that are similar to standard dry basins, except that they contain a forebay for capturing the heavier sediment and floatables, non-turf grass vegetation along the bottom of the basin, a multi-stage outlet that detains the runoff from the more frequent storm events and no low flow channel so sheet flow can be promoted. Water quality benefits include uptake and filtering through deep rooted, native plants; extended detention time to encourage increased particle settling; temporary stormwater detention; and a slower rate of release that reduces downstream bank erosion.

Green Infrastructure An adaptable term used to describe various materials, technologies, and practices that use natural systems—or engineered systems that mimic natural processes— to enhance overall environmental quality and provide utility services. As a general principal, greeninfrastructure techniques use soils and vegetation to infiltrate, evapotranspirate, and/or recycle stormwater runoff. Examples of green infrastructure include green roofs, porous pavement, rain gardens, and tree boxes.

Green Wet Basins Stormwater management practices that are similar to standard wet basins, except that they contain an aquatic bench along the perimeter of the pond just below the normal pool level and possibly other plantings above the normal pool elevation in the extended portion of the basin. Water quality benefits include uptake and filtering through deep rooted, native plants; extended detention time to encourage increased particle settling; temporary stormwater detention; and a slower rate of release that reduces downstream bank erosion.

Heat Island Effect Causes an area to be consistently warmer than its surrounding rural area, often due to urban development. Affects communities by increasing energy demand, air pollution, and water quality.

Impaired Waters Surface water that is negatively impacted by pollution, resulting in decreased water quality. Kentucky Division of Water publishes impaired waters in its 303(d) list.

Impervious surface Surfaces that do not allow water to permeate or infiltrate through the material, such as paved roadways, sidewalks, rooftops, etc.

Infiltration The process through which stormwater runoff penetrates into the soil from the ground surface.

Infiltration Rate A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions including the presence of an excess of water.

Infiltration Trench Shallow, excavated areas that receive stormwater that are typically filled with aggregate and contain no outlet structure.

Inlet A place or means of entry into the stormwater system.

Intensive Green Roof A stormwater management practice comprised of a waterproof layer, drainage system, engineered soils and vegetation. Intensive green roofs have soil depths greater that six inches to support the root growth of larger vegetation, including: plants, shrubs and trees.

Invasive Species A non-native species that adversely affect the habitats that they invade by disrupting the natural balance of the habitat either by dominating resources, habitat or native species.

MS4 Permit Program Municipal Separate Storm Sewer System; Permitted by the Kentucky Division of Water, operated by MSD with its co-permittees including Louisville Metro and the Cities of Anchorage, Jeffersontown, St. Matthews and Shively.

Mulch A natural or artificial layer of plant residue or other materials covering the land surface which conserves moisture, holds soil in place, aids in establishing plant cover and minimizes temperature fluctuations.

Nonpoint Source Pollution The EPA defines this term as any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. Nonpoint source pollution is caused by rainfall or snowmelt moving over and through the ground and carrying with it pollutants that are eventually deposited in lakes, rivers, wetlands, coastal waters and ground water.

Nutrients A type of water pollution that degrades waterways. Nutrients including excess nitrogen and phosphorous lead to significant water quality problems including harmful algal blooms, hypoxia and declines in wildlife and wildlife habitat.

Outlet The point at which water discharges through a pipe or drain.

Overland Flow Surface runoff that occurs when soil is saturated and excess water from rain or snowmelt flows over the land.

Pathogen An organism capable of causing disease, including disease-causing bacteria, protozoa, and viruses.

Peak Flow The maximum flow of water during a storm event, usually expressed in CFS (cubic feet. per second).

Permeable Pavers Pavement surfaces that promote infiltration of stormwater that consist of individual concrete or stone shapes that are placed adjacent to one another over a sub-base.

Permeable/Pervious/Porous Allows water to pass through.

Pervious Concrete A permeable pavement that allows the water to infiltrate into the subsoil through the pavement surface and base layers.

Phosphorus A type of nutrient pollution that causes degradation of waterways. See Nutrients.

Planters Are similar to rain gardens and bioretention basins in that they detain, filter and infiltrate stormwater; and are suitable for plants ranging from native flowers to shrubs or small trees. They are most commonly used as infiltration of stormwater runoff from rooftop downspouts.

Pretreatment The process removing pollutants from stormwater before entering green infrastructure and either infiltrating into subsurface soil or exiting into waterways or water bodies.

Proprietary Water Quality Units A manufactured structure connected to a storm sewer system that removes debris and pollutants from stormwater runoff through mechanical or hydrodynamic means.

Rain Garden A stormwater management practice, sometimes referred to as bioretention cells, bioinfiltration cells, or biofiltration cells which are shallow stormwater basins that mimic the ecological functions of a natural landscape. Rain gardens contain deep rooted vegetation or cultivar species to filter and infiltrate stormwater.

Recharge Replenishment of groundwater reservoirs by infiltration and transmission from the outcrop of an aquifer or from permeable soils.

Retrofit Refers to the addition of new technology or features to older systems.

Riparian Area Ecosystems that occur along waterways or bodies of water.

Sanitary Sewer A pipe or conduit (sewer) intended to carry wastewater or water-borne wastes from homes, businesses, and industries to the publicly owned treatment works.

Sanitary Sewer Overflow (SSO) Any discharge of wastewater to Waters of the United States from MSD's Sewer System through a point source not authorized by a KPDES permit, as well as any release of wastewater from MSD's Sewer System to public or private property that does not reach Waters of the United States, such as a release to a land surface or structure that does not reach Waters of the United States; provided, however, that releases or wastewater backups into buildings that are caused by blockages, flow conditions, or malfunctions in a building lateral, or in other piping or conveyance system that is not owned or operationally controlled by MSD are not SSOs.

Sensitive Areas Areas of particular environmental significance or sensitivity as determined by the Kentucky Pollutant Discharge Elimination System (KPDES) permitting authority in coordination with State and Federal agencies, that include Outstanding National Resources Waters, waters with threatened or endangered species and their habitats, waters with primary contract recreation, public drinking water intakes or their designated protection areas.

Spillway See Emergency Spillway.

Stipend A stipend is a short-term financial incentive for green infrastructure construction cost recovery.

Stormwater Water runoff that is a result of natural precipitation.

Stream Defined by the Clean Water Act, see Waters of the US.

Treatment Train The use of multiple BMPs in series on a site to meet the water quality volume requirement for stormwater management.

Tree Box provides similar benefits as a rain garden/bioretention basin in its design purpose and stormwater benefits by infiltrating, treatment, temporary detention, and biological uptake using trees and tall bushes.

Turbidity The cloudiness of a fluid caused by microscopic particles suspended in the fluid.

Underdrain A pipe or series of pipes that run longitudinal with the ground surface and capture excess stormwater to allow the green infrastructure practice to drain.

Underground Storage The practice of collecting and detaining stormwater runoff underground in pipes, vaults, chambers or modular structures with the intent of releasing the stormwater runoff to the surface drainage system at a reduced rate and completely drained prior to the next rain event, similar to a green dry detention pond.

United States Environmental Protection Agency The federal agency responsible for enforcing the Clean Water Act, Safe Drinking Water Act and other federal environmental regulations.

Urbanization The development, change or improvement of any parcel of land consisting of one or more lots for residential, commercial, industrial, institutional, recreational or public utility purposes.

Vegetated Buffer Uniformly graded and densely vegetated area that treats and infiltrates stormwater runoff, generally consisting of native, deep rooted grasses, shrubs and trees.

Water Quality A term used to describe the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water Quality Standards Standards that set the goals, pollution limits, and protection requirements for each waterbody. These standards are composed of designated (beneficial) uses, numeric and narrative criteria, and antidegradation policies and procedures.

Water Table The upper surface of the free groundwater in a zone of saturation; locus of points in subsurface water at which hydraulic pressure is equal to atmospheric pressure.

Waters of the United States As defined in 40 CFR I22.2: and the Clean Water Act.

Watershed Land area that drains to a common waterway, such as a stream, lake, estuary, wetland, or ultimately the ocean.

Wetlands A region of land whose soil is saturated with moisture permanently or seasonally.

18.1.3 Kentucky Pollutant Discharge Elimination System Permit for Stormwater Quality

Louisville Metro's Municipal Separate Storm Sewer System (MS4) is regulated by the Kentucky Pollutant Discharge Elimination System (KPDES) Permit, as required by the Clean Water Act, which is administered by Kentucky Division of Water. MSD, the City of Anchorage, the City of St. Matthews, the City of Jeffersontown, the City of Shively and Louisville Metro are MS4 co-permittees and collaborate to meet permit requirements. As a result of this co-permittee relationship, Louisville MSD leads, implements and enforces designated permit activities, including post-construction stormwater management. Post-construction stormwater management is regulated through MSD's Wastewater/Stormwater Discharge Regulations (WDRs).

18.1.4 MSD Wastewater/Stormwater Discharge Regulations (WDRs)

Effective August 1, 2013, MSD amended the WDRs to include post-construction minimum control measures and green infrastructure. The post-construction requirements apply to all new development and redevelopment with a disturbed area equal to or greater than one (1) acre, including projects less than one acre that are part of a larger common plan of development or a common scheme of development equal to or greater than one acre, located in the City of Louisville, Jefferson County, and the incorporated cities of Jefferson County. Water quality best management practices (BMPs) must treat at least 90% of the impervious area on the site. Pursuant to the WDRs, MSD has the authority to:

- Review and approve post-construction plans
- Perform pre-construction site meetings, inspections and negotiated compliance efforts in the enforcement of these regulations
- Provide education and training program for contractors
- Develop, implement, and administer a post-construction Best Management Practice Long-Term Maintenance Program
- Administer and manage a fee in lieu program

18.1.5 Impacts of Stormwater Management

With urbanization, naturally occurring pervious areas are reduced and replaced with impervious surfaces. Urbanization also increases the types and amounts of pollutants that enter local streams and drainage ways. Some of the increased pollutant runoff is due to the increased stormwater runoff volume. Research indicates that small frequently occurring rain events account for a significant amount of the pollutants generated from stormwater runoff. Pollutants typically found in stormwater runoff include the following:

- Nutrients
- Bacteria and pathogens
- Petrochemical products
- Heavy metals
- Pesticides and herbicides
- Thermal pollution
- Sediments
- Deicers
- Floatables

Floatables in Middle Fork Beargrass Creek at Cherokee Park

A summary of the potential pollutants including pollutant sources and pollutant impacts is provided in the following paragraphs.

Nutrients Naturally occurring nutrients, such as phosphorous and nitrogen, are commonly found in manmade fertilizers which are typically used on lawns, golf courses, parks, and construction sites to promote vegetative growth. These chemicals can disrupt the aquatic ecosystem through increased vegetative and algae growth, which can result in lower dissolved oxygen (DO) levels, as well as taste and odor problems. Lower DO levels are caused by the decomposition of organic materials in waterways and algae respiration. The resulting lower DO levels can lead to fish kills and the loss of sensitive aquatic species.

Bacteria and Pathogens
Bacteria and pathogens can impact human health when they enter the body through ingestion or open wounds. Coliform bacteria originate from human and animal waste, including wildlife and domestic animals. Leaking sewer systems, failing septic systems, sanitary sewer overflows (SSOs) and combined sewer overflow (CSOs) are also potential sources of these pollutants.

Petrochemical Products
Petrochemical products such as plastics and cosmetics enter the waterways through litter, garbage can overflows, and mishaps in the waste collection process. These products travel and gather in our streams. Accumulated plastics modify the structures of aquatic habitat, reduce light levels to deeper waters, and often deplete oxygen levels. Furthermore, aquatic life ingests these toxic products, which alter the biological processes within aquatic organisms.

Heavy Metals
Heavy metals originate from such sources as preserved wood, paint, and metals from automobile tires and brake liners. These enter the waterways through corrosion, flaking, dissolving, decaying or leaching. Heavy metals are toxic to aquatic organisms, terrestrial wildlife, and humans, can be bioaccumulative, and can contaminate drinking water supplies.

Pesticides and Herbicides
Pesticides and herbicides, used to control vegetation, , have the potential to enter water sources through storwater runoff. Both can be toxic to aquatic life and terrestrial wildlife, as well as the general public.

Thermal Pollution
The change of ambient water temperature can affect the level of DO in the water and the life cycle of some aquatic species. Water temperature can be increased by cooling waters used by power plants, as well as urban runoff and loss of tree canopy. As water temperature increases, DO levels decrease, which is harmful to aquatic animals and can promote algae growth.

Sediments
The amount of particulate matter in water is usually measured by total suspended solids (TSS), which is the amount of solids suspended in a water column. Fine sediments can become suspended in water affecting the clarity of water, or turbidity. Sediment typically comes from soil/streambank erosion, construction activities, or roadways. The impacts from excessive sediment include: stream warming, transportation of pollutants during rain events, destruction of stream habitats, declines in certain sensitive mussel, fish and macroinvertebrate populations, and decreased flow capacity of pipes and channels, which can lead to localized flooding. Water that is too turbid does not allow sunlight to penetrate the water and grow phytoplankton, which are the foundation for the aquatic food chain.

Deicers

Deicers are used to melt snow and ice from roadways and walkways. Deicers can harm aquatic life by increasing salt levels and conductivity within stormwater runoff that enters streams and rivers.

Floatables

Floatables include trash and organic materials such as leaves, grass, and other yard waste that float on the surface of the water. Floatables are unsightly and can damage aquatic habitats. As organic floatables decompose, they deplete the level of DO needed by fish and other aquatic organisms.

18.1.6 BMP Benefits to Water Quantity and Quality

Pollutant loadings to local waterways can be decreased by treating and reducing stormwater runoff. Table 18.1 contains a summary of the relative pollutant treatment and stormwater management benefits that can be provided by well-maintained BMPs. The intent of this table is to provide a brief summary of the potential benefits of the recommended BMPs including: pollutant reduction, hydrologic characteristics, and a reduction in potential runoff volumes.

18.1.7 Resources

Plan review requirements, checklists, calculation sheets, stormwater quality long-term maintenance agreements, and other resources are available on MSD's website, www.louisvillemsd.org.

Table 18.1 Water Quality BMP Summary

● Significant Benefit ◐ Partial Benefit ○ Low or Unknown Benefit	Pollution Reduction							
	Sediment	Phosphorus	Nitrogen	Metals	Pathogens	Floatables	Oil and Grease	Dissolved Pollutants
Rain Gardens	●	◐	◐	◐	◐	◐	◐	◐
Bioswales	●	◐	◐	◐	◐	◐	◐	◐
Constructed Wetlands	●	◐	◐	◐	◐	◐	◐	◐
Green Wet Basins	●	◐	◐	◐	◐	◐	◐	◐
Green Dry Basins	●	◐	◐	◐	○	◐	◐	○
Green Roofs	○	○	○	○	○	○	○	○
Permeable Pavers	◐	○	◐	◐	○	○	○	○
Tree Boxes	●	◐	◐	◐	○	◐	◐	◐
Vegetated Buffers	◐	◐	◐	◐	○	◐	○	○
Underground Storage	◐	○	○	○	○	◐	○	○
Catch Basin Inserts	◐	○	○	◐	○	◐	◐	○
Proprietary Water Quality Units	Varies by Technology							
Infiltration Trenches	●	●	●	●	◐	◐	◐	◐

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Table 18.1 Water Quality BMP Summary (continued)					
● Significant Benefit ◐ Partial Benefit ○ Low or Unknown Benefit	**Hydrologic Characteristics**				**Runoff Volume Reduction**
	Surface Flow Reduction	Infiltration	Stormwater Conveyance	Peak Flow Control	Runoff Capture
Rain Gardens	◐	●	○	◐	●
Bioswales	◐	◐	●	◐	◐
Constructed Wetlands	◐	○	◐	◐	○
Green Wet Basins	◐	○	◐	◐	○
Green Dry Basins	◐	◐	◐	◐	◐
Green Roofs	●	○	○	◐	◐
Permeable Pavers	●	●	○	○	●
Tree Boxes	◐	◐	○	○	◐
Vegetated Buffers	◐	◐	◐	○	◐
Underground Storage	◐	●	○	●	●
Catch Basin Inserts	○	○	○	○	○
Proprietary Water Quality Units	Varies by Technology				
Infiltration Trenches	●	●	○	◐	●

18.2 SELECTION PROCESS

18.2.1 Introduction

The purpose of this section is to provide guidance for managing the water quality requirements on a project site. The primary goal of a BMP is to provide water quality improvements before runoff leaves a site. Although the process for selecting BMPs is the same for all sites, the BMP selections will vary from site to site. It is important for a design professional to consider and assess numerous factors, including but not limited to: site characteristics, the Water Quality Volume (VR) required to be managed on a site, site design, constructability of BMPs, and long-term operation and maintenance of BMPs. This section provides the process for selecting post-construction water quality design components for a site, but is not intended to address every site planning or design variable that a designer may encounter. The application of sound engineering, planning, surveying principles and judgment apply. Approval of plans pursuant to this process does not relieve the designer from required compliance with the other sections of the MSD Design Manual and other applicable standards.

The BMPs in the MSD Design Manual should be considered as a list of tools and implemented based on the site conditions, and stormwater management needs to comply with the Clean Water Act and post-construction stormwater water quality requirements.

18.2.2 Water Quality BMP Practice Selection Steps

Developing a post-construction water quality project involves considering long-term BMPs throughout the life of the project, from the concept stage through the final design and subsequent operation and maintenance.

STEP 1: Determine Required Water Quality Rain Event (RE)*

RE = 0.60 inch (80^{th} percentile storm)*

* RE requirements may be greater than 0.60 inch for projects applying for MSD financial incentives

STEP 2: Calculate Water Quality Volume Required (VR)

$$VR \text{ (cubic feet)} = (1/12)(RE)(A)(0.05+(0.009)(\mathbf{I}))$$

where **I** = Percentage of impervious cover and
A = Disturbed drainage area in square feet

STEP 3: Select the appropriate BMP(s) and determine water quality volume provided (VP) for each selected BMP**

Consideration should be given to selecting BMPs with runoff reduction abilities. The water quality volume calculation for each BMP type can be found in Section 18.4 for each BMP type.

**See Section 18.4.10 for design criteria related to water quality units

STEP 4: Verify total Volume Provided (VP) for all BMPs is greater than VR determined in Step 2

The designer should experiment with various BMPs or a combination of BMPs until VR is managed and/or treated. If the total VP is greater than or equal to VR, then the designer can move to Step 5. BMPs must be oversized (up to 10%) to account for areas that bypass the BMP. The VP of the BMP or the sum of the BMPs must always be equal to or greater than VR.

$$\sum VP = \sum VP_1 + VP_2 + \ldots \text{ for each BMP}$$

STEP 5: Provide Operation and Maintenance (O&M) Documentation, including an operation and maintenance plan and signed Long Term Operation and Maintenance Agreement

During Step 5 of the selection process for BMPs, consideration should be given to operation and maintenance of BMPs, including documentation requirements (see 18.7 for details on operation and maintenance needs).

18.2.3 Minimum Design Requirements

18.2.3.1 Runoff Capture

Runoff from at least 90% of the site's disturbed impervious area is required to be managed or treated by a BMP. This allows for flow from discharges at property lines or locations with little to no setback to be accommodated. In these instances other site BMPs must be oversized to capture additional VR to make up the difference for the total site water quality volume. The maximum oversizing of BMPs to account for bypassing site area shall be 10%.

18.2.3.2 Pretreatment

Pretreatment practices are required for underground infiltration basins, wet and dry basins, and constructed wetlands and are recommended for other practices to facilitate long-term maintenance and extend the life of the practice. Protection of BMPs from erosive velocities and clogging from sediment is critical to sustain designed soil infiltration rates. Once this material becomes clogged, the practice must be excavated and reinstalled.

The following pretreatment measures may be used:

- Forebay
- Vegetated strip
- Proprietary water quality unit
- Catch basin inserts

Proprietary water quality units and vegetated strips can be used as pretreatment or as stand-alone BMPs. Design criteria for proprietary water quality units and vegetated strips are located in 18.4. Forebays are typically used for rain gardens, constructed wetlands, and wet and dry basins. Design criteria for forebays for each BMP are located within each section in 18.4. Design criteria for catch basin inserts is discussed in more detail in the following subsection.

18.2.3.2.1 Catch Basin Inserts

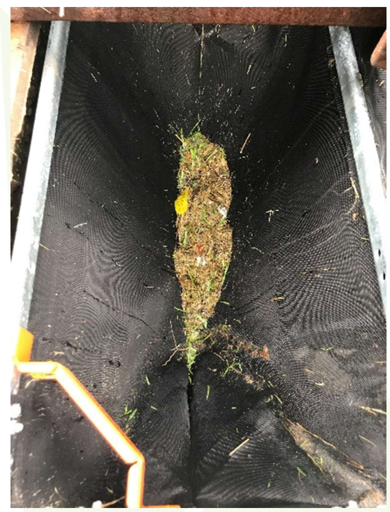
Catch Basin Inserts are devices added to catch basins for the purpose of capturing or retaining stormwater pollutants including sediment, debris, oils or metal. They may only be used as pretreatment for other BMPs, and cannot receive credit toward a site's required water quality volume.

They are are installed underneath the grate of an inlet to remove sediment, debris, oils or metals from stormwater inflow by filtering, settling or absorbing pollutants. Catch basin inserts are beneficial because they install easily in retrofit systems and work well in a treatment train as they minimize clogging in downstream water quality features.

Because of their minimal storage capacity for captured sediment, catch basin inserts should only be used where appropriate. They are suitable for use in unpaved areas with minimal erosion or in parking lots with a small drainage area but are not suitable for receiving runoff from areas with heavy sediment flow.

Performance ability and size vary based on the manufacturer and/or project need. Inserts should be designed and installed based on the manufacturer’s recommendations. Recycled and reusable products are available for some types of insert media. The following types of material are generally used in combination with the catch basin inserts:

- Metal/Plastic Screens—typically effective in the removal of sediment and other debris
- Fabric—typically effective in the removal of oil and grease
- Filter Inserts—designed to remove metals or other types of pollutants



Catch basin insert removes debris underneath an inlet grate on Trade Port Drive.

Catch basin inserts should be designed to bypass stormwater flow in excess of the water quality design volume into another system or inlet. This prevents overflow of the catch basin if it becomes clogged or when there is excessive rainfall. The bottom of the filter media should be located above the crown of the outlet pipe. This will ensure that the water quality design volume is filtered through the media.

The catch basin should be located in an area that is accessible for maintenance at any time. Special consideration should be given during the design phase to ensure that the basin will not be blocked for maintenance by vehicles or other obstructions.

18.2.3.3 Hotspots

Hotspots are a land use or activity that generate higher concentrations of pollutants, including but not limited to; hydrocarbons, sediments and trace metals that are found in stormwater near the land use. Due to the potential for groundwater contamination, BMPs that utilize infiltration are prohibited to treat stormwater runoff from hotspots as defined below. Separation from the groundwater table or an impermeable liner for impoundment structures should be considered for hotspots.

Hotspot locations include:

- Gas/fueling stations
- Vehicle washing/steam cleaning
- Auto salvage yards/auto recycling facilities
- Outdoor material storage areas
- Landfills
- Facilities that store or generate hazardous materials
- Industrial sites

18.2.3.4 Infiltration Rates

The minimum average infiltration rate for all infiltrating practices shall be 0.5 inches/hour. Where the minimum infiltration rate is not achieved, design cannot account for infiltration and an underdrain is required. Perched or elbowed underdrains, a minimum of 4 inches in diameter with minimum 0.5% slope, are required to increase exfiltration through increased contact time with native soils. All underdrain systems require a 4 inch minimum cleanout.

Infiltration rates may decrease over time due to settlement of filter media, compaction, or accumulation of sediment in the practice. To sustain infiltration rates long-term, it is important that a maintenance plan is in place. Regular maintenance should be conducted to optimize operating infiltration rates.

18.2.3.5 High Water Tables

High water tables can impact the efficiency of a BMP. High infiltration BMPs are prohibited in these areas since high water tables can prevent the percolation of stormwater into the subsoil. In addition, special geotechnical considerations may be necessary in these areas, especially for embankment or impoundment facilities.

Where a high water table occurs (vertically) within two feet of the plane of infiltration (bottom of BMP), infiltration shall not be considered as part of the water quality volume. High water table data must be acquired by geotechnical exploration.

18.2.3.6 Shallow Soils/Depth to Bedrock

Thin soil zones and shallow bedrock limit the capacity of BMPs to exfiltrate into native soils. Where shallow soils and depth to bedrock occurs (vertically) within three feet of the plane of infiltration, infiltration shall not be considered as part of the water quality volume. Depth to bedrock data must be acquired by geotechnical exploration.

18.2.3.7 Karst Areas

Sinkholes and karst topography limit options for BMPs, and additional infiltration may cause sinkholes to develop. Where sinkholes or karst features are present onsite, infiltration shall not be considered as part of the water quality volume.

18.2.3.8 Engineered Soils

The soil composition for engineered soils may vary based on site conditions, project objectives, and proposed plantings. The clay content for the composite mix must not exceed 10% of the overall mix, by volume. The following soil mix is recommended, but other soil mixtures may be used based on site characteristics and proposed plantings. To enhance infiltration rates and prevent soil consolidation over time, a soil mix with a high sand content is recommended. The typical soil mix to enhance infiltration rates and prevent soil consolidation over time consists of the following materials, by volume:

- 70%-85% sand
- 10% to 20% silt + clay, with no more than 5% to 10% clay;
- 5% to 10% organic matter

18.2.3.9 Mosquito Control

For mosquito control, BMPs must be designed to have no ponding or standing water within 36 hours of a rainfall event.

18.2.4 Construction

For BMPs designed to infiltrate stormwater runoff, it is essential that soils are not compromised by compaction from construction equipment. Care should be taken to minimize soil compaction throughout the BMP and especially at the plane of infiltration so that infiltration rates of native soils are not impacted. Acceptable excavation methods at infiltration practices include hand labor with shovels or the use of an excavator such as a backhoe or track hoe (located outside the perimeter or footprint of the practice). Heavy equipment should never be used over existing or the footprint of planned infiltration practices. Prior to site disturbance, the perimeter of the practice should be partitioned off with temporary fencing/tape to keep heavy equipment from crossing the perimeter throughout time of active construction. In cases where the BMP is sufficiently large that equipment must enter it, methods proposed to limit and restore compacted soil must be approved in advance.

Designers should also consider construction access and staging during the design process. BMPs should be constructed last whenever possible and remain offline until at least 80%, preferably 100%, of the contributing area is stabilized. Activities that could compact soils where BMPs are sited should be avoided. Where site constraints make this unavoidable, the designer shall compensate accordingly in the design of the BMP.

18.2.5 As-built Drawings

MSD requires that as-built drawings be submitted for all BMPs used to meet the water quality volume. The as-built drawings must contain at a minimum the following information for each BMP as applicable:

- Location and dimensions of BMP, including pretreatment, diversion structures, underdrain systems, inlets, outlets, and overflows
- Depth and area of engineered soil and aggregate layers
- Manufacturer model and size (water quality unit only)
- Post-Construction infiltration rates (infiltration practices only)

The site disturbance permit will not be released until the as-built drawings are approved.

18.2.6 Alternative Practices for Post-Construction Water Quality BMPs

To encourage innovation, alternative management practices that are not included in the MSD Design Manual, Standard Specifications, and Standard Drawings may be allowed upon review and approval by MSD. The alternative management practice must be supported by evidence that it will perform at least equivalently to a currently approved control contained in the MSD Design Manual, Standard Specifications, or Standard Drawings and conforms to current American Society for Testing and Materials (ASTM) Standards. However, if the control or practice fails, or is inadequate to contain the target pollutants (i.e. TSS) onsite or meet long-term post-construction stormwater management objectives, the permittee will be required to remove and replace it with a control approved by MSD and in accordance with the MSD Design Manual Standard Specifications and Standard Drawings.

18.2.7 Fee in Lieu Program

MSD has the authority per the Wastewater/Stormwater Discharge Regulations to establish a fee in lieu program to mitigate stormwater runoff off-site. This program would allow developments where green infrastructure is not feasible on-site to mitigate for water quality off-site or pay a fee that would fund stormwater quality mitigation projects.

18.2.8 Design Considerations

Consideration should be given to preserving the natural features of a project site. Post-construction water quality BMPs can range from natural features on a property that treat runoff, to manmade structures that treat stormwater before it enters the drainage system. Research indicates that it is more effective to treat stormwater at its source; therefore, preserving the natural features on a site can be a cost effective means for stormwater management.

When determining the best BMP(s) for the project, consider the following:

Development Features
Development features include both the natural and manmade features of the site, including utilities, park areas, waterfront areas, landscaping, conservation areas, roads, and sidewalks. Development features should be considered during the site assessment and planning phase.

Watershed Factors
Watershed factors to consider include pollutants, water quality, sources of water pollution and location of the property within the watershed. The applicability of some BMPs will be limited due to the size of the contributing drainage area and the functionality of BMPs. Where applicable, the maximum and minimum contributing drainage area sizes are shown on the BMP fact sheet guidelines.

Aesthetic and Habitat Related Issues
Aesthetic and habitat related issues can include a site's proximity to impaired waters or sensitive areas, and if there are threatened and/or endangered species or their suitable habitat identified on the site.

Topography
A site's topography will impact the location and types of BMPs that can be used. It is important to try to utilize the natural topography to the best extent possible.

Proximity to Sensitive Features or Obstructions
Proximity to wells, wellhead protection areas, septic systems, buried utilities, overhead utilities and other obstructions can limit which BMPs are applicable to a specific site.

Vegetation
Vegetation on a site can both enhance and impede the effectiveness of a BMP. For example, deciduous trees near pervious pavement can clog the BMP with leaves, but reduce stormwater runoff by rainfall interception and evapotranspiration. In spite of these challenges, appropriately selected vegetation in BMPs can improve performance.

Existing Development and Steep Slopes
One goal of stormwater management is to allow for the natural recharge of groundwater. This process also has the potential to impact adjacent ground during and after storm events.

Saturating the soils on steep slopes (6 percent or greater) can cause the failure of the slope and adjacent structures.

Local Planning and Regulatory Requirements

Federal, state and/or local regulatory requirements may prohibit or require certain BMPs to meet specific standards. The designer should consult all applicable ordinances and regulatory requirements, as they may impact the design process, selection criteria, operation and maintenance and the cost of the BMPs. Some of the planning and regulatory aspects to consider when planning BMPs for a site are: CSO mitigation, TMDL requirements, 401/404 permitting, floodplain permitting, and MSD credits/incentives. Review local ordinances and zoning codes to verify that potential BMPs comply with these requirements and that there are not any regulatory impediments to the BMPs proposed for the site.

Operation and Maintenance

The operation and maintenance schedule and costs may impact the decision to use a BMP. Some BMPs require more long-term maintenance than others, resulting in increased cost of the BMPs.

Treatment Trains

A treatment train is the use of multiple BMPs in series on a site to meet the VR for stormwater management. Treatment trains can include structural and non-structural BMPs. When assessed and planned, a treatment train consists of all of the design concepts and BMPs that work to accomplish the desired water quality volume volume. The general approach for treatment trains should consider:

1. Avoiding additional stormwater runoff volume.
2. Managing stormwater runoff as close to the source as possible.
3. As appropriate, infiltrating as much of the stormwater runoff as possible.

18.3 Infiltration Testing Specifications

The purpose of many BMPs is to store, treat and infiltrate stormwater into the soil, mimicking natural systems. Subsurface conditions are key in assessing the feasibility of infiltration in the design of BMPs. Infiltration capacity testing and design of BMPs that rely on infiltration to treat the stormwater quality volume shall follow the specifications summarized in this chapter. . Where the infiltration rate cannot be demonstrated to be equal to or exceed 0.5 inches per hour, either an underdrain will be required or a non-infiltration BMP selected.

Single-ring infiltrometer infiltration test (Photo: URS)

While National Resources Conservation Service (NRCS) soil classification of the site is encouraged as part of a desktop analysis to gain familiarity with potential native soil conditions, it is not adequate justification for infiltration testing results and cannot be substituted for infiltration testing using infiltrometers or test pits. The following infiltration testing options are addressed:

- Single-Ring Infiltrometer
- Test Pit
- Other Infiltration Testing and Verification Methods

18.3.1 Infiltration Testing Requirements

All infiltration practices used to meet the water quality volume standard are subject to the following testing requirements:

- Infiltration tests shall not be conducted in the rain or within 24 hours of significant rainfall events (greater than 0.5 inches), or when the temperature is below freezing.

- Infiltration testing performed, including testing procedures followed, shall be documented and submitted as part of the plan approval process to MSD.

Portions of this Section present testing methods at the bottom of an excavation. It is the testing personnel's responsibility to be aware of and take proper health and safety precautions for activities in an excavation. See the U.S. Occupational Health and Safety Administration (OSHA) for guidelines and requirements (www.osha.gov).

Minimum testing requirements are summarized in Table 18.2.

Table 18.2 Infiltration Testing Requirements	
BMP Type	**Conceptual Design Testing**
Linear practices (i.e. bioswales, interconnected tree boxes, infiltration trenches, etc.)	All of the following are required: • 1 single-ring infiltrometer test • 1 test pit per 400 linear feet • Minimum 1 infiltration test per test pit of BMP practice
Non-linear practices (rain gardens, basins, etc.)	All of the following are required: • 1 single-ring infiltrometer test • 1 test pit per 2500 square feet of practice area for 10,000 square feet or less of practice area • Minimum 1 infiltration test per test pit per BMP More tests are acceptable as long as additional tests are spaced evenly. An effective infiltration rate should be determined by averaging infiltration tests.

18.3.2 Qualified Professionals

Infiltration testing shall be conducted by a qualified professional and plans including infiltration testing results must be certified by a professional engineer or professional geologist.

18.3.3 Background and Desktop Analysis

A desktop analysis of soils data, topography, location of streams, waterbodies, existing/previous land uses, and structures is encouraged to identify potential BMP locations and types. Existing, previous soil investigation or lab data may also be used to support preliminary siting of BMPs and infiltration testing. While NRCS soil classification desktop analysis is encouraged to gain familiarity with potential native soil conditions, it cannot be substituted for infiltration testing using infiltrometers or test pits.

18.3.4 Test Pits

Where the feasibility analysis meets minimum infiltration criteria, the test pits are necessary for conducting infiltration testing per Table 18.2 to further verify site information characteristics.

This test method consists of a trench or pit that allows visual observation of the soil horizons and overall soil conditions at a particular location on the site. Multiple test pit observations can be made for a relatively low cost and in a short time period. The use of soil borings shall not be substituted for test pits. Test pits allows in-situ visual observation of soil conditions, where soil borings do not. Soil borings are encouraged to supplement data collection, but cannot be substituted for infiltrometer or test pits.

1. Dig a backhoe-excavated trench/pit, 2-1/2 to 3 feet wide, to the proposed depth of the infiltration plane of the practice at the location of the proposed BMP.
2. Safe test pit entry should always be observed. A test pit should never be accessed if it is not safe to do so. OSHA regulations should always be followed.

3. Document the soil profile (soil horizons, soil texture and color and depth below ground surface, depth to water table, and depth to bedrock, etc).
4. Based on observed field conditions, the qualified professional should consider modifying the proposed infiltration plane of the practice and adjust infiltration testing locations as necessary.
5. Perform Single-Ring Infiltrometer test (below) at depth of infiltration plane of the proposed practice.
6. Soil samples may be collected at various horizons for additional analysis at the designer's discretion.
7. After testing is complete, re-fill the test pit with original native soils and stake the location of the test pit.

18.3.5 Single-Ring Infiltrometer Infiltration Test

This test method utilizes perforated 200 millimeter (mm) to 250 mm (8- inch to 10-inch) plastic or metal canisters with bottom set in coarse drainage sand to minimize disturbance to in-place soils and to prevent siltation of the test hole during testing.

1. Holes in the test canister should be 3 mm (1/8 inch) diameter and spaced on 25 mm (1 inch) centers.
2. Excavate a test hole to the depth of the infiltration plane, or the bottom of the BMP, and approximately 25 mm (1 inch) larger diameter and approximately 25 mm (1 inch) deeper than the dimensions of a test canister. If the depth of testing is greater than 18 inches, it may be necessary to excavate a shallow test pit to conduct testing.
3. Check that the sides of the test hole are not smooth, but scarified.
4. Place coarse drainage sand in the bottom of the hole and place the canister firmly into the hole. The bottom of the hole should be uncompacted.
5. Backfill the space around the canister with soil and tamp the soil into place.
6. Fill canister with water and allow to drain completely or to soak the surrounding soils for a minimum of one hour, whichever occurs first.
7. Refill the canister and measure the rate at which the water level drops.
8. Record the infiltration rate as the decrease in depth of water per hour (inches/hour).

Where the feasibility analysis does not meet minimum infiltration criteria, the designer may prefer the use of an underdrain rather than continue with further testing.

18.3.6 Other Infiltration Testing and Verification Methods

Other infiltration testing standards that are acceptable include ASTM D3385-09 Standard Test Method for Infiltration Rate of Soils in Field Using Double Ring Infiltrometer.

Verification methods such as soil borings may be used to verify site conditions where final locations of BMPs are adjusted and do not fall within the original testing location. Test results must verify that the soil conditions are the same as those from the original test results.

18.4 BMP Fact Sheets

This section provides design standards and requirements for the following BMPs:

- Rain Gardens/Bioswales
- Constructed Wetlands
- Green Wet Basins
- Green Dry Basins
- Green Roofs
- Permeable Pavers
- Tree Boxes
- Vegetated Buffers
- Underground Infiltration Basins
- Proprietary Water Quality Units
- Open Infiltration Trenches

Information on each BMP is provided in the fact sheets, as well as:

- Benefits and limitations
- Application and site feasibility
- Design criteria
- Step by step design procedures

MSD has developed companion documents to support the design and plan submittal process. Plan review checklists and design calculation sheets are available at www.louisvillemsd.org.

18.4.1 Rain Gardens/Bioswales

Rain gardens, also referred to as bioretention/biofiltration cells, are shallow stormwater basins (minimum ponding depth 4 to 12 inches) that mimic the ecological functions of a natural landscape. Rain gardens contain deep rooted native vegetation or cultivar species to filter stormwater, promote infiltration and provide wildlife habitat. They can also take form in a raised landscape bed, or stormwater planter box. Similar to rain gardens, bioswales (or linear rain gardens) are vegetated channels that provide treatment and retention; however bioswales also convey stormwater flows.

Rain garden at Louisville & Jefferson County MSD main office with naturalized native plantings.

Rain gardens and bioswales improve water quality through:

- Treatment of stormwater percolating through soil and filter media
- Groundwater recharge and detention of stormwater
- Natural evapotranspiration
- Biological uptake

Advantages/Benefits	Disadvantages/Limitations
• Provides infiltration and groundwater recharge, filtering pollutants and reduces stormwater runoff volume • Suitable for runoff from highly impervious areas • Increases biodiversity by providing urban habitats for wildlife • Good retrofit capability	• Location constraints (utilities, shallow groundwater, shallow bedrock, sinkholes, down gradient from buildings/basements, overflow pathway, etc.) • Maintenance commitment (basic gardening/landscape maintenance) • Available space for capture of target volume • Not for slopes > 4%

18.4.1.1 Application and Site Feasibility

A bioswale treats stormwater runoff from paved surfaces.

Rain gardens and bioswales can be flexible in design to accommodate landscape requirements. Rain gardens are infiltration practices and bioswales are filtration/conveyance practices that are appropriate in a wide variety of land use applications such as commercial, industrial, or residential areas and they are often located adjacent to parking lots or roof downspouts. Where a raised bed or box is desired, a planter box type of rain garden may be suitable for the site. Infiltration planters are designed to capture and infiltrate stormwater runoff through an open box design.

This section includes guidance for rain gardens and bioswales on a larger scale. MSD's *A How-To Guide for Building Your Own Rain Garden* was developed specifically for homeowners. A copy can be downloaded from the MSD website at www.louisvillemsd.org.

18.4.1.2 Physical Requirements

Key physical considerations are:

- Soil type and infiltration—Rain gardens should drain within 36 hours. Infiltration rates for native soils with clay content may improve over time with installation of deep rooted plants as they have the potential to penetrate and loosen the soils. Soils shall have an infiltration rate of 0.5 inches per hour or greater. Sandy, permeable soils promote infiltration but are also susceptible to erosion, and should be protected in applications receiving or directing stormwater conveyance.
- Deep rooted plants—Native plants are preferred, but non-invasive cultivars/hardy plants can also be used to landscape the rain garden. Native, hardy plants with deeper root systems and tolerance for drought to wet conditions are suitable for the varying wet and dry conditions of rain gardens. See Chapter 13 of the MSD Design Manual for a list of approved plants.
- Slopes—Slopes affect flow rates, bioswale/linear rain garden capacities, infiltration rates, and erosion.
- Building foundations—Sufficient space is required from building foundations. Where a gravel infiltration trench is used in a rain garden, the gravel infiltration trench of the rain garden must be set back from building foundations a minimum of 10 feet. For all applications, buildings and building foundations must be waterproofed with foundation drains to limit seepage into basements or lower levels.
- Space available—Sufficient space is required to plant herbaceous plants, shrubs or trees and allow space for foliage growth above ground and root growth below ground. Plant type and species vary by preferred landscape, tolerance for inundation, and aesthetic qualities.
- Groundwater table – The groundwater table shall be at least 2 feet, preferably 4 feet, below the bottom of the rain garden or bioswale.

18.4.1.3 Design Criteria

The design of a rain garden or bioswale includes several elements to manage stormwater ponding and infiltration as well as to facilitate water quality improvement. For a summary of design parameters, see Table 18.3.

18.4.1.3.1 Types

Based on site characteristics and desired aesthetics, select the type of rain garden, i.e. traditional rain garden, planter box or linear rain garden/bioswale.

Traditional Rain Garden: Where conveyance is not required and mild slopes exist, traditional rain gardens may be suitable. Rain gardens are generally shallow, relatively flat, depressed areas that contain deep rooted native vegetation to help slow and filter stormwater.

Linear Rain Gardens or Bioswales: Where conveyance is required and mild slopes exist on site, linear rain gardens or bioswale type of rain gardens may be suitable. Bioswales are generally shallow, wide, and gently sloped, and contain deep rooted native vegetation that helps slow and filter stormwater.

Planters: Where a raised bed or box is desired, a planter box type of rain garden may be suitable for the site. Infiltration planters are designed to capture and infiltrate stormwater runoff through an open box design. If infiltration into native soils is not desired, planters may be designed to capture and retain stormwater runoff with a flow-through closed box design, also called flow-through planters. Flow-through planters include an overflow pipe and underdrain system. If the in-situ soil infiltration rate is less than 0.5 inches per hour, then an underdrain is required. Underdrains should be designed to be a minimum of 4 inches in diameter, minimum 0.5% slope and include a 4 inch minimum cleanout. The amount of infiltration that can be accomplished in the open box design will depend on the infiltration rate of the soil composition in the box and surrounding soils. If an underdrain is needed, storage space can be provided beneath an underdrain system to allow more time for infiltration to occur. A planter should not accept drainage from more than 0.25 acres of impervious area; a smaller drainage area is encouraged for better performance. Planters have specific design criteria and will be considered on a case by case basis.

18.4.1.3.2 Location

Since rain gardens are retention structures, they are designed to effectively capture stormwater runoff. When finding the most appropriate location for the rain garden, it is best to find a site with a small drainage area. For larger drainage areas, it is recommended that multiple rain gardens or larger vegetated infiltration BMPs be established.

Bioswale at Kentucky Gymnastics Academy

Rain gardens should be built where the groundwater table is at least 2 feet, preferably 4 feet, below the lowest point of the rain garden to promote effective infiltration. Areas with erosion or sediment flow are not suitable locations for rain gardens because the structures and soil may become clogged. In addition, rain gardens and bioswales should be placed at least 10 feet from building foundations and underground utilities, with the exception of closed or flow-through planter boxes. See Exhibit 18-1, 18-2 and 18-3 for a rain garden and bioswale typical cross-sections.

18.4.1.3.3 Flow Capacity, Velocity and Freeboard

Since bioswales are conveyance features, they are designed to slow and detain small storm events while also safely bypassing large storms to protect the bioswale from erosion. Bioswales along a roadway should have adequate flow conveyance and maintain adequate freeboard to avoid flooding or overtopping the pavement. When rain gardens or bioswales are in close proximity to the pavement structure, they should have enough flow capacity to provide positive subgrade drainage. See Chapter 10 for drainage design requirements.

18.4.1.3.4 Erosion Prevention

Linear rain gardens, or bioswales, conveying stormwater should be lined with biodegradable erosion control matting for erosion prevention and sediment control during the plant establishment period. Turf reinforcement mats, or other enhanced erosion protection may be necessary in locations of concentrated flow or to protect against high stormwater velocities produced by large storm events. Mat selection should be based upon anticipated flow velocities, vegetation planting requirements, and longevity needs.

18.4.1.3.5 Slopes

Site topography should be considered in bioswale design, including slope and cross-sectional area to maintain nonerosive velocities. Typically, slopes should be less than 2%. In areas with slopes between 2% and 4%, check dams or weirs must be placed perpendicular to the flow to increase detention and extend time for infiltration. Rain gardens or bioswales are not suitable for slopes greater than 4%. Placement of check dams or weirs should include scour protection to limit erosion. Bioswales require a minimum slope of 1%, unless an underdrain is installed. See Exhibit 18-4 for a typical check dam detail.

18.4.1.3.6 Inlet and Pretreatment

Pretreatment eases maintenance, especially in land use areas with high sediment loads. The use of a forebay, or other energy dissipating device, such as a strip of vegetation or gravel filter, to spread the flow at the inlet is recommended to facilitate maintenance and removal of accumulated sediment and to prevent erosion. See Exhibit 18-5 for typical forebay plan and profile.

18.4.1.3.7 Sizing and Ponding Area

The surface storage parameter should be designed to retain/capture the volume produce by the rainfall events specified in Table 18.3. The depth of ponding within these structures should be kept relatively low to prevent hydraulic overloading of the in situ media. Ponding depth should be limited to 12 inches or less. An overflow drain also must be installed to move excess water during a large storm event or due to clogging. The maximum drainage area to rain garden area ratio is 10:1. Ratios greater than 10:1 will be reviewed on a case-by-case basis.

Sizing of a rain garden is determined by the storage capacity, or water quality volume, provided by the porosity of any amended soils and in the ponding above any amended or in situ soils. This volume must be equal to or greater than the Water Quality Volume Required (VR).

See Table 18.3 for the calculation used to determine the storage capacity of the rain garden or bioswale.

18.4.1.3.8 Check Dams

Check dams should be used to pond water within bioswales to slow flows, prevent erosion and promote infiltration. Typical check dam construction materials are earth, stone, river rock, and rot resistant timbers. See Exhibit 18-4 for a typical check dam detail.

18.4.1.3.9 Engineered Soils

Engineered soils (as identified in Table 18.3) must be used unless native soils have a minimum infiltration rate of 0.5 inches per hour. Minimum engineered soil depth is 36 inches. Maximum recommended engineered soil depth is 6 feet. Erosion control should be incorporated into the design when engineered soils are used, particularly when vegetation is being established.

18.4.1.3.10 Underdrains

If the infiltration rate of in situ soil is less than 0.5 inches per hour, an underdrain is required. For Engineered Soils with an Underdrain, underdrains should be constructed with perforated pipe or slotted corrugated pipe with a minimum 4-inch diameter with a mimimum 0.5% slope and bedded in double washed KY #57 stone. Filter fabric should be avoided in this situation due to its propensity for clogging. To minimize the migration of soil particles into the stone layer and underdrain, layer double washed KY #8 stone over the double washed KY #57 stone layer. Where filter fabric is necessitated, choose non-woven filter fabric. Underdrain pipes should be designed to include a 4 inch minimum cleanout. See Exhibit 18-6 for a typical underdrain with clean out detail.

18.4.1.3.11 Plant Selection

Rain gardens and bioswales are typically planted with deep rooted native grasses, sedges, and forbs. In selecting plants, consider the favorable conditions where plants can thrive. The conditions for plants used should be able to survive both droughts and inundated scenarios. Note that plants located on bermed areas on the perimeter of the rain garden or bioswale should never be underwater and should tolerate dry conditions. At inflow and outflow areas of the rain garden, the use of an herbaceous layer of ground cover is recommended over mulching to prevent erosion of mulch and soil layers.

Bioswale at Unipak, LLC in Jeffersontown.

Ground covers also act as a weed control by providing a thick cover that inhibits the growth of unwanted plants. Mulch options include shredded bark mulch, which is preferred to maximize moisture and nitrogen retention, and stone mulch, which is preferred in areas where steeper slopes and higher velocities are present. The slope of the rain garden should be designed to minimize erosion. Mulch should be applied as an even 2 to 3-inch layer avoiding mounding around trees, shrubbery and plants. Whether to plant with seed, plugs or container plants is often an economic and maintenance decision. Seeding is less expensive initially, but requires a longer establishment period, and makes maintenance and weeding more intense. Plugs and container plants are more expensive than seed, but plants will grow and establish quicker and less weeding will be required.

Although native species are preferred, non-invasive cultivars may be used or combined with native species to achieve desired landscape aesthetic qualities. Native species and non-invasive cultivar/hardy species are provided in Chapter 13 of the MSD Design Manual.

18.4.1.3.12 Outlet Design

A high flow bypass or diversion structure must be included to safely convey high flows from large storm events. If an underdrain is used, this may also help expedite the infiltration process when there is an excess amount of water retained within the structure after ground saturation has occurred.

Table 18.3 Rain Garden/Bioswale Application and Site Feasibility Criteria

Design Parameter	**Criteria**
Drainage Area	Dependent on application.
Soils	Minimum infiltration rate for in situ soils is 0.5 inches per hour. Recommended soil mix (by volume) for engineered soils: • 70%-85% sand • 10% to 20% silt + clay, with no more than 5% to 10% clay; • 5% to 10% organic matter Underdrains are required for in situ soils with an infiltration rate less than 0.5 inches per hour. Underdrains to utilize minimum 4-inch diameter perforated pipe.
Sizing	Dependent on application and drainage area. For rain gardens, size so that ponding depth is 4 inches minimum to 12 inches maximum.
Longitudinal Slope	No greater than 4%, 1%-2% preferred. Where greater than 4%, use terracing techniques to achieve slopes as needed. For bioswales, minimum slope of 1% unless an underdrain is installed. For slopes between 2% and 4%, use check dams or weirs to increase detention, extend time for infiltration, and prevent erosion.
Side Slopes	No greater than 3:1 (H:V), 4:1 or flatter recommended.
Design Flows and Conveyance Capacity	Pass the 2- and 10-year, 24-hour storms. Bypass or design overflow of the 100-year, 24-hour storm with 6 inches of freeboard.
Pretreatment	Forebay—Size pretreatment forebay to hold 10% to 15% of the VR with a depth of 2 to 4 feet.

Inlet/Outlet Protection	Overflow outlet or spillway required. Scour protection required at inlet and discharge point for rain gardens. Bioswales, should be lined with biodegradable erosion control matting during the plant establishment period and turf reinforcement mats in locations of concentrated flow as needed.
Volume Provided (VP)	The water quality design volume provided (VP) by a rain garden or bioswale is: VP (ft^3) = (A)(M)(p) + (A)(P), where • A = area of the bioswale (ft^2) • M = depth of the media (ft) • p = media porosity (% void) • P = average height of water above the media during the RE rain event in feet Design calculation sheets are available at www.louisvillemsd.org
Landscape Plan	Landscape plan required showing native plants and/or non-invasive cultivars, plant size, spacing, installation and maintenance notes. Obtaining a one- or two-year maintenance agreement and warranty from the nursery or landscaper is recommended.

18.4.2 Constructed Wetlands

Constructed wetlands incorporate marsh and pool areas to temporarily store stormwater runoff, treat pollutants and create aesthetic value and wildlife habitat. Constructed wetlands are generally shallow and contain dense native aquatic vegetation, typically covering 60% to 80% of the surface area that uptake pollutants from stormwater runoff. Constructed wetlands improve water quality through:

- Control of runoff volumes
- Biological uptake of pollutants through native plants and biodegradation by microorganisms
- Sediment settling and filtering
- Adsorption and other chemical/physical processes

Native plants in a constructed wetland improve water quality.

Advantages/Benefits	Disadvantages/Limitations

• Reduces runoff rates • Increases biodiversity by providing habitat for aquatic and wildlife species • Opportunity for multiple uses, including passive recreation and outdoor recreation • Can be used as a BMP in small areas (pocket wetlands) or on larger tracts of land	• Needs regular flow of water, so stormwater runoff may need to be supplemented during dry conditions • Needs to be properly designed and managed to reduce potential to breed mosquitoes • Water quality of discharge can change with seasonal growth of plantings • Does not provide groundwater recharge • May need maintenance for invasive species

18.4.2.1 Application and Site Feasibility

Constructed wetlands are a depressional feature that are used to treat and temporarily store stormwater runoff. Constructed wetlands can be used in small areas as pocket wetlands, or can be larger shallow emergent marsh systems. Generally, to help sustain wetlands during dry periods, design should incorporate a contributing watershed area of 5 to 10 acres for pocket wetlands, and greater than 10 acres for shallow wetlands. The permeability of the soils around the constructed wetlands should be less than 0.14 inches per hour to prevent drainage. In addition, wetlands should have an aerial extent of 2% to 5% of the watershed they drain. Constructed wetlands are appropriate for use in a wide variety of land use applications such as commercial, industrial, institutional, or residential areas.

Two basic designs of constructed wetlands are addressed: pocket wetlands and shallow wetlands. Pocket wetlands are intended for smaller drainage areas of 5 to 10 acres, consist of a forebay and a shallow marsh area and may be constructed near the groundwater level for a reliable source of water. Shallow wetlands consist of a combination of a forebay, shallow emergent marsh areas, 0 to 6 inches deep, deep emergent marsh areas, 6 to 12 inches deep, in combination with a deeper micropool.

18.4.2.2 Physical Requirements

Key physical considerations are:

- Space availability—Sufficient space is required to treat and temporarily store the stormwater runoff
- Drainage area—Utilize a large drainage area to provide base flow during drier weather
- Soil conditions—Soils need to have a low permeability to allow ponding of the water; constructed wetlands typically do not infiltrate stormwater runoff

18.4.2.3 Design Criteria

The design of constructed wetlands includes several elements to facilitate water quality improvement and routing and detention of stormwater runoff. For a summary of design parameters,
see Exhibit 18-7 for a typical pocket wetland plan view and profile and Exhibit 18-8 for a typical shallow wetland plan view and profile.

18.4.2.3.1 Configuration, Layout and Slope

Common constructed wetlands components include the following:

- Access
- Inlet(s)
- Sediment forebay
- Shallow water zones (0 to 6 inches) and deeper water zones (6 to 12 inches)
- Outlet and overflow structures
- Deeper pool zones, including a micropool near the outlet to allow for final settling and prevent and resuspension of settled matter prior to discharge
- Hydraulic connectivity

The configuration and layout of these components will be dictated by the size available for the constructed wetland, site topography, flow paths and access. Constructed wetlands should not be constructed within 10 feet of a property line or within 50 feet of a private well or septic system.

18.4.2.3.2 Soils

Constructed wetlands are intended to stay wet, so the soils need to be relatively impermeable and limit infiltration; however, they should be above the local high water table. Underlying soils should consist of 20% to 40% clay or greater and less than 50% sand and have a slow to very slow infiltration rate. If the underlying soils have a permeability of 0.14 inches per hour or less, then they will not typically require the use of an impermeable or low permeability liner. Soils with permeability rates greater than 0.14 inches per hour will require the use of an impermeable or low permeability liner.

18.4.2.3.3 Conveyance

Though the constructed wetlands primary function is not conveyance, they do have to convey the stormwater runoff from the inlet to the outlet. Because the pooled water in the wetlands allows opportunity for solid particles in the stormwater to settle, the flow path should be diffuse and as long as possible. Pocket wetlands do not provide a long flow path and are only used in smaller areas. To provide a long flow path in the shallow wetland design, the constructed wetland needs to have a length to width ratio of at least 2:1, with 3:1 preferred, or internal dikes that provide a winding path for the stormwater runoff.

Constructed wetlands need to be capable of passing the larger storms without damaging the vegetation or the surrounding embankments. A wide flow path through the wetlands will help to reduce velocities during larger flows, reducing the potential for erosion. An emergency spillway is also needed to safely convey high flow out of the wetlands. The area downstream of the emergency spillway needs to be protected to prevent scour.

18.4.2.3.4 Pretreatment—Forebay

Excessive sediment accumulation in a wetland can reduce hydraulic capacity, block flow paths and smother vegetation. To remove the solids from the stormwater runoff, a forebay is essential for each inlet into either the pocket wetland or shallow wetland. Forebay are designed to remove sediment from the stormwater flow prior to dispersal into the wetland. Having a typical depth of 2 to 4 feet, they must be sized to provide approximately 10% of the VR and prevent the resuspension of settled solids into the stormwater flow. The forebay outlet should contain a dike, weir or bench to spread flows evenly across the wetlands system and reduce velocities to prevent erosion. Location and design should allow for ready access to perform maintenance, including removal of accumulated sediment.

18.4.2.3.5 Treatment

The primary pollutant removal mechanism in wetlands is sedimentation, since many pollutants are affiliated with sediment particles in stormwater. Consequently, proper design, construction and maintenance of the sediment forebays are critical to the wetlands' performance.

Constructed wetland cell in Buechel

The shallow (0 to 6 inches) and deeper (6 to 12 inches) water zones in the wetlands promote numerous treatment processes. Slowing flows over these zones promotes additional particle settling and biological uptake of organic pollutants by wetland vegetation while exposure to sun and air promotes other degradation processes.

A micropool near the outlet helps keep vegetation from encroaching on and clogging the outlet and helps prevent resuspension of sediment into the discharge.

The pocket and shallow wetlands should be sized to have a minimum pool volume equal to the required VR. The distribution of the volume amongst the forebay, shallow water zone, deep water zone and micropool should be as follows:

- 10% to 15% for forebay
- 10% to 15% for micropool
- 30% to 35% for shallow water zones (0 to 6 inches)
- 35% to 40% for deeper water zones (6 to 12 inches)

Constructed wetlands need to be capable of passing the larger storms without damaging the vegetation or the surrounding embankments.

Because keeping the wetlands wet is critical for their viability, a water balance should be performed. Estimate the seasonal inflows, such as rainfall, stormwater runoff and groundwater contribution, and outflows. Evaporation, transpiration and any infiltration should be included in the estimate. Size the wetlands to be able to sustain the wetland vegetation should there be minimal rainfall and runoff in a thirty day time period. If seasonal drying is anticipated, compensate in the plant selection process, but the effectiveness of the wetlands may be reduced.

18.4.2.3.6 Outlet

The design and configuration of the outlet structure will depend on whether storage is provided over and above the VR. Typical outlet structures include reverse-sloped pipes, weirs or risers connected to a discharge pipe that discharges to the downgradient receiving channel. The outlet structure should be constructed in the embankment to allow for easy access to perform maintenance.   Consideration should be given to providing trash racks to prevent outlet clogging and anti-seep collars for around discharge pipe to prevent seepage.

An emergency spillway, either separate from, or in conjunction with, the outlet structure should be included to safely convey high flows from storm events greater than the RE rain event. A minimum of one foot of freeboard should be provided during the 100-year, 24-hour rain event. The discharge from the outlet structure should be equipped with armoring, plunge pools, energy dissipaters or similar best management practices to prevent scour. The outlet should be designed such that the water surface elevation returns to the VR elevation between 24 and 36 hours after a rainfall.

18.4.2.3.7 Landscaping/Plant Selection

A landscaping plan is required for planting constructed wetlands. The plan should include bed preparation and identification of the various planting zones and plants for each planting zone, depending on type of constructed wetland. Planting zones can include:

- Shallow marsh zone – will include plants appropriate to an average depth of 6 inches and will have a greater diversity of plants than the deep marsh zone
- Deep marsh zone – will include plants appropriate for water depths of 6 to 12 inches
- Ephemeral zone – will include plants that will be subject to wet and dry periods
- Dry zone – will include upland plants suitable for dry conditions
- Temporary cover seed

For a summary of planting zones for the pocket and shallow constructed wetlands, see Exhibit 18-9.

Constructed wetland with native plantings

Choices available for planting the wetlands include seed, rhizomes, bare root stock, potted plants, plugs and transplanting vegetation from an established site. Planting rhizomes and seed is less expensive initially, but requires a longer establishment period. Mature plants are more expensive, but provide aerial coverage quicker and have an increased survival rate. Often a combination of materials is used to balance costs with promoting rapid plant establishment.

Although native species are preferred, non-invasive cultivars may be used or combined with native species to achieve desired landscape aesthetic qualities. A list of native species and cultivar species are provided in Chapter 13 of the MSD Design Manual.

18.4.2.3.8 Safety

Like any BMP that holds water, safety is a significant consideration. The side slopes should be 4:1 (H:V) or flatter. In addition, a vegetated buffer around the wetlands can be provided to minimize undesired access or direct desired access and enhance wildlife habitat.

Maintenance equipment access should be considered while in the configuration/layout phase of design.

Table 18.4 Constructed Wetlands Application and Site Feasibility Criteria	
Design Parameter	**Criteria**
Drainage Area	5 to 10 acres of upstream drainage for pocket wetlands and a minimum of 10 acres for shallow wetlands to maintain adequately wet conditions during dry weather.
Soils	Low permeability soils that typically consist of 20% to 40% clay or greater and less than 50% sand with slow or very slow infiltration rates Soils with permeability rates greater than 0.14 inches per hour will require the use of an impermeable or low permeability liner.
Sizing	Footprint of constructed wetland should be 2% to 5% of the watershed drainage area.
Side Slopes	No greater than 4:1 (H:V), flatter is recommended.
Design Flows and Conveyance Capacity	Pass the 100-year, 24-hour storms with 1 foot of freeboard. Return to VR elevation between 24 and 36 hours. Minimum length to width ratio of 2:1 with 3:1 or more preferred.
Pretreatment	Forebay—Size pretreatment forebay to hold 10% to 15% of the VR with a depth of 2 to 4 feet.
Outlet Protection	Scour protection required at discharge point
Volume Provided (VP)	The water quality design volume provided (VP) by a constructed wetland is: VP (ft3) = (A)[(p)(M) + P] + PD, where • A = area of the constructed wetland (ft^2) • p = media porosity (% void) • M = depth of the media (ft) • P = ponding depth of water (ft) • PD = Volume of Pretreament Device Design calculation sheets are available at www.louisvillemsd.org.
Landscape Plan	Landscape plan required showing native plants and/or non-invasive cultivars, plant size, spacing, installation and maintenance notes. Obtaining a one- or two-year maintenance agreement and warranty from the nursery or landscaper is recommended.

18.4.3 Green Wet Basins

Green wet basins are similar to standard wet basins, except for the addition of vegetation along an aquatic bench around the perimeter of the basin to provide water quality benefits and they retain the stormwater runoff for at least 24 hours. The vegetation helps provide water quality benefits. Green wet basins improve water quality by:

- Biological uptake and filtering of native plants
- Sediment settling, including attached pollutants
- Temporary retention of stormwater

Wet basin with native vegetation along the perimeter

Advantages/Benefits	Disadvantages/Limitations
• Relatively high removal rate for many pollutants • Increases biodiversity by providing habitats for wildlife and aquatic life • Reduces channel/stream bank erosion by reducing number of bankfull events • Opportunity for multiple use, including active and passive recreation	• Projects may require complying with KDOW dam regulations • Large space requirement • Possible safety concerns with a pool of water, fence may be required • Not to be used in high groundwater areas

18.4.3.1 Application and Site Feasibility

Green wet basins are similar to a standard wet basin; however, they contain an aquatic bench around the perimeter of the basin. Native vegetation can be planted from the normal pool level to a depth of no greater than 18 inches for water quality benefits. Native vegetation can also be planted above the normal pool elevation in the safety bench zone around the perimeter of the green wet basin. In addition, features may need to be included in the basin to minimize short circuiting between the inlet and outlet. Green wet basins can be constructed new or can be the result of retrofitted standard wet basins.

Green wet basins are appropriate for use in a wide variety of land use applications such as commercial, industrial, institutional or residential areas.

18.4.3.2 Physical Requirements

Key physical considerations are:

- Space availability - Sufficient space is required to treat and temporarily store stormwater runoff
- Drainage area - Have adequately large drainage area to provide hydrologic inputs during drier weather

- Plantings - Robust aquatic planting around the perimeter of the green wet basin to provide water quality treatment
- Outlet Structure - Outlet structure designed to provide retention for the 2, 10, 25, and 100-yr, 24-hour storms.
- Groundwater table - The groundwater table shall be at least 2 feet, preferably 4 feet, below the bottom of the basin.
- Minimum permanent pool depth of 5 feet.

18.4.3.3 Design Criteria

Generally, green wet basins need to have a drainage area of 25 acres to help sustain water levels during dry periods providing wet conditions for the aquatic bench. The permanent pool should be a minimum of 5 feet and no deeper than 12 feet to prevent thermal stratification. The following criteria should be included in the design of green wet basins. For a summary of design parameters and site feasibility criteria, see Table 18.5. See Exhibit 18-10 for a typical green wet basin profile.

18.4.3.3.1 Conveyance

Although primary function of green wet basins is not conveyance, they do have to convey stormwater runoff from the inlet to the outlet. Because the pooled water in the basins allow opportunity for solid particles in the stormwater runoff to settle, the flow path needs to be diffused and as long as possible. To provide a long flow path, basins need to have a length to width ratio of at least 2:1, with 3:1 preferred.

Green wet basins need to be capable of passing the 100-year, 24-hour storm without damaging the vegetation or the surrounding embankments. The basin should have a normal pool depth of a minimum 5 feet deep and a maximum of 12 feet. A wide flow path through green wet basins will help to spread out and slow down larger flows, reducing the potential for erosion. An outlet structure including an emergency spillway to safely convey the flow out of the green wet basin is also needed. The area downstream of the outlet structure and emergency spillway should be protected to prevent any scour.

18.4.3.3.2 Soils

Green wet basins are intended to hold water; therefore the underlying soils need to be relatively impermeable. Soils should have a permeability ≤ 0.14 inches/hour. Soils with permeability rates greater than 0.14 inches per hour will require the use of an impermeable or low permeability liner.

18.4.3.3.3 Landscaping/Plant Selection/Side Slopes

An aquatic bench around the perimeter of green wet basins is required. This bench must be a minimum of 5 feet wide with a slope of 10% or flatter and a depth of no more than 18 inches below normal pool.

In addition, a safety bench with a 10-foot buffer above the normal pool elevation with native plantings and non-invasive cultivars is required around the basin. These plantings need to be located such that they do not impact access for maintenance activities. A landscaping plan is required for planting green wet basins. The plan should include bedding preparation, identification of the various planting zones and required plants for each planting zone. In addition, the plan should identify wet zones, ephemeral zones that will be subject to wet and dry periods as well as dry zones in order to select plants appropriate for each zone. Plants should be placed so that their roots do not impact any piping or other structures.

Green Wet Basin in Buechel has a naturalized buffer

Choices available for planting the green wet basins include seed, rhizomes, bare root stock and potted plants. Planting rhizomes and seeds is less expensive initially, but requires a longer establishment period. Mature plants are more expensive, but they grow and provide aerial coverage quicker and survive better. Often a combination of materials is used to balance costs with promoting rapid plant establishment.

18.4.3.3.4 Forebay

Excessive sediment accumulation in a green wet basin can reduce hydraulic capacity, block flow paths and smother vegetation. To remove the solids from the stormwater runoff, a forebay is essential for each inlet into the basin. The forebay must be sized to provide approximately 10% of the VR and prevent the resuspension of settled solids into the stormwater flow. Typically the forebay depth will need to be about 2 to 4 feet, which will also prevent the growth of unwanted vegetation and allow for the survival of mosquito eating fish and/or natural colonizing amphibians/insects. The forebay outlet should contain a dike, weir or bench to spread flows evenly across the basin and reduce velocities to prevent erosion. The forebay should also be designed and located to allow for ready access to perform maintenance, including removal of accumulated sediment.

18.4.3.3.5 Outlet Structure

The outlet structure should include orifices or weirs (or a combination there of) to provide at least 24 hours of detention. The outlet must also detain the 2-, 10-, 25-, and 100-year, 24-hour storms. Considerations should be given to protecting the orifices from getting clogged with debris. Basins must be designed to return to normal pool elevation within 36 hours.

Low flow orifices shall be designed using the following equation:

$$a = \frac{2A\,(H - H_o)^{0.5}}{3600CT(2g)^{0.5}}$$

Where:
a = Area of orifice (ft^2)
A = Average surface area of the pond (ft^2)
C = Orifice coefficient, 0.66 for thin, 0.80 for materials thicker than orifice diameter
T = Drawdown time of pond (hrs), must be greater than 24 hours
g = Gravity (32.2 ft/sec^2)
H = Elevation when pond is full to storage height (ft)
H_o = Final elevation when pond is empty (ft)

18.4.3.3.6 Safety

Like any BMP that holds water, safety is a significant consideration. The side slopes within the basin shall be 3:1 or flatter. A safety bench with a maximum slope of 15:1 and minimum width of 10 feet must be provided just above the permanent pool level around the perimeter of the green wet basin. This safety bench shall be planted with native plants or non-invasive cultivars as a buffer to deter public access and enhance wildlife habitat. An aquatic bench functions as a safety feature and should be relatively flat with a maximum slope of 10% and a minimum width of 5'.

Table 18.5 Green Wet Basins Application and Site Feasibility Criteria	
Design Parameter	**Criteria**
Drainage Area	At least 25 acres of upstream drainage area to maintain water levels during dry weather.
Soils	Soil permeability should be ≤ 0.14 inches/hour.
Sizing	Depth 5 feet to 12 feet deep. Length to width ratio of at least 2:1, with 3:1 preferred.
Side Slopes	No greater than 3:1 (H:V), 4:1 or flatter recommended. Aquatic bench shall be a minimum 5-foot wide with a slope should be no greater than 10% and safety bench shall be a minimum of 10 feet wide with a maximum slope of 15:1.
Conveyance	Outlet structure and emergency spillway required.
Design Flows and Conveyance Capacity	Detain for at least 24 hours and pass the 2-, 10- and 100-year, 24-hour storms with at least one foot of freeboard. Green Wet Basins shall drain back to normal pool within 36 hours after the storm event.
Pretreatment	Forebay - Size pretreatment forebay to hold 10% to 15% of the VR with a depth of 2 to 4 feet
Outlet Protection	The area downstream of the outlet structure and emergency spillway should be protected to prevent any scour.
Volume Provided (VP)	The water quality design volume provided (VP) by a green wet basin is equal to VR.
Landscape Plan	Must provide a landscape plan showing native plants and/or non-invasive cultivars within the 10-foot buffer area and the minimum 5-foot aquatic bench.

18.4.4 Green Dry Basins

Green dry basins are similar to standard dry basins. The differences are that a green dry basin contains a forebay for capturing the heavier sediment and floatables, native or non-turf grass vegetation along the bottom of the basin, a multi-stage outlet that detains the runoff from the more frequent storm events, and no low flow channel to promote sheet flow. By design, green dry basins allow for extended detention, about 36 hours. Green dry basins improve water quality through:

- Biological uptake and filtering through deep rooted, native plants
- Sediment settling, including attached pollutants
- Temporary detention of stormwater
- A slower rate of release that reduces downstream bank erosion

Green dry basin concept rendering

Advantages/Benefits	Disadvantages/Limitations
• Effective at removing sediment • Increases biodiversity by providing urban habitats for wildlife • Well accepted by community	• Relatively large space requirement • Tends not to drain well, leading to maintenance challenges • Can pose a safety hazard due to water pooling during rain events • Not to be used in high groundwater areas

18.4.4.1 Application and Site Feasibility

Green dry basins are similar to standard dry basins, except for the addition of native vegetation, a forebay and a multistage outlet. Features may need to be included in basins to minimize short circuiting between the inlet and outlet.

Generally, green dry basins need to have a drainage area of at least 10 acres to keep the vegetation watered during the dry periods and a low flow orifice sized to not likely become plugged with debris. Green dry basins can be constructed new or can be the result of retrofitting standard dry basins. Green dry basins are appropriate for use in a wide variety of land use applications such as commercial, industrial or multi-family residential areas.

18.4.4.2 Physical Requirements

Key physical considerations are:

- Space available - Sufficient space is required to temporarily store the stormwater runoff.
- Drainage area - Have adequately large drainage area to provide some flow during drier weather and maintain larger low flow orifices.

* Plantings - Robust plantings along the bottom of green dry basins provide water quality treatment; plantings need to be able to survive the dry to submerged conditions that they will experience.
* Groundwater table - The groundwater table shall be at least 2 feet, preferably 4 feet, below the bottom of the basin.

18.4.4.3 Design Criteria

The following criteria should be included in the design of green dry basins. For a summary of design parameters, see Table 18.6. See Exhibit 18-11 for typical green dry basin profile.

18.4.4.3.1 Pretreatment—Forebay

Excessive sediment accumulation in green dry basins can block flow paths and smother vegetation. To remove the solids from the stormwater runoff, a forebay is essential for each inlet into the basin. The forebay should be sized to provide approximately 10% of VR and to prevent the re-suspension of settled solids into the stormwater flow. Typically the forebay depth will need to be about 2 to 4 feet deep. The forebay outlet should contain a dike, weir or bench to spread flows evenly across the green dry basin and reduce velocities to prevent erosion. The forebay should also be designed to allow for ready access to perform maintenance, including removal of accumulated sediment and floatables.

18.4.4.3.2 Conveyance

Though the primary function of green dry basins is not conveyance, they do have to convey the stormwater runoff from the inlet to the outlet. Because pooled water in the basins allows opportunities for the solid particles in the stormwater to settle, the flow path needs to be diffuse and as long as possible. To provide a long flow path, basins must have a length to width ratio of at least 2:1, with 3:1 preferred. The minimum slope of the flow path is 2%.

Green dry basins need to be capable of passing the larger storms without damaging the vegetation or the surrounding embankments. A wide flow path through the green dry basins will help to spread out and slow down larger flows, reducing the potential for erosion. An outlet structure and emergency spillway is also needed to safely convey the flow out of the green dry basins. The area downstream of the outlet structure and emergency spillway must be protected to prevent scour.

18.4.4.3.3 Outlet

The design and configuration of the outlet structure should allow for extended detention of the stormwater runoff from the required RE and the 2-year, 10-year, 25-year, and 100-year, 24-hour rain events. The outlet structure will likely consist of a riser connected to a discharge pipe that discharges to the downstream receiving channel. The outlet structure should be constructed in the embankment to allow for easy access to perform maintenance. Consideration should be given to providing trash racks to prevent outlet clogging and anti-seep collars around the discharge pipe to prevent seepage.

Low flow orifices shall be designed using the following equation:

$$a = \frac{2A\,(H - H_o)^{0.5}}{3600CT(2g)^{0.5}}$$

Where:
a = Area of orifice (ft^2)
A = Average surface area of the pond (ft^2)
C = Orifice coefficient, 0.66 for thin, 0.80 for materials thicker than orifice diameter

T = Drawdown time of pond (hrs), must be greater than 24 hours
g = Gravity (32.2 ft/sec^2)
H = Elevation when pond is full to storage height (ft)
H_o = Final elevation when pond is empty (ft)

A high flow bypass either separate from or in conjunction with the outlet structure should be included to safely convey high flows from large storm events. A minimum of one foot of freeboard should be provided during the 100-year, 24-hour rain event. The discharge from the outlet structure should be equipped with armoring, plunge pool, energy dissipater or similar best management practices to prevent scour.

18.4.4.3.4 Landscaping/Plant Selection

A landscaping plan is required for planting green dry basins. The plan shall include bedding preparation, identification of the various planting zones and recommended plants for each planting zone. Identify ephemeral zones that will be subject to wet and dry periods and dry zones and select plants appropriate for each zone. Choices available for planting the green dry basins include seed, rhizomes, bare root stock and potted plants. Planting rhizomes and seed is less expensive initially, but requires a longer establishment period. Mature plants are more expensive, but provide aerial coverage quicker and survive better. Often a combination of materials is used to balance costs with promoting rapid plant establishment.

Although native species are preferred, non-invasive cultivars may be used or combined with native species to achieve desired landscape aesthetic qualities. A list of native and cultivar species are provided in Chapter 13 of the MSD Design Manual.

18.4.4.3.5 Safety

Like any BMP that holds water, safety is a significant consideration. The side slopes should be 3:1 or flatter, 4:1 are preferred.

Table 18.6 Green Dry Basins Application and Site Feasibility Criteria	
Design Parameter	**Criteria**
Drainage Area	At least 10 acres of upstream drainage area.
Soils	Minimum infiltration rate for in situ soils is 0.5 inches per hour Recommended soil mix (by volume) for engineered soils: • 70%-85% sand • 10% to 20% silt + clay, with no more than • 5% to 10% clay; • 5% to 10% organic matter
Sizing	Minimum length to width ratio of 2:1 with 3:1 or more preferred.
Longitudinal Slope	Minimum slope of the flow path is 2%.
Side Slopes	No greater than 3:1 (H:V), 4:1 or flatter recommended.
Conveyance	Outlet structure and emergency spillway required.
Design Flows and Conveyance Capacity	Detain for at least 24 hours and pass the 2-, 10-, 25- and 100-year, 24-year storms with at least one foot of freeboard. Green dry basins shall be fully discharged within 36 hours after the storm event.
Pretreatment	Forebay—Size pretreatment forebay to hold 10% to 15% of the VR with a depth of 2 to 4 feet.
Outlet Protection	The area downstream of the outlet structure and emergency spillway should be protected to prevent any scour.
Volume Provided (VP)	The water quality design volume provided (VP) by a green dry basin is equal to VR.
Landscape Plan	Must provide a landscape plan showing native plants and/or non-invasive cultivars for green dry basin. Turf grass is not permitted in bottom of the green dry basin.

18.4.5 Green Roofs

A green roof is a roofing system made up of the following layers: a waterproof layer, drainage system, engineered soils and vegetation. Extensive green roofs are classified as green roofs with a soil depth of six inches or less. This shallow soil/growing medium layer is designed to support dense, low growing, and drought tolerant vegetation. Intensive green roofs have soil/growing medium depths greater than six inches to support the root growth of larger plants, shrubs, trees or elaborate rooftop gardens. Green roofs may also be called vegetated roofs or eco-roofs. Green roofs improve water quality through:

Green Roof at the Metro Archives

- Significant reduction of roof runoff volume
- Reduction of runoff pollutant loads compared to traditional roof applications
- Reduction of impervious area
- Biological uptake through drought tolerant plants

Advantages/Benefits	Disadvantages/Limitations
• Reduces energy costs • Provides additional roof insulation • Reduces urban heat island effect • Improves air quality • Extends life of roof • Adds landscaping value to outdoor rooftop gathering spaces • Provides wildlife habitat • Allows for retrofit opportunities	• Roof strength/structure may limit retrofit application • Extreme sun and wind conditions can challenge plant survival • Potential for roof leaks if not properly installed and maintained • Irrigation often necessary to establish plants • Planting on a sloped roof requires erosion control structures and is not recommended for intensive green roofs

18.4.5.1 Application and Site Feasibility

A green roof can be placed on high density residential, commercial, or industrial buildings that have the structural stability to support the increased loads of the green roof system. Fully saturated, extensive green roofs weigh approximately 15 to 25 pounds per square foot. Intensive green roofs weigh approximately 25 to 80 pounds per square foot. Passive outdoor amenity/recreational spaces may benefit or compliment a green roof with paths and patio areas adjacent to planting beds. Rooftops may be flat or sloped as steep as 25% for extensive roofs, given consideration for structural stability and erosion control of the system. Intensive green roofs must be flat or slightly sloped. An extensive green roof may be constructed on a new roof, or a remodeled roof that has the waterproofing and structural stability to hold the system in saturated, wet weather conditions. Especially in ultra-urban areas, green roofs can be used as passive recreational spaces including roof garden patios or functioning vegetable and herb gardens, given that structural considerations are met. Intensive green roof beds can be combined with shallower, extensive beds to supplement the roof with larger shrubs or trees at less cost than designing the entire roof as an intensive green roof.

18.4.5.2 Physical Requirements

Key physical considerations are:

- Roof stability—The roof must be structurally capable of supporting saturated soil/growing medium, vegetation and other structural loads. Shallower planting depths can reduce costs and structural loads.
- Roof waterproofing and drainage—The drainage layer is a key component to convey excess moisture through saturated soils/growing medium and off the roof deck. The roof must be waterproofed to prevent leaking and damage of the structure below. The waterproofing layer should be protected to prevent roots from damaging it. Leak detection systems may be installed to identify and locate leaks.
- Plant selection—Plant selection is limited due to extreme rooftop weather conditions including wind, sun, drought and cold winter temperatures. Plants selected should be able to withstand these extreme conditions. Green roofs require increased maintenance or irrigation during extreme conditions.
- Slope of rooftop—Extensive green roofs are suitable for both flat or sloped rooftops, but are much easier to design and install for flat rooftops (with a pitch of up to 1.5%). Rooftops with steep slopes require additional structural components to hold the soil/growing medium and drainage layers in place and prevent erosion. Rooftops with slopes greater than 25% are not suitable for extensive green roofs. Intensive green roofs are suitable for both flat and slightly sloped rooftops, up to 10%.

18.4.5.3 Design Criteria

Green roofs have several elements to manage stormwater including eliminating impervious area, plant absorption, and reduction of stormwater runoff volumes. The area of the green roof shall be considered pervious area and will not require additional water quality treatment. If a green roof covers at least 90% of a roof, the green roof shall be considered to treat 100% of the roof surface.

Proprietary green roof designs and materials available on the market may have requirements in addition to those in the guidance provided here. For a summary of design parameters, see Table 18.7.

18.4.5.3.1 Location of Green Roof Bed

Extensive Green Roof at Healthy House in Louisville, KY

Consider the purpose of the green roof. If the roof is intended for access by building occupants or patrons, beds must be separated by walking paths and patio areas. Beds should be clearly delineated and separated to minimize damage to plants and compression of soils due to walking or standing.

Wind and uplift pressures tend to be higher around the roof perimeter, and therefore should have a vegetation-free buffer between the green roof bed and the edge of the roof. Any rooftop openings should also have a vegetation-free buffer.

18.4.5.3.2 Structural Integrity of Roof

The structural integrity of the roof should be evaluated by a licensed professional engineer to determine the loading limits of the existing or proposed roofing system and feasibility of incorporating a green roof. The dead load, including the total weight of green roof materials; saturated soil and snow loads; and other live loads must be considered. The placement of large trees or shrubs should be located over columns or main beams to support the heavy weight of the soil and plants.

18.4.5.3.3 Waterproofing

Since water is being retained on the rooftop, it is essential to have adequate waterproofing to minimize leaks that can damage the building interior. Waterproofing may be accomplished through the use of a waterproofing membrane or other waterproofing roofing systems. Coordinate with the roofing system manufacturer for application and comply with their specifications for installation.

A protective layer or root barrier should be used to prevent roots from damaging the waterproof membrane. The root balls of large trees and shrubs should also be anchored to avoid piercing the waterproof membrane. Electronic leak detection systems may also be considered to notify and locate leaks when they occur.

18.4.5.3.4 Drainage

The drainage layer often consists of a manufactured material or a shallow gravel layer to store stormwater for plant uptake and routing of stormwater. The design should allow runoff to flow from saturated soils, through the drainage layer and to downspouts during rain events.

18.4.5.3.5 Soil and Plants

Soils for extensive green roofs should be between 3 and 6 inches thick. Soils for intensive green roofs should be greater than 6 inches thick. The soil mix may be determined by the product manufacturer and can vary based on selected plant species. A typical extensive green roof soil mix may consist of the following materials, by volume:

- 50% pumice perlite

- 25% organic compost
- 25% topsoil

Some growing media contain no soil. The manufacturer will recommend plant types suitable for use with their product.

Plant species should be selected based on drought resistance and tolerance of extreme conditions including high winds, heat and cold. Intensive green roof plants require more maintenance such as irrigation and pruning compared to extensive green roof plants. To reduce maintenance, plants should be selected with the goal of reducing the need for irrigation, fertilizer and pesticides after establishment. A list of plant species is provided in Chapter 13 of the MSD Design Manual. Although perennial, self-sustaining, native plant varieties are preferred, non-invasive cultivars may be used or combined with native species to achieve desired landscape aesthetic qualities or function.

Table 18.7 Extensive/Intensive Green Roof Application and Site Feasibility Criteria

Design Parameter	**Criteria**
Drainage Area	The area of the green roof shall be considered pervious area and will not require additional water quality treatment. If a green roof covers at least 90% of a roof, the green roof shall be considered to treat 100% of the roof surface. Area of the green roof is considered pervious area and treatment area is only the area of the green roof.
Soil Mix/Media	The soil mix may be determined by the product manufacturer and can vary based on selected plant species. A typical green roof soil mix may consist of the following materials, by volume: • 50% pumice perlite • 25% organic compost • 25% topsoil
Sizing	The structural integrity of the roof should be evaluated by a licensed professional engineer to determine the loading limits of the existing or proposed roofing system and feasibility of incorporating a green roof. Extensive Green Roof – Soil depth of 3 to 6 inches. Intensive Green Roof – Soil depth greater than 6 inches.
Slopes	Extensive Green Roof – Flat slope (up to 1.5% pitch) to less than 25% slope. Intensive Green Slope – Flat rooftop (up to 1.5% pitch) to 10% slope.
Conveyance	The drainage layer must be present to convey excess moisture through saturated soils and off the roof deck.
Design Flows and Conveyance Capacity	Design should allow runoff to flow from saturated soils, through the drainage layer and to downspouts during rain events.

Outlet Protection	Roof must contain a waterproofing membrane or other waterproofing roofing system. Follow waterproofing manufacturer's recommendations. Additionally, a protective layer should be installed to prevent damage to the waterproof membrane.
Volume Provided (VP)	The water quality design volume provided (VP) by a green roof is: VP (ft3) = (A)[(p)(M)] + (A)S, where • A = area of the roof (ft^2) • p = media porosity (% void) • M = depth of the media (ft) • S = storage depth of the drainage layer (ft) Design calculation sheets are available at www.louisvillemsd.org.
Landscape Plan	Plants should be selected based on drought resistance and tolerance of extreme conditions. For the intensive green roof, plants should be selected that will reduce the need for irrigation, fertilization and pesticide application. Trees and shrubs should be removed and replaced with smaller specimens every 10 to 25 years.

18.4.6 Permeable Pavers

Permeable pavers are pavement surfaces that promote infiltration of stormwater through gaps in the paver system. Pavers can be used in block or grid-systems, are aesthetically pleasing, and are Americans with Disabilities Act (ADA) compliant. Permeable pavers consist of individual concrete or stone shapes that are placed adjacent to one another over a specially designed sub-base. Permeable Pavers improve water quality through:

- Effective removal of light sediment and pollutants
- Reduction of stormwater runoff through infiltration to surrounding soils
- Surface flow reduction of peak flows

Permeable pavers at YMCA East

Advantages/Benefits	Disadvantages/Limitations
• Reduces volume of stormwater runoff • Reduces impermeable areas • Reduces need for drain pipe • Longer life than traditional pavement • Reusable product • Reduces need for detention space • Attractive/aesthetic pavement options	• Higher cost of pavers versus traditional concrete or asphalt pavement • Geotechnical exploration required • Significant maintenance requirements • Specialized knowledge required for proper installation • Not recommended for use in roadway • Not recommended under tree canopy

18.4.6.1 Application and Site Feasibility

Permeable pavers are an alternative to traditional asphalt and concrete paving methods and allow stormwater to infiltrate into the soil below. A professional (geologist or engineer) with geotechnical experience shall evaluate the soil to determine the proper design for the site being considered for permeable pavers. To minimize the frequency and amount of needed maintenance, it is recommended that strict silt control measures be used. Keeping the site clean during construction and maintaining vegetation along edges of the application will reduce clogging of the practice. Permeable paver design shall consider vehicular loads. Most current permeable pavers are not designed for high traffic areas or for areas used by heavy vehicles. For this reason, it should not be used in driving lanes and is best applied for parking areas or areas of pedestrian traffic only.

18.4.6.2 Physical Site Considerations

Minimum site requirements:

- The ratio of Drainage Area to Paver Footprint Area should not exceed 5:1. Ratios greater than 5:1 will be reviewed on a case-by-case basis
- The groundwater table should be a minimum of 2 feet below the base of the paver system
- Surrounding topography should have a maximum slope of 20%
- There should be a minimum separation of 10 feet from buildings
- Permeable pavers shall only be used in parking stalls and walkways

18.4.6.3 Design Criteria

The base layer under the permeable pavers is key to their performance. The design of this layer is based on vehicle equivalent single axle loads (ESALS), soil subgrade (geotechnical review), frost heave, design vehicle, pedestrian usage and the paver manufacturer's instructions. While the actual paver is designed to last much longer, most pavement/base designs are based upon a 20 year pavement life. The design and installation of permeable pavers shall be performed by qualified professionals. For a summary of design parameters, see Table 18.8. See Exhibit 18-12 for typical permeable pavement section.

18.4.6.3.1 Intended Use

Intended use is a key consideration when selecting the type of permeable paver. This fact sheet addresses brick, concrete, and articulated concrete block/paver types. Permeable pavers shall only be used in parking stalls and walkways. Pavers shall not be used in drive lanes.


Permeable Pavers at Brown Foreman

18.4.6.3.2 Storage Capacity

The base layers of the permeable paver system are designed to store stormwater until it can infiltrate into the subsoil or drainage system. The engineer will design the base layers, or the appropriate outlet system, to provide a depth that will accommodate the required VR. The VP provided by the designed permeable paver system can be calculated using the equation in Table 18.8.

18.4.6.3.3 Slopes (Subsoil and Pavement)

If a large slope is applied to either the pavement surface or subsoil, the depth of the base and/or the effective subsoil must be increased to account for the loss of capacity. If the base depth cannot be increased, trenching or piping may have to be used to transfer water from the system and avoid overflows. Because of this concern, it is recommended that the subsoil have a 0% slope and the surface have a 0.5% slope if it is at all possible. For subsurface slopes greater than 2%, benching is required.

18.4.6.3.4 Soil Stabilization

Soil stabilization is a concern with any type of pavement, but it is especially concerning with permeable pavers as a result of water being introduced into the pavement system and the lack of soil compaction to allow for proper drainage of the system. To address stabilization concerns, geogrid shall be placed on the subsoil surface before any of the aggregate layers are placed. If the aggregate layer is greater than 12 inches it is recommended to place a second layer of geogrid on the aggregate at this depth. The remaining aggregate will be placed on the second layer of geogrid. The selection of geogrid will be based on the size of aggregate used in the pavement system. The geogrid will convert the point loads created by vehicle tires into a uniform load distributed over the entire pavement area. By having a uniform load as opposed to point loads, the deformation/failure of the soil and pavement are greatly decreased, resulting in less failure in the pavement system over time. Any geogrid used in conjunction with the permeable pavers shall include the following geogrid specifications, at a minimum:

- Manufactured from a punched polypropylene sheet
- Triangular geogrid shall be used
- Resistant to weathering and chemical degradation

Geotextile fabric shall not be used as a soil stabilization device; however, it may be used in conjunction with geogrid if the Engineer has concerns with soil separation between the aggregate and subsoil.

18.4.6.3.5 Edge Restraint

An edge restraint is a barrier around the perimeter of the permeable pavers. It must be made of concrete and be adjacent to asphalt and other paved surfaces. This feature can be placed flush with the top of the pavers so that it can be driven over if overflow is desired, but must adhere to Louisville Metro/ADA requirements. The concrete edge restraint should extend to the lesser of: the bottom of the base layer or 18 inches below the surface of the permeable pavers. The edge restraint is used to keep the pavers from shifting after a load is placed on them. Edge restraints are required for brick, concrete, and articulated concrete block/paver types.

18.4.6.3.6 Base Design

Mechanical installation of permeable interlocking concrete pavers

The base of the permeable paver system will act as the storage layer for stormwater until the water infiltrates into the subsoil or is removed from the system through an underdrain system. The base should be made up of 2 layers of double washed aggregate. The first layer is placed directly on the geogrid and consists of double washed No. 3 stone. This first layer should be a minimum thickness of 18.5 inches. Due to the thickness of the first layer, a second layer of geogrid is recommended to be placed between the two layers of stone in the base layer. The second layer of stone consists of double washed (with quarry certification letter confirming the stone was double washed) No. 57 stone and should be placed directly upon the geogrid covering the No. 3 stone. This second layer of base should be a minimum of 4 inches thick. The entire base layer, including both the No. 3 and No. 57 layers, should be a minimum of 22.5 inches thick. See Section 18.6, Aggregate Specifications, for additional guidelines on the aggregate used for this practice. This minimum thickness will be structurally sufficient for the design ESAL of permeable pavers. The base thickness may be increased based on storage capacity. The base layer should completely drain after a design storm event if properly maintained.

18.4.6.3.7 Choker Course

The choker course is placed on top of the base layer and should be comprised of double washed No. 8 aggregate. The minimum thickness of the choker course is 1.5 inches. This course serves as a leveling surface for the pavers. The aggregate in the base is too large to produce an even surface suitable for the pavers to achieve a smooth surface. Choker course should be used for brick, concrete, and articulated concrete block pavers. Choker course may be omitted provided manufacturer specifications state that pavers can produce a level surface without a choker course.

18.4.6.3.8 Frost Heave Considerations

As with any type of pavement surface, frost heave is a concern where freezing temperatures are prevalent in the winter months. To reduce the possibility of frost heave, the base layer should be placed at 65% of the frost line (approximately 24 inches below the surface in the Louisville area for an average of a 3 feet frost depth).

18.4.6.3.9 Underdrain System

Underdrains are required when the in-situ soil infiltration rate is less than 0.5 inches/hour. Underdrain systems are a series of pipes that run longitudinal with the pavers. The pipes used in an underdrain system are perforated pipes that tie into a non-perforated outlet. The size of the pipe is determined by the calculated stormwater capacity drained onto the permeable pavers. Underdrains should be designed to utilize slotted pipe with a minimum of 4 inches in diameter, minimum 0.5% slope and include a 4 inch minimum cleanout. The underdrain should be elevated above the base of the excavation to encourage infiltration. Perched or elbowed underdrains are encouraged to allow for temporary storage and groundwater infiltration.

18.4.6.3.10 Overflow Design

An overflow must be designed for all paver designs to allow for larger storm events to drain to a suitable outlet and limit ponding over the pavers to no more than 6 inches.

18.4.6.3.11 Joint Aggregate Material

Chip stone or aggregate shall be installed between all paver joints to be even with paver surface. Chip stone or aggregate must be double washed.

Table 18.8 Permeable Paver Application and Site Feasibility Criteria	
Design Parameter	**Criteria**
Drainage Area	Drainage Area to Paver Footprint Area should not exceed 5:1. Permeable pavers shall not be used in high traffic areas or for areas used by heavy vehicles.
Soils	Underdrains are required when the in-situ soil infiltration rate is less than 0.5 inches/hour. Geogrid will be placed on the subsoil for stabilization. Underdrains shall utilize slotted pipes with a minimum diameter for four inches.
Sizing	The area and depth of the paver system shall be determined based on the design storage capacity.
Profile Grade	The subsoil is recommended to have a 0% slope and the surface is recommended to have a 0.5% slope. For subsurface slopes greater than 2%, benching is required. Maximum surface slope is 3%.
Slopes	Surrounding topography shall have a maximum slope of 20%. Recommended subsoil slope is 0% and the surface slope is 0.5%. For subsurface slopes greater than 2%, benching is required.
Outlet	An overflow must be designed for all paver designs to allow for larger storm events to drain to a suitable outlet as the maximum allowed ponding on pavers is 6 inches.
Volume Provided (VP)	The water quality design volume provided (VP) by a permeable pavers is: $VP\ (ft^3) = (A)(p1)(d1)$ • A = area of permeable pavers (ft^2) • p1 = porosity of base layer (% void), typically 40% • d1 =depth of base layer (ft) *Note: this formula only applies if the paver surface and sub soil have a 0% slope Design calculation sheets are available at www.louisvillemsd.org.

18.4.7 Tree Boxes

A tree box is very similar to a rain garden/bioretention cell in its design purpose and stormwater management benefits, except it exclusively uses trees and tall shrubs. At a minimum, a tree box temporarily detains the stormwater runoff as it flows through the box prior to discharge into the storm sewer system, drainage trench, overflow pipe or surface overflow through inlets and outlets. If surrounding soils have adequate permeability, a tree box can also be designed to promote infiltration of the stormwater runoff. A tree box can be used as a single BMP or connected in series through trenches. A tree box improves water quality through:

- Reduction of runoff volume through infiltration
- Treatment of stormwater percolating through soil and filter media
- Temporary detention of stormwater runoff
- Biological uptake through deep rooted, native plants

Advantages/Benefits	Disadvantages/Limitations
• Visually appealing • Can be used to address landscaping requirements • Provides infiltration, reducing runoff volume • Increases biodiversity by providing urban habitats for wildlife • Reduces heat island effects	• Increased maintenance over traditional curb and gutter drainage systems • Soil conditions may limit application • Limited to small drainage areas • Not recommended for high groundwater level areas • May not comply with KYTC requirements for state roads

18.4.7.1 Application and Site Feasibility

A tree box is a local feature that is used to treat and detain, and possibly infiltrate stormwater runoff. It may be connected in a series to provide opportunities for enhanced treatment of the stormwater and promote better tree viability. A tree box is appropriate for use in a wide variety of land use applications including commercial, industrial, institutional or multi-family/high density residential areas. Tree boxes will need Metro/KYTC approval during the design phase, depending on where the tree boxes are installed and which entity holds jurisdiction.

Tree boxes along Story Avenue

18.4.7.2 Physical Requirements

Key physical considerations are:

- Space availability - Sufficient space is required to plant the tree or shrub and allow space for its growth both above ground and below ground.
- Soil types - Soil types affect infiltration and the ability for the tree roots to grow and spread. In addition, soils under existing infrastructure around the tree box need to be evaluated to determine their ability to allow the tree roots to spread.
- Tree box media - The infiltration rate of the media in the tree box will dictate how large a box area will be required for the VR.
- Location - Construction in a Louisville Metro right-of -way (ROW) or KYTC ROW will require conformance to applicable standards
- Footprint - A grate covering the tree box footprint is preferred to a fence around the perimeter of the box.
- Curb Cuts - Curb cuts must be rounded or covered with a plate.

18.4.7.3 Design Criteria

The design of a tree box includes several elements to manage stormwater: detention and conveyance to facilitate water quality improvement and infiltration to reduce stormwater runoff volumes into the sewer system. Generally, a tree box follows the same design approach as a rain garden/bioretention cell. There are proprietary tree boxes with standard sizes from manufacturers. If a proprietary tree box is not chosen, the following guidance can be used to size a tree box. For a summary of design parameters, see Table 18.9. See Exhibit 18-13 for typical tree box section.

18.4.7.3.1 Selection of Tree Box Type and Size

A tree box can be designed to capture and infiltrate the stormwater runoff through an open box design. If infiltration is not desired, temporary detention of the stormwater runoff can be accomplished using a flow-through sealed box design. The sealed box design will include an underdrain system connected to the storm sewer system, while the need for an underdrain system in the open box design will depend on the infiltration rate of the surrounding soil. The amount of infiltration that can be accomplished in the open box design will depend on the infiltration rate of the soil composition in the box and surrounding soils. Storage space can be provided under an underdrain system to allow more time for infiltration to occur. The tree box should not accept drainage from more than 0.25 acres of impervious area, but a smaller drainage area is encouraged for better performance.

Sizing of a tree box is based on the volume provided by the porosity of the tree box media and in the ponding above the tree box media. The volume should at least be equal to the Required VR.

Evaluate in situ soil conditions to determine if they have the needed infiltration for the tree box. If in situ soil have an infiltration rate less than 0.5 inches per hour, engineered soils and an underdrain are required.

18.4.7.3.2 Soil Composition

The soils around the tree box are extremely important, especially in an open box design where the tree roots are allowed to expand out past the tree box. If tree roots are allowed to spread, they will typically extend at least as far as the branches. However, if the surrounding soils are too compacted, the tree roots may not be able to penetrate the soil, thus limiting its viability.

The infiltration rate of the surrounding soil type is an important consideration for the open box design. Heavier clay or compacted soils have lower infiltration rates, while sandy, permeable, uncompacted soils promote infiltration.

If the primary purpose of the tree box is temporary detention with subsequent drainage to the storm sewer system (sealed box design), then an underdrain system is required. An underdrain system is required for open box designs that do not have the needed infiltration rates in the surrounding soils. Underdrains should be constructed with perforated pipe or slotted corrugated pipe (minimum 4 inches in diameter, minimum 0.5% slope and include a 4 inch minimum cleanout) and bedded in double washed No. 57 stone. Topsoil should be stripped and stockpiled for reuse. When grading and soil mix is placed, care should be taken that the soil is not compacted, resulting in a diminished infiltration capacity.

18.4.7.3.3 Plant Selection

A tree box is typically planted with a deep rooted, native tree or shrub. In selecting a tree or shrub, consider the box and soil depth, space for roots to grow, if the box will retain water for extended periods of time and select species accordingly.

Although native species are preferred, non-invasive cultivars may be used or combined with native species to achieve desired landscape aesthetic qualities. A list of native species and cultivar species are provided in Chapter 13 of the MSD Design Manual.

Table 18.9 Tree Box Application and Site Feasibility Criteria Chart	
Design Parameter	**Criteria**
Drainage Area	Tree boxes should not accept drainage from more than 0.25 acres of impervious area. Smaller drainage areas are encouraged for better performance.
Soils/Media	Ideal soils are sandy loam, loamy sand, or loam texture. Soil infiltration should be > 0.5 inches per hour or an underdrain must be used. Ideal media will contain adequate content for plant growth while maintaining infiltration rates greater than 1 inch per hour. A tree box should dewater within 36 hours. If necessary, an underdrain system can be added.
Sizing	Sizing of a tree box is based on the volume provided by the porosity of the tree box media and in the ponding above the tree box media.
Outlet	Overflow outlet or spillway required.
Volume Provided (VP)	The water quality design volume provided (VP) by a tree box is: $VP\ (ft^3) = (A)[(p)(M)+h]$ • A = area of tree box (ft^2) • p = media porosity (% void) • M = depth of the media (ft) • h = average height of water above the media during the RE rain event in feet Design calculation sheets are available at www.louisvillemsd.org.
Landscaping	A deep rooted, native tree or shrub planting is preferred. When selecting a species, consideration should be given to box size, soil depth, and typical water retention times. A list of native species and cultivar species are provided in Chapter 13 of the MSD Design Manual.

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18.4.8 Vegetated Buffers

A vegetated buffer, or filter strip, is a uniformly graded and densely vegetated area that treats and infiltrates stormwater runoff. The vegetation in the buffer works to slow down the stormwater runoff, settling and filtering some pollutants and uptaking others. The stormwater runoff volume can also be reduced by infiltration into the pervious soil, if available, and by absorption and evapotranspiration of the vegetation. For a vegetated buffer to be effective, the stormwater has to enter and flow through the buffer in sheet flow. The slope shall be a minimum of 2% and a maximum of 6%. The vegetation shall consist of native, deep rooted grasses, shrubs and trees. A vegetated buffer can be managed or unmanaged depending on the desired aesthetics. A vegetated buffer improves water quality through:

Vegetated buffer strip along a bike path

- Settling and filtering pollutants
- Reducing stormwater peak flows due to infiltration of stormwater runoff

Advantages/Benefits	Disadvantages/Limitations
• Reduces stormwater runoff volume through infiltration and groundwater recharge • Can be used as part of conveyance system and provides pretreatment for other BMPs	• Need to provide sheet flow to and throughout the buffer • Limited applications (i.e. adjacent to trails and sidewalks) • Not recommended for steep slopes or “hot spot” areas

18.4.8.1 Application and Site Feasibility

A vegetated buffer usually receives stormwater runoff from an upgradient impervious area and through sheet flow, is able to treat the runoff and if the soils allow, infiltrate some of the stormwater runoff volume. For the buffer to be effective, the runoff needs to enter and flow through the entire buffer length in sheet flow. Often a vegetated buffer is used as preliminary treatment of the stormwater prior to entering another BMP. A vegetated buffer is appropriate for use in a wide variety of land use applications including commercial, industrial, institutional or multi-family/high density residential areas.

18.4.8.2 Physical Requirements

Key physical considerations are:

- Space availability—Sufficient space to provide the buffer width and length is required
- Slope—The slope of the vegetated buffer shall be a minimum of 2% and a maximum of 6%
- Soil types—Soil types affect the amount of infiltration and the ability for the vegetation to thrive
- Sheet flow—Sheet flow needs to be provided throughout the vegetated buffer

18.4.8.3 Design Criteria

The design of a vegetated buffer includes several elements to manage stormwater treatment and infiltration. For a summary of design parameters, see Table 18.10. See Exhibit 18-14 for typical vegetated buffer plan and profile.

18.4.8.3.1 Buffer Slope and Length

Uniform grading within the buffer is required to maintain the sheet flow throughout the buffer. The vegetated buffer slope in the direction of flow shall be a minimum of 2% and a maximum of 6%, which prevents ponding of the runoff, but does not promote the formation of concentrated flow. The length of the buffer (parallel to flow) shall be a minimum of 25 feet and shall be determined using the formula given in Table 18.10.

18.4.8.3.2 Buffer Width and Drainage Area

Stormwater runoff must enter the vegetated buffer as sheet flow across its entire width (perpendicular to flow) at a depth no greater than 1 inch for the required RE rain event. The buffer width shall be greater than or equal to the width of the contributing drainage area, with a minimum of 25 feet. Minimum travel time is 10 minutes.

The vegetated buffer is intended to treat runoff from a small contributing drainage area, typically not to exceed 3 acres. The flow length of the contributing drainage area shall be less than 300 feet. This will maintain sheet flow of stormwater into the vegetated buffer and reduce the risk of shallow concentrated flow forming.

18.4.8.3.3 Soil Composition

Soils with minimal clays are recommended for a vegetated buffer. The objective is to use soils that are able to sustain a dense vegetative growth.

18.4.8.3.4 Location

Vegetated buffers must be located in an open space. Area must be labeled as a “no mow” area and have signage showing area is a “no mow” area.

18.4.8.3.5 Naturalized Planting Plan

A naturalized planting plan is required for vegetated buffers. The plan shall include bedding preparation, identification of the various planting zones and recommended plants for each planting zone. Native species or native, non-invasive cultivars are required for use in vegetated buffers. Plants shall consist of native or native cultivars of deep rooted herbaceous plants (grasses, forbs, wildflowers), shrubs and trees. Native plants require minimal watering (once established), weeding, pest control fertilization and pruning; they are ideal for naturalized vegetated buffers. For this reason, exotic, non-native species are not suitable for vegetated buffers due to watering and other maintenance requirements. Include an inventory of all plants present in the vegetated buffer in the planting plan.

Remove invasive plant species if they are present in the vegetated buffer and replace with approved native plants. A list of native and native cultivar species (nativity categories N and C) are provided in Chapter 13 of the MSD Design Manual.

Plants should be selected based site conditions (i.e. sun/shade and wetland indicator status) suitable for each zone (see Chapter 13 of the MSD Design Manual). The planting plan and established plant density shall be consistent with the Manning's "n" value specified in design for buffer length and travel time. See Chapter 13 of the MSD Design Manual for plant spacing requirements.

Table 18.10 Vegetated Buffers Application and Site Feasibility Criteria	
Design Parameter	**Criteria**
Drainage Area	The area draining to the vegetated buffer shall be less than 3 acres. The flow length of the contributing drainage area shall be less than 300 feet.
Soils	Soils with minimal clays are recommended for a vegetated buffer.
Sizing	The width of the vegetated buffer (perpendicular to the flow) shall be greater than or equal to the width of the contributing drainage area, with a minimum of 25 feet. The length of the buffer (parallel to flow) shall be a minimum of 25 feet.
Slopes	The slope shall be uniformly graded with a minimum of 2% and a maximum of 6%.
Conveyance	Stormwater runoff must enter the vegetated buffer in sheet flow across its entire width.
Design Flows and Conveyance Capacity	Minimum travel time through the vegetated buffer is 10 minutes. Use the following equation to calculate travel time, T (in minutes): $T=[0.42*(n*L)^{0.8}]/(P^{0.5}*S^{0.4})$ or $L = ((T_c\text{^}1.25)*(P\text{^}0.625)*(S\text{^}0.5))/(338*n)$ • L = length of the buffer parallel to the flow path (ft) • T = travel time through the vegetated buffer (minutes) • P = RE (typically 0.6”) • S = slope of the filter strip along the flow path (ft/ft) • n = Manning’s “n” roughness coefficient, typical values (per USDA Urban Hydrology for Small Watersheds, TR-55) • T_c = time of concentration (hours)
Velocity (V)	Calculate the velocity of the stormwater runoff across the buffer to be sure that it is less than 2.0 feet per second (fps) using the following equation: V=Q/(d*W), where • d = the depth of flow (ft) • Q = peak discharge to the buffer from the required RE rain event (cfs) • W = minimum width (perpendicular to flow) of the filter strip (perpendicular to the flow (ft) Design calculation sheets are available at www.louisvillemsd.org.
Landscaping	The vegetation shall consist of dense, native, deep rooted grasses, shrubs and trees. Planting Plan required with native plants and/or non-invasive cultivars and their locations.

18.4.9 Underground Infiltration Basins

Underground Infiltration Basin at Churchill Downs

Underground infiltration basins include the practice of collecting and detaining stormwater runoff underground in pipes, vaults, chambers or modular structures. The collected stormwater runoff is intended to be infiltrated, with overflows being released back to the surface drainage system or storm sewer system at a reduced rate. The basin must be completely drained prior to the next rain event, similar to a green dry detention basin. An underground storage system may be constructed of a variety of materials, including concrete, steel or plastic. There are many proprietary products on the market. Underground storage improves stormwater management through:

- Detention of stormwater runoff, reducing peak flows
- Reduction of stormwater runoff volume through infiltration to surrounding soils

Advantages/Benefits	Disadvantages/Limitations
• Reduces channel/stream bank erosion by reducing the number of bankfull events • Increased public safety compared to surface detention BMPs • Can be used where available surface space is limited	• Requires pretreatment to reduce maintenance efforts • Not to be used in areas with high groundwater table

18.4.9.1 Application and Site Feasibility

Underground infiltration basins are applicable in areas where water quantity control is desired and land is not available or is too expensive for above ground BMPs. Underground infiltration basins need to be located such that the stormwater runoff gravity feeds into and out of the storage system. Underground infiltration basins should be located in areas that can be excavated in the future, should the need arise. Underground infiltration basins are appropriate for use in a wide variety of land use applications such as commercial, industrial, institutional or multi-family/high density residential areas, typically in ultra-urban areas.

18.4.9.2 Physical Requirements

Key physical considerations are:

- Space availability - Sufficient space is required to locate the required storage volume and provide access for maintenance vehicles.

- Material selection - Select the material of construction for the underground infiltration basin based on desired useful life, earthwork requirements, overburden support and potential for the system to float.
- Access – Multiple, appropriately spaced manholes/access ports need to be provided to allow for maintenance and inspection of the system.
- Slopes - The bottom of the underground infiltration basin should be sloped between 0.5% and 4% to allow for complete draining.
- Groundwater table - The groundwater table shall be at least 2 feet, preferably 4 feet, below the bottom of the infiltration basin.

18.4.9.3 Design Criteria

The design of underground infiltration basins includes several elements to properly reduce stormwater runoff volumes and reduce peak flow rates into the sewer system. For a summary of design parameters, see Table 18.11. Refer to Chapter 10 of the MSD Design Manual for detention requirements. See Exhibit 18-15 for typical plan and profiles for underground infiltration basin.

18.4.9.3.1 EPA Regulations for Class V Injection Well (Underground Injection Control, UIC)

Infiltration basins can be classified as a Class V Injection well by the EPA if it meets the following criteria (see the Class V wells page at www.epa.gov):

- "Any bored, drilled, or driven shaft, or dug hole that is deeper than its widest surface dimension, or"
- "An improved sinkhole, or"
- "A subsurface fluid distribution system."

If the infiltration basin designed meets any of the criteria listed above, the EPA form 7520-16 should be filled out and all other additional EPA regulations should be followed. Other terms including well, injection well, improved sinkhole or drywell will trigger requirements by the EPA.

18.4.9.3.2 Inlet and Pretreatment

Inlets need to be provided in the quantity, size and configuration needed for the desired stormwater runoff to enter the underground infiltration basin. Pretreatment, focused on the removal of floatables and sediment, must be provided at each inlet to the basin to reduce maintenance efforts and prevent any groundwater contamination. Pretreatment may include catch basin inserts or proprietary water quality units.

18.4.9.3.3 Outlet

The outlet orifices need to be sized to prevent clogging, typically no smaller than 6 inches, but provide the required retention of the stormwater runoff.

18.4.9.3.4 Overflow and Bypass

The underground infiltration basin must have an emergency overflow to allow for safe passage of the larger storm events. In addition, a bypass system or overflow path should be provided to allow the underground infiltration basin to be taken out of service should it become inoperable.

18.4.9.3.5 Infiltration

Soils must have a permeability rate of at least 0.5 inches/hour to promote infiltration.

18.4.9.3.6 Overburden Support

When selecting the underground infiltration basin material, consider the loading coming from above. The loading will include backfill, pavement, and possibly vehicular traffic.

18.4.9.3.7 Drawdown Time

The stormwater runoff VP collected in underground storage should drain out to a surface drainage or sewer system or infiltrate into the surrounding soils within 36 hours or as approved by MSD.

Table 18.11 Underground Infiltration Basins Application and Site Feasibility Criteria

Design Parameter	**Criteria**
Drainage Area	Underground infiltration basins need to be located such that the stormwater runoff gravity feeds into and out of the storage system.
Soils	Minimum soil permeability of at least 0.5 inches/hour is required.
Sizing	Sufficient space is required to locate the required storage volume and provide access for maintenance vehicles.
Slopes	Slopes between 0.5% minimum and 4% maximum.
Design Flows and Conveyance Capacity	Detain for at least 24 hours and pass the 2-, 10-, 25- and 100-year, 24-year storms. Shall be fully discharged within 36 hours after the storm event. Must have an emergency overflow to allow for safe passage of the larger storm events and a bypass system allowing basin to be taken out of service should it become inoperable.
Pretreatment	Pretreatment is required at each inlet to the basin to reduce maintenance efforts and prevent any groundwater contamination. Pretreatment may include catch basin inserts or proprietary water quality units.
Outlets and Access	The outlet orifices need to be sized to prevent clogging, typically no smaller than 8 inches, but provide the required retention of the stormwater runoff. Multiple, appropriately spaced manholes/access ports to be provided to allow for maintenance and inspection of the system.
Volume Provided (VP)	The water quality design volume provided (VP) by a underground infiltration basin is: VP (ft^3) = (A)(M)(p),where • A = area of the infiltration basin (ft^2) • M = depth of the media (ft) • p = media porosity (% void) • Design calculation sheets are available at www.louisvillemsd.org.

18.4.10 Proprietary Water Quality Units

Proprietary water quality units (WQUs) vary based on manufacturer, but are typically underground treatment systems installed at the downgradient end of an on-site stormwater system. These systems are space-efficient and use a swirling vortex or multiple chambers to separate sediments and floatables, such as oil/grease, from stormwater inflow. Proprietary water quality units improve water quality through:

- Effective removal of total suspended solids
- Effective removal of oil/grease
- Pretreatment and use in series with other BMPs

Water quality unit

Advantages/Benefits	Disadvantages/Limitations
• Ease of installation • Optimal for sites less than 5 acres, with space limitations or where infiltration capacity is limited • Appropriate for retrofit applications • Good for impervious area runoff that may clog other types of BMPs • Can be designed to be suitable for hazardous substance runoff	• Not effective for volume reduction or infiltration of stormwater • Maintenance frequency varies depending on size of structure and quantity of flow and pollutants • Not effective for removal of dissolved pollutants and fine particles • Potential source of pollutants if maintenance is neglected • Low community amenity value (habitat, flood control, landscaping)

18.4.10.1 Application and Site Feasibility

Proprietary water quality units can provide water quality benefits for sites with limited area for infiltration opportunities. Some systems are suitable for areas with impervious runoff or hazardous materials because they provide treatment of water before it is infiltrated into the soil.

18.4.10.2 Physical Requirements

Proprietary water quality units vary based on the manufacturer; the approved types of units are outlined below.

18.4.10.2.1 Chambered Devices

Chambered devices allow water to flow into a sump-like structure separated by vertical baffle plate walls, dividing the structure into chambers. Typically, sediment and debris settle and oil and grease collect at the surface in the first two chambers, and flow exits the unit in a third chamber. As with hydrodynamic units, these structures must be designed to bypass larger storms. Regular inspection and maintenance frequency must be considered as part of the design process.

18.4.10.2.2 Hydrodynamic Devices

Hydrodynamic units route flow through the system using a swirling motion. Particles of sediment and debris separate and fall to the bottom, while floating materials are retained by a baffle wall. Hydrodynamic devices must be designed to bypass flow from larger storm events to prevent re-suspension of captured sediment and debris. Regular inspection and maintenance frequency should be considered as part of the design process.

18.4.10.3 Design Criteria

Design for water quality units shall be based on MSD minimum design requirements as well as the manufacturer's recommendations.

18.4.10.3.1 Location

Water quality units can be installed upstream of BMPs in series for pretreatment. Pretreatment is required for BMPs where maintenance access is limited such as infiltration trenches and underground detention and infiltration systems. Refer to manufacturer's recommendations for maximum drainage area. Water quality units must be located in an easily accessible area, not in a public roadway, for maintenance and inspection. The maximum depth of the water quality unit is 25 feet to allow for inspection of the unit. See Exhibit 18-16 for typical diversion structure arrangements.

18.4.10.3.2 Inflow Regulation

All proprietary water quality units shall be configured as offline systems, diverting the water quality volume into the unit for treatment and returning flow to the conveyance system or downstream BMP. Inflow regulation protects the unit from peak flows while treating the first flush and designed water quality volume. A bypass structure should direct the water quality flow rate into the water quality unit and allow larger storm events to bypass the unit. Bypass can be accomplished through a weir or offset pipes.

Weir

A junction box with an internal weir structure directs the required water quality peak flow rate (Q_p) though the WQU while higher flows bypass the WQU over the weir. Weirs are typically 6 inches to 24 inches tall but must be designed based upon the characteristics of the upstream pipe system, with a minimum weir height of 6 inches. A critical factor when designing the weir height is the hydraulic jump that is created when the Q_p hits the weir. A weir that is set too low will allow the hydraulic jump to overtop the weir and thus allow some Q_p to bypass the WQU. Conversely, a weir set too high will send flows beyond Q_p through the WQU possibly causing the re-suspension of previously captured solids and debris. The most important variable in the hydraulic jump is the slope of the pipe immediately upstream of the diversion structure. The higher the slope, the larger the energy head and thus, the higher the hydraulic jump. The slope of the upstream pipe should be kept as low as possible to lower the hydraulic jump. As a general rule, the weir height should be no more than ½ of the diameter of the pipe immediately downgradient of the junction box. If more than one pipe converges in the junction box, design the weir height assuming all of the Q_p enters the junction box through the larger pipe.

Offset pipes

Another method to direct Q_p to the WQU while bypassing high flows is to use offsite pipes with a "low flow" pipe to the WQU at the invert of the junction box while a larger pipe is located at a higher elevation in the junction box structure. In an offset pipe configuration, the low flow pipe is typically in a submerged condition with flow to the WQU calculated through the appropriate orifice equation with the bypass pipe invert set at the top of the required height "h" to force the Q_p through the orifice. A hydraulic jump is still a key design consideration and must be accounted for when setting the bypass pipe elevation. The minimum offset shall be 6 inches.

18.4.10.3.3 Pretreatment

Proprietary water quality units containing a filter media require a pretreatment/settling chamber to remove coarse sediment, solids, and debris that could clog the filter media.

18.4.10.3.4 Sizing

The Required Water Quality Peak Flow Rate (Q_p) to be treated by a WQU shall be calculated using the Rational Method (see Sections 10.2.3 and 10.3.1 of the MSD Design Manual). The area and composite c-factor should match the pipe chart on the Composite Drainage Plan sheet except that the rainfall intensity value (i) shall be 0.5 inches per hour (the 80th percentile storm intensity for an average year), regardless of the Time of Concentration (Tc).

18.4.10.3.5 Installation

Installation should always occur per manufacturer's recommendations. A manufacturer's representative should be present on-site during the installation of the water quality unit to ensure proper installation. Based on the water quality unit chosen, screens may also need to be installed to prevent mosquitos and rodents from entering the unit.

18.4.10.3.6 Pollutant Removal

Pollutant removal varies based on the individual design of the water quality unit and can be customized per manufacturers' recommendations. At a minimum, units must achieve a Total Suspended Solids (TSS) removal efficiency of 80% based on OK-110 (D50=110μm) particle size distribution for the peak flow rate and be on the approved list for the City of Indianapolis (see Section 18.4.10.3.7). If the water quality unit is to be used as pretreatment for another BMP, a minimum of 50% TSS removal is required.

18.4.10.3.7 Proprietary Water Quality Unit Approval

MSD formally allows reciprocity with the City of Indianapolis for approving proprietary water quality units using the currently approved version of the "City of Indianapolis Stormwater Quality Unit (SQU) Selection Guide". Units approved by the City of Indianapolis using the TSS specification above may be considered "approved" for use in Jefferson County for the required flow rate.

If a unit is not on the list, the design engineer must submit third party verification of performance (such as New Jersey Department of Environmental Protection, New Jersey Corporation of Advanced Technology, Maine Department of Environmental Protection, etc.) to show that the proposed unit meets MSD's specifications, for MSD review and approval for use.

18.4.11 Open Infiltration Trenches

Open infiltration trench in the Parklands at Floyds Fork.

Open infiltration trenches are shallow, excavated areas that receive stormwater. Overland flow or a perforated inlet pipe allows stormwater to infiltrate through an aggregate bed and into the underlying soil, filtering stormwater pollutants. Design requirements for infiltration trenches include: pretreatment, drainage area size, storage capacity, and the exfiltration of the water to subsurface soil. Infiltration trenches improve water quality through:

- Treatment of stormwater percolating through soil
- Removal of light sediment/pollutants (pretreatment required to prevent clogging)

Advantages/Benefits	Disadvantages/Limitations
• Suitable for sites with limited space • Reduces volume of stormwater runoff and provides peak flow control • Appropriate for small sites (< 5 acres) unless large infiltration area is available • Provides infiltration and pollutant filtration	• May not be suitable for locations impacting utilities, shallow groundwater, bedrock, sinkholes and buildings/basements • Not suitable for slopes >3% • Access to infiltration interface is limited

18.4.11.1 Application and Site Feasibility

Infiltration trenches are filled with aggregate and have a designed overflow or bypass during high flow events. Infiltration trenches are applicable for a wide variety of uses such as the perimeter of parking areas or medians between drive lanes; however, they are not applicable for conveyance areas. Bottom slope shall not exceed 3%.

18.4.11.2 Physical Requirements

Key physical constraints:

- Surface dimension vs. depth - if an infiltration trench is designed so that it is deeper than it is wide, then it meets the EPA definition of a Class V Injection Well. See the Design Criteria section for more information.
- Infiltration - Trenches should drain in 24 to 36 hours. Native soils shall have an infiltration rate of 0.5 inches per hour or greater. For infiltration rate less than 0.5 inches per hour, an underdrain is required.
- Groundwater table - The groundwater table shall be at least 2 feet, preferably 4 feet, below the bottom of the infiltration trench.

18.4.11.3 Design Criteria

The design of an infiltration trench includes several elements to manage stormwater infiltration to facilitate water quality improvement. For a summary of design parameters, see Table 18.12. See Exhibit 18-17 for typical open infiltration trench plan and profile.

18.4.11.3.1 EPA Regulations for Class V Injection Wells and Underground Injection Control (UIC)

Infiltration trenches are generally long, narrow stormwater quality features that capture stormwater; however, an infiltration trench can be classified as a Class V Injection well by the EPA if it meets certain criteria (see the Class V wells page at www.epa.gov):

- "Any bored, drilled, or driven shaft, or dug hole that is deeper than its widest surface dimension, or"
- "An improved sinkhole, or"
- "A subsurface fluid distribution system." (epa.gov)

If the infiltration trench designed meets any of the criteria listed above, the EPA form 7520-16 must be filled out and all other additional EPA regulations shall be followed. Wells, injection wells, improved sinkholes or dry wells will trigger EPA permitting requirements. MSD cannot approve injection wells without EPA approval.

18.4.11.3.2 Location

Infiltration trenches are retention structures when they are designed to effectively capture and infiltrate stormwater runoff. When finding the most appropriate location for the trench, it is best to find a location with a small drainage area that receives overland flow with no concentrated flows. The flow length of the contributing drainage area shall be less than 300 feet. This will maintain sheet flow of stormwater into the infiltration trench and reduce the risk of shallow concentrated flow forming.

Areas with heavy sediment flow or a significant pollutant load are not suitable locations because the pretreatment device and subsurface aggregate may become clogged or the groundwater contaminated. Infiltration trenches should be located at least 10 feet from building foundations and underground utilities.

18.4.11.3.3 Sizing

The surface storage parameter should be designed to retain/capture the volume produced by the rainfall events specified in Table 18.12. The depth of ponding within these structures should be kept relatively low to prevent hydraulic overloading of the in situ media. An overflow feature shall be installed to move excess water during a large storm event or in case of clogging. Sizing of infiltration trenches is based on the volume provided by the porosity of the media in the trench and in the ponding area above the trench media. The volume should at least be equal to the VR. See Table 18.12 for the VP formulas.

18.4.11.3.4 Storage Capacity

Infiltration trenches are designed to detain small storm events while also safely passing large storms with adequate freeboard. Infiltration trenches should have an adequate overflow system and maintain adequate freeboard to avoid flooding or overtopping of the area surrounding the BMP.

Open Infiltration Trench at Misa Metal Fabricating, Inc.

18.4.11.3.5 Slopes

Site topography should be considered in an infiltration trench design. Typically, the slopes of the contributing drainage area should be less than 10%. This prevents excessive scouring of the vegetated area due to high velocities from stormwater inflow. Additionally, the contributing area should be stabilized to reduce unnecessary silting of the practice.

18.4.11.3.6 Pretreatment

Pretreatment must be used for all applications to prevent clogging and ease maintenance, especially in land use areas with high sediment loads. Examples of pretreatment are pea gravel and vegetated buffers.

18.4.11.3.7 Infiltration Testing and Native Soils

Infiltration testing is required to be performed per Section 18.3. Infiltration trenches typically contain no outlet structure; however, an overflow structure is required. The native soils beneath the trench should have an infiltration rate of 0.5 inches per hour or greater and should be designed to drain in 24 to 36 hours. For infiltration rate less than 0.5 inches per hour, an underdrain is required.

The slope of subsurface native soils shall not exceed 3% and shall be sloped away from building foundations.

18.4.11.3.8 Storage Media

Infiltration trenches shall be installed using double washed aggregate (with a certification letter from the quarry), pea gravel, sand, and filter fabric. All storage media shall be clean and free of fines. For more information on aggregate requirements, see Section 18.6. River rock maybe used in trenches with non-load-bearing applications. A 6-inch to 12-inch layer of sand should be installed on the bottom of the trench to promote infiltration and to prevent compaction of the native soils. Filter fabric shall also be installed on the sides only of the trench to prevent migration of the native soils into the storage media. A 6-inch to 12-inch layer of double washed pea gravel is required for the top layer of the trench to facilitate capture of sediment before it enters the storage layer and to facilitate maintenance for removal of sediment that passes through pretreatment structures.

18.4.11.3.9 Underdrains

If the infiltration rate of in situ soil is less than 0.5 inches per hour, an underdrain is required. Underdrains should be constructed with perforated pipe or slotted corrugated pipe with a minimum 4-inch diameter and bedded in double washed KY #57 stone. Filter fabric should be avoided in this situation due to its propensity for clogging. Where filter fabric is necessitated, choose non-woven filter fabric. Underdrain pipes should be designed to be a minimum of 4 inches in diameter, minimum 0.5% slope and include a 4 inch minimum cleanout. See Exhibit 18-6 for a typical underdrain.

18.4.11.3.10 Overflow

An overflow must be included to safely convey high flows from large storm events. The planning and installation of the high flow bypass or diversion structure will be largely based on each site design. For overflows tied into the combined sewer system, backflow prevention is required. Use splash blocks or other BMPs at overflow outlets to prevent scour.

18.4.11.3.11 Observation and Cleanout Wells

Observation and clean-out wells must be installed near the inlet and the center of the trench to monitor the water level of the trench and check for clogging. The observation well shall be a 6-inch perforated PVC pipe with a removable and lockable cap. See Exhibit 18-18 for typical observation well section.

Table 18.12 Open Infiltration Trench Application and Site Feasibility Criteria Chart	
Design Parameter	**Criteria**
Drainage Area	Small contributing drainage areas receiving overland sheet flow with no concentrated flows are best suited. The flow length of the contributing drainage area shall be less than 300 feet.
Soils	Native soils shall have an infiltration rate of 0.5 inches per hour or greater. For infiltration rate less than 0.5 inches per hour, an underdrain is required.
Sizing	Sizing of infiltration trenches is based on the volume provided by the porosity of the media in the trench and in the ponding area above the trench media.
Slopes	Bottom slope shall not exceed 3%. Slopes of the contributing drainage area should be less than 10%.
Design Flows and Conveyance Capacity	Pass the 2-,10-, and 100-year, 24-hour storms with 6 inches of freeboard.
Pretreatment	Pretreatment must be used to prevent clogging. Examples of pretreatment include pea gravel and vegetated buffers.
Observation and clean-out Wells	Observation and clean-out wells must be installed near the inlet and the center of the trench to monitor the water level of the trench and check for clogging.
Outlet Protection	An overflow feature shall be installed to convey excess water during a large storm event or in case of clogging and maintain adequate freeboard to avoid flooding or overtopping of the surrounding area. Use splash blocks or other BMPs at overflow outlets to prevent scour.
Volume Provided (VP)	The water quality design volume provided (VP) by an open infiltration trench is: $VP\ (ft^3) = (A)(p1)(d1)$ • A = area of trench (ft^2) • p1 = porosity of base layer (% void) • d1 =depth of base layer (ft) Design calculation sheets are available at www.louisvillemsd.org.

18.5 CONSTRUCTION

Construction of permeable paver parking lane and tree boxes

This section addresses construction practices unique to construction of post-construction water quality BMPs as a supplement to MSD's erosion prevention and sediment control requirements. Proper construction practices are critical to the initial and long-term functionality of the BMPs. Because most post-construction water quality BMPs rely on infiltration to maximize treatment volumes, it is important to protect the location of the BMPs on construction sites from compaction and sedimentation.

18.5.1 Construction Sequencing

Erosion and sedimentation carried from other areas of the construction site can clog and compromise the permeability of filter media and native soils. BMPs should be constructed in the final phases of construction. Once constructed, BMPs must be kept offline until at least 80% of the contributing area of the site is stabilized. All BMPs must be free of sediment and trash prior to site disturbance permit release. BMPs shall not be used as an erosion control device.

18.5.2 Good Housekeeping and Pollution Prevention

Good housekeeping practices, or pollution prevention practices, protect BMPs as well as keep harmful pollutants and construction waste out of our waterways. Spills and excess materials should be promptly cleaned up so that they do not wash into downstream drainages.

18.5.3 Compaction

Compaction must be minimized in locations for green infrastructure construction. These areas should be identified and marked by stakes or construction fencing to create a barrier so that heavy equipment does not compact native soils. Excavation should be performed by hand or performed from outside of the footprint of the practice when heavy equipment is necessary.

18.5.4 Infiltration Test

An infiltration test must be performed for all infiltrating practices after construction is complete to show minimum infiltration rate is met.

18.6 AGGREGATE SPECIFICATIONS

18.6.1 Clean Aggregate Specification

There are fundamentally different aggregate specifications for green infrastructure and traditional gray infrastructure practices. Green infrastructure requires water flow, storage, and infiltration through media and aggregate, whereas traditional projects combine aggregate with binding agents, creating impermeable surfaces. For aggregate used in green infrastructure projects, it is especially important to minimize fines coating the surface of the aggregate stone by double washing. Aggregate that is not double washed and clean is not suitable for post-construction water quality practices. Aggregates used in post-construction water quality practices must be accompanied with a certification letter from the quarry indicating that the stone was double washed.

18.6.2 Compaction and Settlement

The aggregate components of post-construction water quality practices should be compacted to minimize post-construction settlement while allowing exfiltration into in situ soils. Compact the aggregate utilized for storage volume or load-bearing structures to minimize settlement at the surface. Compaction of the aggregate needs to be determined by the designer based on the anticipated loads at the surface. Typically, vibratory plate compactors are used to obtain about 95% compaction of the aggregate.

At the aggregate/in-situ soil interface, the intermixing of these two materials should be minimized. Two typical approaches for minimizing this intermixing is the use of geotextile fabric (non-woven, sides only) and geogrids. Geogrids provide structural stability and keep the different layers of aggregate separated (i.e. the No. 3 aggregate layer should be kept separate from the No. 57 aggregate layer). This separation will help reduce settling due to the smaller particles filling in the void space provided by the larger aggregate. The aperture size of the geogrids is important in keeping the aggregate layers separated. See specifications for BMP for use of geogrid and geotextile fabric in combination with manufacturer specifications. Typically, geogrid is applied at each layer of aggregate size, and geotextile fabric is placed on the sides only, not on the bottom of the practice.

18.6.3 Prohibited Materials

Post-construction water quality practices rely on the void space and connection with in situ soils to store and exfiltrate stormwater. Dense Grade Aggregate (DGA) is aggregate that includes a wide variety of stone sizes. Stormwater cannot pass through DGA as readily as coarse grades and is not acceptable for use in post-construction water quality practices. For this reason, the use of DGA, construction waste, waste concrete, recycled materials, and similar materials is prohibited in the construction of post-construction water quality practices.

Stone used as base layer for green infrastructure

18.6.4 Non-Structural Applications

For non-structural applications (i.e. rain gardens, bioswales, etc), river rock may be used instead of a crushed limestone as the coarse aggregate. Additional caution shall be used in the vicinity of roads, parking lots and sidewalks when using river rock. Double washed crushed No. 3 Stone, No. 57 Stone, and No. 8 Stone is also acceptable. River rock is considered an acceptable substitute because there are less fines and grit on the rock. However, river rock is not recommended for practices with a loading (i.e. roads, parking lots pavers and sidewalks); due to reconsolidating and shifting. River rock is typically available in the following sizes: 1/2 inch and down, 3/8 inch to 5/8 inch, and 3/4 inch to 2 inches.

18.6.5 Structural Applications

For structural applications where post-construction water quality practices are to be used to support applications carrying load (i.e. permeable pavers), conform to KYTC gradations.

Furnish crushed aggregate meeting the quality of section 805 of the KYTC Construction Standards with the following exception: a shale content of 2% will be allowed, providing the combined shale, friable particles, and minus No. 200 content does not exceed 2%.

18.6.6 Required Documentation

A specification sheet showing the aggregate has been double-washed, certified by the quarry, is required for all structural applications or otherwise where coarse aggregate stone is used for post-construction water quality practices. Certifications for double washed coarse aggregate specifications shall be supplied to MSD inspectors and the property owner on site for each load of aggregate.

18.6.7 Number 3 Stone

Number 3 Stone (No. 3) is placed at the very bottom of the infiltration BMP and is used as a storage area. The stones must be double washed to keep as much fine material out of the storage area as possible.

Table 18.13 Gradation Sizes of No. 3 Stone
Sieve Size-Percent Passing*

2 ½ inch	2 inch	1 ½ inch	1 inch	½ inch
100	90-100	35-70	0-15	0-2

*No greater than 2% passing No. 200

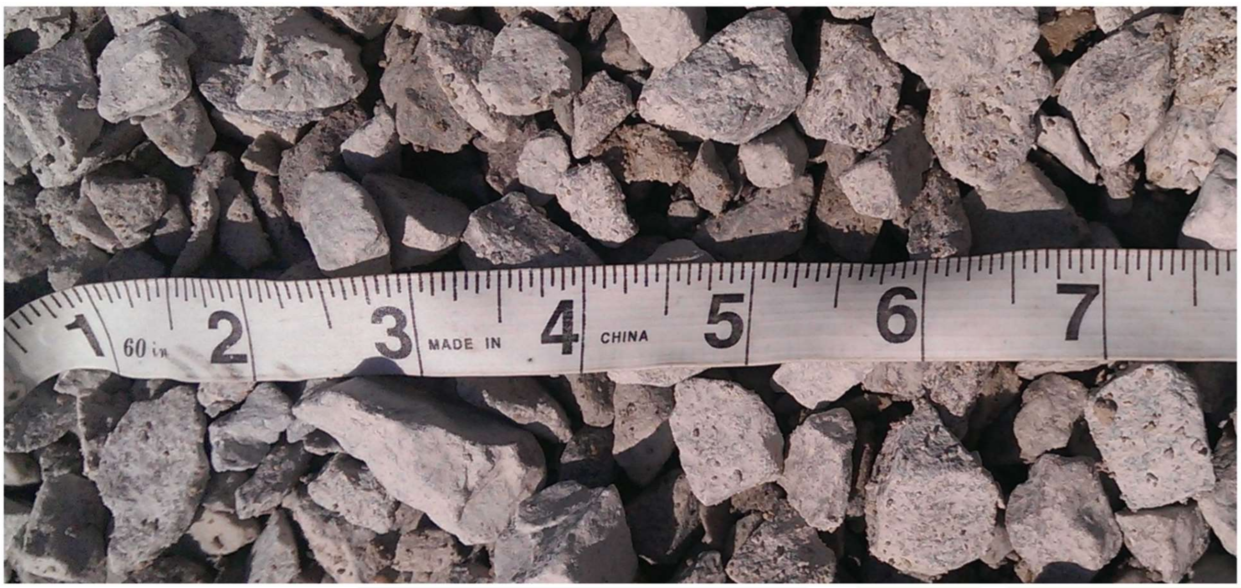
Number 3 Stone

Number 3 Stone

18.6.8 Number 57 Stone

No. 57 stone should be used as a base for a structure with loadings. An example of this would be sidewalks and roadways. In addition, it is generally placed on top of No. 3 stone. For practices that include pervious pavers, the No. 57 rock should be placed directly below the bricks. Most practices require double washed No. 57 stone. This ‘washing’ allows for fine material to be removed from the rocks, reducing the amount of clogging in the structure.

Table 18.14 Gradation Sizes of No. 57 Stone **Sieve Size-Percent Passing***				
1 ½ inch	1 inch	½ inch	No. 4	No. 8
100	90-100	25-60	0-10	0-2
*No greater than 2% passing No. 200				



Number 57 Stone

Number 57 Stone

18.6.9 Number 8 Stone

No. 8 stone should be placed between the brick, concrete, or articulate concrete pavers. The stone should be washed, to keep fine material out of the storage areas and reduce clogging.

Table 18.15 Gradation Sizes of No. 8 Stone Sieve Size-Percent Passing*				
½ inch	3/8 inch	No. 4	No. 8	No. 16
100	85-100	10-30	0-10	0-5
*No greater than 2% passing No. 200				

Number 8 Stone

Number 8 Stone

18.7 OPERATION & MAINTENANCE GUIDANCE

Maintenance is a critical aspect of a properly functioning BMP. Pursuant to the Wastewater/Stormwater Discharge Regulations, sites with BMPs are required to enter into long-term Operations & Maintenance (O&M) agreements with MSD regarding the inspection and maintenance requirements for the BMPs. Annual reports are required for all BMPs. These records must be made available to MSD or Louisville Metro government upon request.

18.7.1 Overview of Maintenance Procedures

Routine inspections will help to maintain function of the BMP systems and prevent problems from arising. As most BMP systems are largely affected by the seasonal changes and storms, inspections should typically be conducted at the beginning of each season as well as after large rain events.

In general, the inspection and maintenance of BMP systems includes:

- Removal of sediment buildup
- Removal of debris from any inflow and outflow points
- Local erosion prevention and sediment control
- Routine inspection of the structural integrity of the BMP to ensure function
- Replacement of filter media (if needed)

In general vegetation maintenance includes:

- Irrigation and weeding during the first few months of planting to ensure species establishment
- Maintenance of the health and abundance of native species and plantings
- Annual trimming or pruning to prevent woody species growth
- Removal of any invasive species

This section provides detailed O&M procedures for each BMP.

18.7.2 Bioretention (Rain Garden, Bioswale, Tree Box or Planter Box)

Maintenance should be periodically conducted to ensure that the bioretention area is functioning properly. Initially (for the first year), the plantings will require more intensive maintenance to ensure proper species establishment and function. This initial maintenance of the system will primarily consist of:

- Monthly inspections of the soil
- Removal of accumulated debris or sediment buildup
- Erosion repair
- Watering during periods with no rain
- Replacement of dead or diseased vegetation
- Weeding of non-native invasive species.

Vegetation should be cut back and removed from the garden during the winter months when plants are dormant. Mulch should be added every 1-2 years; 2-3 inches of shredded hardwood mulch is preferred. Care should be given when mulching not to allow mulch to pile up on the stems of plants (woody or herbaceous).

After major rain events, it is important to inspect bioretention cell and make sure drainage paths are clear and any pooling water dissipates within 36 hours; note that water may pool for longer times during the winter and early spring.

If the bioretention BMP is not functioning properly, repairs to the under-drain as well as inflow and outflow structures may be needed.

By their design, bioretention cells are not in danger of becoming a breeding ground for mosquitoes. It takes 24 to 36 hours for a mosquito egg to hatch, after which it takes 10 to 14 days for the mosquito to complete its larval development to become an adult. By having a properly functioning and draining bioretention cell, the chances of providing mosquito habitat are virtually eliminated. If the bioretention cell holds enough water for mosquitoes to successfully breed, there is a problem with the soil, underdrain or outflow structure that should be addressed.

Table 18.16 Bioretention (Rain Garden, Bioswale, Tree Box or Planter Box) Maintenance Schedule

Schedule	Activity
As needed	• Water as recommended by the nursery during establishment and then as needed during dry conditions
At least 3 times per year	• Prune and control weeds • Remove and replace dead or damaged vegetation • Mow perimeter areas as needed
Semi-annually in spring and fall	• Remove sediment, trash and debris from inlets/forebays • Inspect inflow points for clogging and remove any sediment • Inspect for erosion, rills or gullies and repair • Herbaceous trees and shrubs should be inspected to evaluate their health and remove any dead or severely diseased vegetation • Remove fallen, clipped or trimmed plant material from rain garden to prevent clogging and replace dead plants • Develop/adjust vegetation maintenance plan for trimming and dividing perennials (if applicable) to prevent overcrowding and stress and to achieve desired aesthetic qualities; remove any non-native, invasive species • Inspect vegetation for health and signs of stress; if vegetation begin showing signs of stress, including drought, flooding, disease, nutrient deficiency, insect attack or improper mowing, treat the problem or replace the plants • Observe infiltration rates after rain events; bioretention BMPs should drain within 36 hours of a storm event • A mulching depth of about 2-3 inches should be inspected and obtained, and additional mulch should be added if necessary • Evaluate areas containing low flow stone or gravel; replace if necessary
Upon failure	• Replace/repair inlets, outlets, scour protection or other structures as needed • Replace vegetation as needed to align with original planting plan • If the rain garden is not meeting desired infiltration rates or over time soil has compacted, check soil infiltration rates by performing a percolation test • Re-aerate or replace soil and mulch layers as needed to achieve infiltration rate of 0.5 inches per hour • When removing soil for replacement, take to landfill or soil recycling center

18.7.3 Constructed Wetland

Constructed wetlands should be visited every quarter and following major rain events during the first year after construction. Inspections should evaluate:

- The success of the native plantings
- Establishment of invasive non-native plants
- Inlet/outlet conditions
- Sediment/debris accumulation

Repairs, replacements, and maintenance should be conducted as problems arise to maintain the functionality of the wetland. Maintenance will consist of:

- Repairs to the structural integrity of the outlet and containment edges
- Erosion and burrow repair
- Monitoring and removal of debris and sediment buildup with special care not to impact water storage capacity
- Invasive non-native species control
- Replacement of native plant material as needed to a minimum coverage of 50% of the wetland

Visits to the site can be reduced to 2 times per year in the second and third years after establishment.

A high level of qualitative monitoring should occur during the first three years after the wetland is installed to insure proper function and establishment of the constructed wetland. Monitoring should focus on successful establishment of native wetland plants, water storage capacity, and pollutant removal. Visual observations of the wetland can be recorded to determine how frequently sediment/debris should be removed. Over time, large wetlands that are heavily loaded will require more frequent monitoring than smaller less loaded wetlands.

Visual observations should be recorded for the establishment and density of native wetland vegetation and the presence of non-native and invasive species. Changes of concern include an increase in the numbers of aggressive non-native species, a decrease in the density of the vegetative cover to less than 50% of the wetland, and signs of disease. An invasive species management plan may need to be implemented if invasive species are present within the constructed wetland.

If near a populated area, monitor the wetland regularly for mosquito populations and develop and implement a control plan as needed.

Table 18.17 Constructed Wetland Maintenance Schedule	
Schedule	**Activity**
Quarterly during the first growing season	• Remove and replace dead, severely diseased vegetation, or damaged plants • Remove or control weeds and invasive species • Monitor wetland after major storm events to ensure structures are functioning properly and inspect for erosion
Semi-annually in spring and fall	• Inspect inflow points for clogging • Inspect for erosion, rills or gullies along the embankments and repair • Remove fallen, clipped, or trimmed plant material from wetland to prevent outlet clogging • Harvesting of seasonally dead plant material in the fall may be needed if high nutrient level treatment is desired • Inspect vegetation for health and signs of stress; if plants begin showing signs of stress, including drought, flooding, disease, nutrient deficiency, insect attack or improper mowing, treat the problem or replace the plants • Observe water levels to confirm that they are as designed • Mow maintenance access areas around wetland • Maintain signs in "no mow" areas
Annually or as needed	• Remove sediment, trash and debris from inlets/forebays when one-quarter of the forebay volume has been lost
5 plus years or upon failure	• Monitor sediment accumulation and remove when one-quarter of the constructed wetland's design volume has been lost • Dredge sediment to meet original design volume and replace vegetation as needed to align with original planting plan

18.7.4 Green Wet Basin

A wet basin should be inspected semi-annually in the Spring and Fall as well as after major rain events. The basin should be maintained for structural stability and proper inflow and outflow discharge. Accumulated sediment and debris should be removed from the basin as well as the inflow area to prevent future clogging during rain events. Overall health and abundance of the native vegetation should be maintained, replacing dead or diseased plants as necessary. In addition, seasonal or yearly management should be conducted to remove or control invasive non-native vegetation from the site as well as to remove woody vegetation from all embankment areas.

Inspection of the buffer zone, downstream of the outflow point, should be conducted regularly to make sure that the wet basin is functioning properly and the outflow is not negatively impacting downstream habitats. This includes inspection for any erosion along the embankment of the basin.

Table 18.18 Green Wet Basin Maintenance Schedule

Schedule	Activity
Monthly during the first growing season	• Remove and replace dead or damaged plants • Remove or control weeds and invasive species • Inspect and repair erosion • Water as needed to keep plants alive
Semi-annually in Spring and Fall	• Inspect inflow/outflow points for clogging • Remove any trash and debris • Inspect for erosion, rills or gullies along the embankments and repair • Vegetation should be inspected to evaluate their health and remove any dead or severely diseased vegetation • Remove fallen, clipped or trimmed plant material from basin to prevent outlet clogging • If plants begin showing signs of stress, including drought, flooding, disease, nutrient deficiency, insect attack or improper mowing, treat the problem or replace the plants • Inspect for plant root damage due to piping and mammal burrows; remove/repair when discovered • Mow maintenance access areas around green wet basins; do not mow buffer area around basin • Clean pond and forebay of debris and trash
Annually	• Remove sediment from inlets/forebays when one-quarter of the forebay volume has been lost
5 plus years or upon failure	• Monitor sediment accumulation and remove when one-quarter of the green wet basin's design volume has been lost • Dredge sediment to meet original design volume and replace vegetation as needed to align with original planting plan

18.7.5 Green Dry Basin

The seasonal maintenance of a dry basin consists primarily of the inspection of the inlet and outlet pipes for structural integrity; the clearing of sediment and debris from the inlet and outlet pipes as well as the basin; and the removal of debris from upstream areas to prevent it from washing into the basin. It is important to note that improperly maintained basins can reduce the storage volume of the pond as well as create breeding areas for mosquitoes.

Native vegetation should be maintained seasonally and after major rain events. Maintenance consists of replacement of dead or diseased plants, replanting of eroded areas, and invasive species control. The basin should also be trimmed annually to prevent the growth of woody species.

Table 18.19 Green Dry Basin Maintenance Schedule	
Schedule	**Activity**
Monthly during the first growing season	• Remove and replace dead or damaged plants • Remove or control weeds and invasive species • Inspect for erosion • Water as needed to keep plants alive
Semi-annually in spring and fall	• Inspect inflow/outflow points for clogging • Remove any trash and debris from forebay • Inspect for erosion, rills or gullies along the embankments and repair • Vegetation should be inspected to evaluate their health and remove any dead or severely diseased vegetation • Remove fallen, clipped or trimmed plant material from basin to prevent outlet clogging • If plants begin showing signs of stress, including drought, flooding, disease, nutrient deficiency, insect attack or improper mowing, treat the problem or replace the plants • Inspect for plant root damage due to piping and mammal burrows; remove/repair when discovered • Mow maintenance access areas around green dry basins • Green dry basins should drain within 36 hours of a storm event • Clean pond of debris and trash • Remove any sediment accumulation
Annually	• Remove sediment from inlets/forebays when one-quarter of the forebay volume has been lost
5 plus years or upon failure	• Monitor sediment accumulation and remove when one-quarter of the green dry basin's design volume has been lost • Remove sediment to meet original design volume and replace vegetation as needed to align with original planting plan

18.7.6 Green Roof

Green roofs will require irrigation or natural precipitation at least once a week until the plants have fully established. Once the plants have matured, extensive green roofs no longer need to be irrigated except in cases of extreme drought. The roof will require regular weeding during the establishment phase and only seasonal weeding thereafter. Vegetation should be monitored seasonally to maintain overall health and plants should be replaced or resown as needed. Plants should be fertilized annually or as recommended by the source nursery.

The increased weight and the addition of more intensive plantings tend to increase the maintenance requirements of those green roofs. The same overall maintenance noted for an intensive green roof should be followed, but on a more frequent basis. Plantings will need additional care and maintenance due the increased soil depth and the likelihood of additional invasive exotic plants becoming established.

The severe consequences of drainage backups, root punctures, and leaks in the waterproofing membrane system make seasonal inspections crucial. Drainage routes should be kept clear so that leakage is avoided and plants are not susceptible to increased moisture in the soil. Debris and dead vegetation should be removed along with any woody vegetation. See minimum maintenance schedule in Table 18.17 below.

Table 18.20 Green Roof Maintenance Schedule (Extensive and Intensive Green Roofs)

Schedule	Activity
As needed	• Water as recommended by the nursery during establishment and then as needed during dry conditions
Minimum 3 times during growing season	• Remove sediment, trash, weeds and debris • Implement landscaping maintenance plan for trimming to achieve desired aesthetic qualities • Mulch as needed • Inspect landscaping for health and signs of stress • If vegetation begins showing signs of stress, including drought, flooding, disease, nutrient deficiency or insect attack, treat the problem or replace the vegetation • Inspect underneath roof system • Drainage routes should be kept clear so that leakage is avoided and plants are not susceptible to increased moisture in the soil • Observe infiltration rates after rain events; green roof should drain within 24 hours of a storm event
Upon failure	• Replace green roof system

18.7.7 Permeable Pavement

Permeable pavers, require that the surface be kept clean of organic materials and debris through periodic vacuuming and low-pressure washing. Cleaning should be conducted seasonally with certain sites requiring additional maintenance due to the local conditions, and the frequency of storm events. Such cleaning will help to maintain the pavement’s flow capacity and restore permeability. Areas should be routinely inspected for settling and loss of water flow through the system and maintenance should be conducted as problems arise. Regular maintenance should help prevent these issues.

For permeable pavers, after cleaning additional aggregate fill may need to be added and the pavers should be inspected for damages and repaired as needed. Research has shown that the use of a street sweeper or air jet to maintain pavers is relatively ineffective, that a vacuum/water jet combination attachment is most effective for surface maintenance, and that the rate of surface clogging can be slowed by adding a chip stone to the gaps between blocks.

Table 18.21 Permeable Pavement Maintenance Schedule	
Schedule	**Activity**
At least once per year	• Vacuum/water jet combination attachment • Replace aggregate between pavers as necessary (if applicable)
Monthly during the growing season	• Inspect the pavement for trash, debris and dirt • Keep weeds and grass out of the paved area (unless concrete grid pavers are being used) • Mow/trim adjacent vegetation and remove clippings and other debris from the area using a leaf blower • Visually inspect the pavement after large storms to ensure the overflow drainage system is working After cleaning, additional aggregate fill may need to be added and the pavers should be inspected for damage and repaired as needed
Semi-annually in spring and fall or as needed	• Sweep or vacuum the pavement with a street sweeper or street vacuum • If the pavement are installed in an area that is subject to higher than normal amounts of sediment (i.e. an area with large trucks traveling on it daily) it may need to be cleaned more often • Replace any joint material that may have eroded • Observe the system during a rain event • Areas should be routinely inspected for settling and loss of water flow through the system

As needed in winter	• Organic deicers may be used to melt ice and snow
	• Snow plows may be used when necessary under the following conditions:
	  ○ The edges of the plow are beveled
	  ○ The blade of the snow plow is raised 1 to 2 inches
	  ○ The snow plow is equipped with snow shoes which allow the blade to glide across uneven surfaces

Upon failure	• When the base layer becomes clogged, remove pavers or pavement and replace/repair base layer to achieve design infiltration volume/rate. Note: Chip stone aggregate may be used between paver joints to prevent complete failure

18.7.8 Tree Boxes

Tree boxes should be kept free of debris and trash, and periodic cleaning should be conducted to clear the inflow and outflow mechanisms. The vegetation in the boxes will require more intensive maintenance over the first several months after installation, but this demand will decrease as the plants become established. Boxes should be kept free of invasive species and the overall health of the plants should be maintained. The soil and mulch in the boxes should be tested periodically to avoid the build-up of pollutants that may harm the vegetation. Any mulch used should be replaced biannually.

Tree boxes require regular irrigation during dry periods. If an under-drain system is used, maintenance of inflow and outflow structures will require periodic inspection and removal of sediment and debris, if necessary. In addition to general maintenance procedures, the tree/shrub should be trimmed or pruned according to an established maintenance plan.

18.22 Tree Box Maintenance Schedule

Schedule	Activity
As needed	• Water as recommended by the nursery during establishment and then as needed during dry conditions
Semi-annually in spring and fall	• Remove sediment, trash, weeds and debris • Implement vegetation maintenance plan for trimming to achieve desired aesthetic qualities • Inspect vegetation for health and signs of stress • If tree/shrub begins showing signs of stress, including drought, flooding, disease, nutrient deficiency or insect attack, treat the problem or replace the vegetation • Observe infiltration rates after rain events. The tree box should drain within 24 hours of a storm event • Replace mulching as needed, maintain at least 2-3 inches of mulch
10-25 years	• Remove tree/shrub and replace with smaller specimen

18.7.9 Vegetated Buffer

Initially, vegetated buffers should be inspected after major rain events to ensure proper draining. The vegetated buffer should maintain desired slope, length and width. Bare spots or eroded areas should be repaired to ensure they are functioning according to design specifications. Vegetation should only be mowed according to maintenance plans and “No Mow” areas should be clearly defined. Inspections should consist of replacement and care of plant materials and irrigation during dry periods. Accumulated sediment or other trash and debris should be removed and the buffer should be checked for erosion.

Table 18.23 Vegetated Buffer Maintenance Schedule	
Schedule	**Activity**
As needed	• Water as recommended by the nursery during establishment and then as needed during dry conditions • Trim vegetation in accordance with nursery recommendations
Semi-annually in spring and fall during first year and annually thereafter	• Inspect grading of vegetated buffer to ensure sheet flow across the entire buffer length and width • Inspect vegetation for health and signs of stress; if tree/shrub/grass begins showing signs of stress, including drought, flooding, disease, nutrient deficiency or insect attack, treat the problem or replace the vegetation • Inspect buffer for erosion and bare spots and repair
Following significant rain events (>10 yrs)	• Inspect and repair eroded or damaged areas to maintain sheet flow to and across the vegetated buffer

18.7.10 Catch Basin Inserts

Catch basin inserts will require very frequent sediment removal as their volume is very limited in comparison to the volume of the catch basin sump. It is necessary to routinely remove sediment, trash and debris and to replace the inserts if they are damaged. Inspections of catch basin inserts should be scheduled, at a minimum, prior to the first seasonal rains as well as during and after each major rain event.

The site should also be checked for excessive erosion or sediment flow upstream of the catch basin. It may also be necessary to periodically check the catch basin to ensure stormwater is flowing through the filter system. In addition to general maintenance procedures, the catch basin inserts should be replaced annually.

Table 18.24 Catch Basin Inserts Maintenance Schedule	
Schedule	**Activity**
Preventative measures	Inflow should flow through the filter system
Regularly and after Major Storm Events	Inspect catch basin inserts for clogging and remove sediment, trash or debris
Semi-annually in spring and fall	Visit site to ensure there is not excessive erosion or sediment flow upstream of the catch basin insert
As Needed	Replace catch basin inserts

18.7.11 Proprietary Water Quality Units

Proprietary water quality units should be inspected seasonally and after major rain events or per manufacturer's recommendations to ensure proper function. Manufacturer's guidelines should be followed and an individual maintenance plan should be developed for all systems based on routine inspections. In general, maintenance will include pumping and pressure washing the unit and cleaning blockage or sediment buildup with use of vacuum trucks or boom trucks. Drainage areas should be regularly maintained to prevent the flow of trash, sediment and debris into the system. Note that the system may need additional cleaning in the event that a spill of a foreign substance enters the unit.

Inspections should be conducted after the first rain event and also after major storms. Repairs to inlets, outlets, control valves or other structures should be performed periodically. Safety and maintenance practices for confined spaces should be followed when appropriate.

Table 18.25 Proprietary Water Quality Units Maintenance Schedule

Schedule	Activity
As needed	• Inspect drainage areas to proprietary WQUs for trash, erosion and debris • Perform cleanout if hazardous or foreign substances are spilled in the drainage areas • Repair inlets, outlets, control valves or other structural features as needed • Inspect system after major rain events to ensure it is draining properly
Quarterly	• Inspect system for blockage or sediment buildup and perform cleanout if necessary • Follow manufacturer's guidelines and develop/adjust maintenance plan for the system
Annually	• Perform cleanout of the system with vacuum or boom trucks • Clean any sediment or oil chambers • Inspect inlets, outlets and other structural features; repair as needed

18.7.12 Infiltration Trench or Basin (Open and Underground Storage)

Infiltration trenches and basins (Open or Underground Storage) will require maintenance inspections at least annually but more frequent inspections are recommended. It is necessary to check the observation well for clogging annually or as-needed basis (if applicable). All pretreatment systems and other structures connected to the infiltration BMP should be routinely checked for clogging. If the aggregate layer becomes clogged with sediment and debris, it may be necessary to remove the layer and replace it with new aggregate. It may also be necessary to check the observation well after major rain events to ensure the trench is draining properly. The top of the trench and all pretreatment devices should be cleared of leaves and other debris routinely. It is necessary to mow the area around the pretreatment devices, as well as the perimeter of the trench to clear access for maintenance. If the entire system appears to be clogged with sediment and is no longer functioning properly, this may trigger the removal of the sediment accumulation and replacement aggregate.

Table 18.26 Infiltration Trench Maintenance Schedule (Open and Underground Storage)

Schedule	Activity
Open Storage	
Schedule	**Activity**
2-3 times per year as needed	• Monitor the drain observation well after large rain events and check for any ponding water • Mow or trim the perimeter of the practice and any pretreatment devices; grass clippings should be removed to prevent clogging • Check observation well for clogging
Semi-annually	• Check pretreatment systems and other structures for clogging; remove sediment and debris as necessary • Inspect the top layer of the trench for ponding water, leaves, grass clippings or other debris • Inspect any piping or other structural devices for damage and replace as necessary
Upon failure	• If the entire system becomes clogged, remove and install clean, double washed trench aggregate • It may also be necessary to replace piping, filter fabric, etc.
Underground Storage	
As needed	• Inspect drainage areas to BMP for trash, erosion and debris • Perform cleanout if hazardous or foreign substances are spilled in the drainage areas • Repair inlets, outlets, control valves or other structural features as needed • Inspect system after major rain events to ensure it is draining properly
Quarterly	• Inspect system for blockage or sediment buildup and perform cleanout if necessary
Annually or as needed	• Perform cleanout of the system with vacuum or boom trucks • Clean pretreatment device • Clean any trapped or sump manhole structures connected to system (if applicable) • Inspect inlets, outlets and other structural features; repair as needed
Upon failure	• When the base layer becomes clogged and no longer infiltrates at the design rate/volume, the subsurface will need to be removed and replace to achieve the design infiltration rate/volume Note: Pretreatment is required for the system to prevent complete failure

18.8 REFERENCES

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