8.6.5 Green Roof

A Green Roof consists of a series of layers that create an environment suitable for plant growth without damaging the underlying roof system. Rainfall is initially intercepted by vegetation installed on the roof, held on foliage or soaked up by plant roots. Runoff that exceeds the holding capacity of the growing medium is released from the rooftop through an underdrain system. A Green Roof can be installed on either a new or existing rooftop, provided the roof structure is able to hold the additional weight and meet local building code. Green Roofs are not new technology, with many of their known benefits only being added to in recent years. The technology provides an insulation benefit to the installed building, decreasing rooftop temperatures, mitigates urban heat island effects, and can provide stormwater quantity and quality benefits making them a valuable structural BMP alternative in urban settings where land area is limited. In addition, they may provide an aesthetic benefit helping a building to meet potential landscaping requirements, and can be designed to be used by pedestrians and/or building occupants. As the variations in Green Roof vary widely, the focus of this section will be to describe the key components of a Green Roof system. Each system will need to be designed to fit the structure and purpose for the respective building. However, there are common design elements and considerations that are instrumental to the success of each Green Roof system.

Design Considerations	
Location characteristics (Slope, Soil Type)	Slope: Extensive Systems 2% to 25% Intensive Systems 2% to 10% Soil Type: Engineered Growing Medium/ Soil
Contributing drainage area	Vegetated Rooftop Area
Design size	Vegetated Rooftop Area
Detention time for WQCV treatment	Soil matrix designed to store WQCV
Median Effluent Concentrations[3]	TN = 1.08 mg/L[1]; TP = 0.15 mg/L[1,2]
Implementation and Maintenance Considerations	
Potential for use with other BMPs	High; Green Roofs can be used as the first structural BMP in a treatment train
Maintenance	Low – Vegetation maintenance, Inspection of drainage outlets and waterproofing layer

[1] NC State University/ NC State University Bio & Ag Engineering and North Carolina Department of Environment and Natural Resources (NCDENR), 2011
[2] Water Environment Research Foundation (WERF), 2005 for Media Filters
[3] The effluent concentration from a Green Roof system is highly dependent on the characteristics of the unique soil matrix for each application combined with any contamination through atmostpheric deposition. A Green Roof only treats stormwater that falls directly on the Green Roof surface itself.

8.6.5.1 General Application

Green Roof systems are a good BMP for use in urban areas, as they can be designed and/or retrofit in the defined building footprint. Green Roofs provide several benefits for the building. Through the vegetation and engineered growing medium, a Green Roof provides an insulating mechanism. This can provide energy savings, as well as insulation from typical urban environment sounds, such as building system equipment installed on rooftops. The vegetation assists in insulating a building through the evapotranspiration process. The vegetation and growing medium also treats and reduces the volume of stormwater runoff that is generated by the roof area on which the Green Roof is installed.

Because stormwater is stored by a Green Roof and released over a period of time, stormwater flow peaks typically seen following high intensity rainfall events are reduced and delayed over a period of time (Dunnet and Kingsbury, 2004). This allows downstream drainage systems to convey "moderately increased flow" over an extended time period instead of increased peak flow over a relatively short period of time, characteristic of highly impervious areas. If a Green Roof is constructed within the drainage area of a downstream BMP, the area of the Green Roof can be subtracted from the WQCV calculation for the BMP. Because the rainfall is not infiltrated, a Green Roof acts as a filter and increases the time it takes for rainfall to reach the primary storm sewer system. In the case of a Green Roof with a slope of less than 25-percent, the result of stormwater filtering through a Green Roof is approximately a 45-percent reduction in the volume of runoff (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau [FLL], 2002).

As Green Roofs capture and filter rainfall falling immediately on the surface of the roof, their water quality benefits are limited to that immediate rainfall. Additional stormwater flow should not be routed to a Green Roof for treatment. Green Roofs have been shown as a poor BMP for nutrient storage and removal, due to the fact that filtration of water through plant material and substrate will yield added nutrient runoff (Minnesota, 2008). Concentrations of nutrients in stormwater runoff from Green Roof systems have shown in studies to be very similar to other vegetated systems that you would find in a typical landscape (EPA, 2009). However, it should be noted that even if concentrations of nutrients are typical to other vegetated systems, the loading of a pollutant is often reduced because the total stormwater runoff from a Green Roof is reduced (EPA, 2009).

Figure 8-26 Saddlebrook School, Library, and Community Center, Omaha, Nebraska (www.omahaice.org)

There are two basic types of Green Roof systems to consider for installation: Extensive Systems and Intensive Systems.

Extensive Systems

An Extensive System consists of a lightweight Green Roof system, with a shallow depth that supports a limited variety of vegetation. These systems use drought tolerant vegetation and can structurally support limited uses (such as maintenance personnel). Figure 8-26 shows an example of an Extensive System.

Intensive Systems

An Intensive System is a heavyweight Green Roof system, having greater soil depths which can support a wider range of plants and increased pedestrian traffic. Figure 8-27 show an example of Extensive Systems in combination with Intensive Systems in a Green Roof application.

Figure 8-27 Gallup Campus Green Roof, Omaha, Nebraska (www.omahaice.org)

8.6.5.2 Advantages and Disadvantages

Advantages	Disadvantages
Treat and reduce the volume of stormwater runoff	Additional roof loads may require an enhanced structural design, limiting the retrofit of existing buildings.
Conserve energy by providing additional insulation, using the evapotranspiration process of plants to cool the roof during the summer, and reducing the heat lost to wind convection during the winter	Leaks can be difficult to locate and repair. Leak detection systems can assist with this process.
Offset urban heat island effects by reducing the amount of heat typically absorbed by a conventional roof and thus lowering the ambient temperature of the roof	Conditions can be harsh for vegetation establishment.
Extend the lifespan of a conventional roof by protecting the roof surface from UV light, large temperature fluctuations, and normal wear and tear associated with exposed surface roofs	Maintenance costs can be higher than for conventional roof systems; however, roof life cycle costs may be lower.
Improve the aesthetics of a building; provides attractive views from other buildings and/or an opportunity for pedestrian traffic	
Effective sound insulators that can reduce the impact of noise from equipment on the roof or other outside noises	
Plants on Green Roofs use carbon dioxide and produce oxygen	

8.6.5.3 Design Requirements and Considerations

This Section provides a narrative and discussion of typical design requirements and consideration for a Green Roof. Any differences in requirements between Extensive System and Intensive System design and construction are noted. This information is outlined by how it would be presented on construction drawings: Green Roof – Plan View, Green Roof – Cross Section, and Green Roof – Calculations. As the application of a Green Roof will always vary with the building, the focus of this Section is to look at the main function of key components in the Green Roof Section. Each of these key components will need to be designed to meet criteria of a specific application. It is recommended that the designer consult and design to the following minimum industry standards for all Green Roof applications:

- ANSI/SPRI RP-14 Wind Design Standard for Vegetative Roofing Systems.
- ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs.
- ASTM E2397-05 Standard Practice for Determination of Dead Loads and Live Loads associated with Green Roof Systems
- ASTM E2400-06 Standard Guide for Selection, Installation, and Maintenance of Plants for Green Roof Systems

Green Roof – Plan View

At a minimum, the following components should be clearly labeled on the plan view of a Green Roof design project:

1. **Structural Supports.** Placement of the heaviest components of the Green Roof should be on column heads or over beams. A Green Roof retrofit should consider additional loads imposed on the existing roof. A structural support plan should be provided in addition to the plan view of the Green Roof.

2. **Drainage.** The location of underdrains in the gravel ballast should be clearly designated, including diameter of PVC pipe to be installed and perforation requirements. All underdrains should be connected to a roof downspout or means of conveyance away from the Green Roof system. These underdrains serve as overflow points in the Green Roof system. The purpose of these underdrains is to quickly release excess runoff from larger storm events. All downspouts or means of conveyance away from the Green Roof system should be clearly labeled.

3. **Gravel Ballast.** A width of gravel, stone, or paver material along the perimeter of the Green Roof provides several functions. First, this volume of permeable material can provide additional storage capacity of the Green Roof, filtering and conveying flows in excess of the WQCV. Secondly, this width can provide protection from wind shears (Dunnet and Kingsbury, 2004). Thirdly, this ballast can serve as a separation point between roof components, and can provide a fire break point in the roof system. Having this width along a Green Roof's edge can prevent possible vegetation growth into the waterproof layer. The perimeter gravel ballast should be labeled with a width, depth, and gradation for installation. Calculations should be included on the porosity of this material. All stone used in the gravel ballast should be triple-washed.

4. **Vertical Elements.** All vertical elements sited on or penetrating the Green Roof, such as air vents and heating/air conditioning components should be clearly labeled on the plan view. It is ideal to place gravel ballast along the perimeter of all vertical elements on the Green Roof. This allows access to the element that may be required for periodic maintenance.

5. **Slope.** The slope of each area of the Green Roof should be indicated in the plan view, clearly labeled with an accompanying arrow indicating the direction of slope. Slopes exceeding 15-percent will require additional stabilization measures (horizontal strapping, laths, battens, or grids), which should be accounted for in the structural calculations (Dunnet and Kingsbury, 2004). These greater slopes can create a problem of slippage between the materials used in construction of the Green Roof.

6. **Vegetation Plan and Schedule.** The vegetation zones on the Green Roof should be clearly designated and dimensioned on the plan view. A planting plan, with list or schedule of plants and their method of installation should be included on this sheet. For more details on vegetation selection see discussion in the following paragraphs.

Green Roof – Cross Section

Each layer in the Green Roof system should be clearly labeled in cross-section view and reference manufacturer/design specifications. The layers described as follows are the minimum to be installed as part of a functioning Green Roof system. Figure 8-28 shows the typical Green Roof cross section.

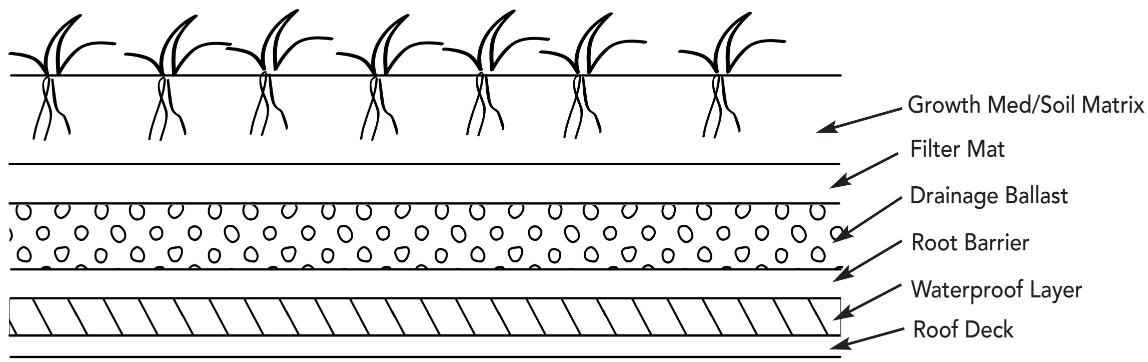

Figure 8-28 Typical Green Roof Cross Section

1. **Waterproof Layer.** An effective, durable waterproof layer is important to the longevity of a Green Roof installation. The waterproof layer protects the building's structural components from being exposed to the elements. Two common types of waterproof applications include tile/sheet single-ply roof membranes or fluid applied membranes. Either should be applied strictly according to the manufacturer's instructions. Tile/sheet membranes are installed by overlapping and sealing joints, therefore it is important to inspect the seal at each joint prior to installing the next layer of the Green Roof system to mitigate potential system leaks and opportunities for vegetation root penetration.

2. **Root Barrier/Waterproof Protection Layer.** A root barrier and/or waterproof protection layer should be installed as the next layer in the Green Roof system. This layer deters root growth into the underlying waterproof layer, in addition to providing protection to the waterproof membrane from anything installed above it during and after construction (City of Eugene, Oregon [Eugene], 2008). This layer is typically a dense material such as a PVC sheet. Sheets are overlapped and sealed together. It is critical to extend this layer beyond the actual planting area, and install around any vertical elements to create a barrier to vegetation root growth in the system. Membranes should not be impregnated with pesticides or with copper, both of which could adversely affect the water quality of any runoff from the Green Roof (Eugene, 2008). It is recommended that any investigation of this layer to assess root penetration follow ANSI/GRHC/SPRI VR-1 2011.

3. **Drainage Ballast.** The drainage ballast should be designed to convey the volume of stormwater runoff that can be absorbed by the growth medium; the purpose of this layer is not to detain stormwater. Unlike other structural BMP systems, excess runoff is conveyed as underflow in the Green Roof system; surface runoff should not occur (Dunnet and Kingsbury, 2004). It is important to remove the excess runoff in order to prevent over saturation of the vegetation. The drainage ballast can be constructed from coarse, washed granular materials, porous mats, or manufactured drainage modules, and connected to the perimeter gravel ballast.

4. **Filter Mat.** A semi-permeable fabric or mat should be installed between the drainage ballast and the growth medium/soil matrix. The purpose of this mat is to filter any small particles that could be transferred from the growth medium/soil matrix through the infiltration of runoff into the drainage ballast; it prevents the drainage ballast from becoming clogged or from potentially

blocking any drainage outlets in the Green Roof system. The filter mat should not only be installed as a horizontal layer, but also vertically at all perimeter edges of the growth medium/soil matrix layer, wrapping up around this layer.

5. **Growth Medium/Soil Matrix.** The growth medium for the Green Roof should be designed to permeate or filter the calculated WQCV. If this is not feasible, additional BMPs on the building site may be required. In addition, the depth and soil matrix of this layer must be designed to support the vegetation to be installed (either an Extensive System or an Intensive System). Soil matrixes for both must be well drained, while at the same time being able to absorb and retain rainfall volume, providing a medium for Green Roof vegetation to thrive. The filtering capacity of the growth medium and the components of the soil matrix should be designed by a landscape architect or other approved vegetation specialist.

Sizing Guidelines

All designs for new or existing Green Roofs must account for the dead and live loads associated with this type of construction in addition to the requirements of the existing building code, as adopted by the City of Omaha. Additional roof loads will require an enhanced structural design and may limit the retrofit of existing buildings. The following calculations are required as part of a Green Roof submittal:

- **Live Loads.** If the Green Roof is accessible, people load must be accounted for. Another example of live load is wind. Each live load must be itemized with appropriate supporting calculations.
- **Dead Loads.** Dead loads would include, but are not limited to, saturated weights of Green Roof materials, snow, and ice. Each dead load must be itemized with appropriate supporting calculations.
- **Building Structure Loading Capacity.** The building's structure capacity must be able to carry the calculated live loads and dead loads.

All submitted calculations must be sealed and signed by a professional structural engineer licensed in the state of Nebraska.

The growth medium or soil matrix has two critical functions: to store the WQCV and to permeate runoff in excess of the WQCV to the ballast layer with little to no ponding on top of the vegetation. As each Green Roof application is unique, the depth of growth medium/soil matrix will be unique to each project. It is recommended that a minimum depth of 2-in. be used as a guideline to detain and filter the WQCV and support vegetation.

Stormwater runoff in excess of the WQCV will need to be conveyed from the Green Roof. This involves using the drainage ballast, the gravel ballast, any overflows in the roof system, and roof downspouts. This conveyance will be unique to each Green Roof application. It is recommended that the designer submit a routing plan for stormwater runoff that includes all major elements, complete with conveyance and volume calculations.

Considerations for Vegetation Selection

A Green Roof requires very different plant material selection when compared to other vegetated structural BMPs (Minnesota, 2008). The vegetation selected must thrive in very constrained growing conditions, and account for seasonal fluctuations in temperature and moisture.

Vegetation should be installed using one of two preferred methods: vegetation mats/modular systems or plugs/potted plants.

- Vegetation mats/modular systems are pregerminated systems that achieve immediate full plant coverage. These systems provide several immediate advantages to the Green Roof installation and establishment process, including a reduction in exposed soil which reduces potential erosion and weed concerns during plant establishment. Long-term maintenance is minimal, and may require intermittent watering during very dry periods and weeding (Eugene, 2008).

- Plugs or potted plants provide can provide more options for Green Roof vegetation. A variety of plant species can be used in one Green Roof installation. Using plugs or potted plants will require initial mulching of the Green Roof, preventing erosion during vegetation establishment. Until establishing a minimum of 90-percent vegetated cover on the roof, subsequent mulching, weeding, and irrigation may be necessary.

The selection of plants to install on a Green Roof is primarily based on the depth of growing medium and the composition of the soil matrix, in addition to climate considerations (rainfall, temperature). For Green Roofs where the growing medium is shallow, xeriscape plantings are commonly used. Xeriscape plantings include a mix of sedum/succulent plant communities that are ideal for installation on a Green Roof due to their drought tolerance, growth patterns, low maintenance needs, resiliency, and fire resistance (Eugene, 2008). For richer, deeper substrates, shrubs and trees may be used. In general, plants with deep root systems typical of an infiltration type structural BMP may not be suitable for a Green Roof.

8.6.5.4 Inspection and Maintenance

Critical inspection points occur during the Green Roof installation process to ensure the integrity of the Green Roof system. In addition, key maintenance activities for Green Roof systems include both short-term and long-term tasks. The following industry standard procedures for investigation are recommended for all Green Roof applications:

- ANSI/GRHC/SPRI VR-1 2011 Procedure for Investigating Resistance to Root Penetration on Vegetative Roofs.

- ASTM E2396-05 Standard Test Method for Saturated Water Permeability of Granular Drainage Media [Falling-Head Method] for Green Roof Systems.

- ASTM E2398-05 Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems.

- ASTM E2399-05 Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems.

Inspection During Installation

1. Any Green Roof layer applied as sheets, mats, or rolls should be sufficiently overlapped and sealed during the installation process, as directed per the manufacturer instructions.

2. The waterproof layer should be inspected prior to the subsequent installation of Green Roof layers. Green Roof systems may include a pre-installed electronic leak detection system. If this is not included in the design of the installation, it is advised to administer a waterproofing test with an electronic leak detection system (such as vector mapping) prior to installation of subsequent Green Roof layers.

3. It is advised to complete an inspection at the completion of each layer's installation.

4. The installation of modular products can increase installation efficiency (Minnesota, 2008).

Short Term: Installation – Year 1

1. A goal of 90-percent vegetated coverage should be achieved within 6-months for Green Roofs installed at the beginning of the growing season (Spring).

2. Temporary irrigation may be required in order to establish vegetation. A permanent irrigation system may be needed, depending on vegetation selection in the Green Roof system.

3. Monthly weeding of the Green Roof during Year 1 is recommended to deter weed seedlings and saplings from establishing.

4. All drainage outlets and/or overflows should be inspected after any rain event exceeding 0.5-in. during the first year of installation. The purpose of this inspection is to ensure the flow of excess stormwater from the roof surface. During vegetation establishment, these outlets are more susceptible to clogging.

Long Term: Year 1 – later

1. Biannual weeding of the Green Roof is recommended to deter weed seedlings and saplings from establishing.

2. Conduct annual surveys to verify that the waterproofing system remains watertight below the vegetated cover (Minnesota, 2008).

3. All drainage outlets and/or overflows should be inspected at least two times per year. The purpose of this inspection is to ensure the flow of excess stormwater from the roof surface.

4. After vegetation is well established, it is recommended to fertilize the system only as needed, and not at an interval more frequent than every other year. Fertilization at this interval allows the content of nutrient in the substrate to become exhausted, and can therefore enhance vegetation growth and appearance (Dunnet and Kingsbury, 2004). Attention should be paid to the impact any fertilization will have to the overall water quality of stormwater runoff from the Green Roof system.

8.6.5.5 Submittal Requirements

For review purposes prior to construction, the following minimum submittal requirements are recommended:

1. Green Roof dimensions and setbacks from roof lines. This plan view should also include all components outlined in Section 8.6.5.3, clearly labeled.

2. Profile view of facility, including typical cross-sections and dimensions, with all components outlined in Section 8.6.5.3, clearly labeled.

3. Specifications of all materials to be used in the Green Roof construction, including but not limited to: Growth medium/soil matrix specification, including depth; filter mat specification; drainage ballast specification; root barrier specification; waterproof layer specification.

4. Vegetation plan with schedule for installation and initial maintenance. Appropriate erosion control

measures should be included.

5. Stormwater conveyance and volume calculations.

6. Structural dead load and live load calculations. This should include verification that structure will support additional loads.

7. Long-term inspection and maintenance plan.

8.6.5.6 References

Dunnet, Nigel and Kingsbury, Noël. 2004. *Planting Green Roofs and Living Walls.* Timber Press, Inc.

USEPA. 2009. Green Roofs for Stormwater Runoff Control (EPA/600/R-09/026). US*EPA Office of Research and Development, National Risk Management Research Laboratory – Water Supply and Water Resources Division:* www.epa.gov/ord

Eugene. 2008. Stormwater Management Manual: http://www.eugene-or.gov/DocumentCenter/Home/View/4545

FLL e.V. 2002. Guidelines for the Planning, Execution, and Upkeep of Green-roof sites: http://www.greenroofsouth.co.uk/FLL%20Guidelines.pdf

Minnesota Stormwater Steering Committee and Minnesota Pollution Control Agency (Minnesota). 2008. Minnesota Stormwater Manual Version 2.

NCDENR. 2011. Jordan/Falls Lake Stormwater Load Accounting Tool (Version 1.0) User's Manual: http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/3638/JAllen_NScott_2011.pdf?sequence=1

Single Ply Roofing Industry (SPRI). 2010. ANSI/SPRI RP-14 Wind Design Standard for Vegetative Roofing: Systemshttp://www.greenroofs.org/resources/ANSI_SPRI_RP_14_2010_Wind_Design_Standard_for_Vegetative_Roofing_Systems.pdf

SPRI. 2010. ANSI/SPRI VF-1 External Fire Design Standard for Vegetative Roofs: http://www.greenroofs.org/resources/ANSI_SPRI_VF_1_Extrernal_Fire_Design_Standard_for_Vegetative_Roofs_Jan_2010.pdf

SPRI. 2011. ANSI/GRHC/SPRI VR-1 2011 Procedure for Investigating Resistance to Root Penetration on Vegetative Roofs: http://www.greenroofs.org/resources/ANSI%20GRHC%20SPRI%20VR1%20Procedure%20for%20Investigating%20Resistance%20to%20Root%20Penetration%202011.pdf

WERF. 2005. Median of Average Effluent Concentrations for BMPs. *ASCE/EPA ISBMPD*.

8.6.6 Manufactured Systems

A manufactured system is generally a structural BMP whose function provides more traditional, treatment via settling and different forms of filtration. Manufactured systems are typically proprietary units; however, some may have their components designed separately by the site designer. These systems are generally designed to fit or work within an existing conveyance system component, and can be ideal for more urban areas where open space is minimal. As manufactured systems vary depending on application and the manufacturer, this Section's guidance will focus on three main categories of manufactured systems and their respective functions: filtering, storage, and separation.

A manufactured system whose primary function is filtration is typically designed to filter, at a minimum, the water quality discharge, Q_{WQ} (Section 8.3.2). Filtration systems typically remove pollutants in stormwater by passing runoff through filter cartridges or filter media.

Detention systems or manufactured systems whose primary purpose is to store stormwater runoff are designed to retain the WQCV. Pollutants settle out in these systems over a period of time.

Manufactured separation devices include two types of systems: chambered and hydrodynamic. In chambered systems, stormwater runoff passes through a series of chambers where pollutant particles settle out. Hydrodynamic systems create a vortex motion to runoff flow which drives separation of pollutant particles for removal.

Design Considerations	
Location characteristics (Slope, Soil Type)	Slope: Variable Soil Type: N/A
Contributing drainage area	< 5 acres[1]
Design size	Variable
Median Effluent Concentrations	Filter System: Variable[2,3], TP = 0.14 mg/L Detention/Storage Systems[3]: Variable, TP = 0.19 mg/L Separators: Variable[2,3], TP = 0.14 mg/L
Implementation and Maintenance Considerations	
Potential for use with other BMPs	High – Manufactured systems may be appropriate for installations in special situations (discussed in Section 8.2.2.5) Filter System or Separators: Pre-treatment in a treatment train application Detention/Storage Systems: Can be used as downstream treatment and storage in a treatment train application
Maintenance	High; Frequent removal of collected material and cleaning/changing of filter media.

[1] Metropolitan St. Louis Sewer District (MSD), 2009
[2] Removal efficiencies are very variable. The use of phosphorus as the target pollutant is recommended when using performance based water quality criteria (Virginia, 1999).
[3] Table 8-3

8.6.6.1 General Application

In general, a manufactured system can be appropriate for small drainage areas of highly impervious cover. Often, these drainage areas have high hydrocarbon or sediment loadings that need to be addressed. Care should be taken to not exceed manufacturer's recommended flow rates or volumes to a system. Manufactured systems are extremely variable in design details, design concept, and pollutant removal characteristics.

A manufactured filter system is designed to filter flow which is regulated by an inflow pipe. The filtered stormwater is then routed to a discharge point. The filters in these manufactured systems may be designed or selected to remove specific pollutants from stormwater. The filter media is typically based on the target pollutants to be removed, and can provide a pre-treatment option for stormwater discharging to another structural BMP as part of a treatment train. Typical applications of manufactured filtration systems include retrofit applications into curb inlets and catch basins. Maintenance of these systems on a schedule similar to erosion and sediment control inspections is critical to the long-term success of these BMPs. An example of a manufactured filter system is shown in Figure 8-29.

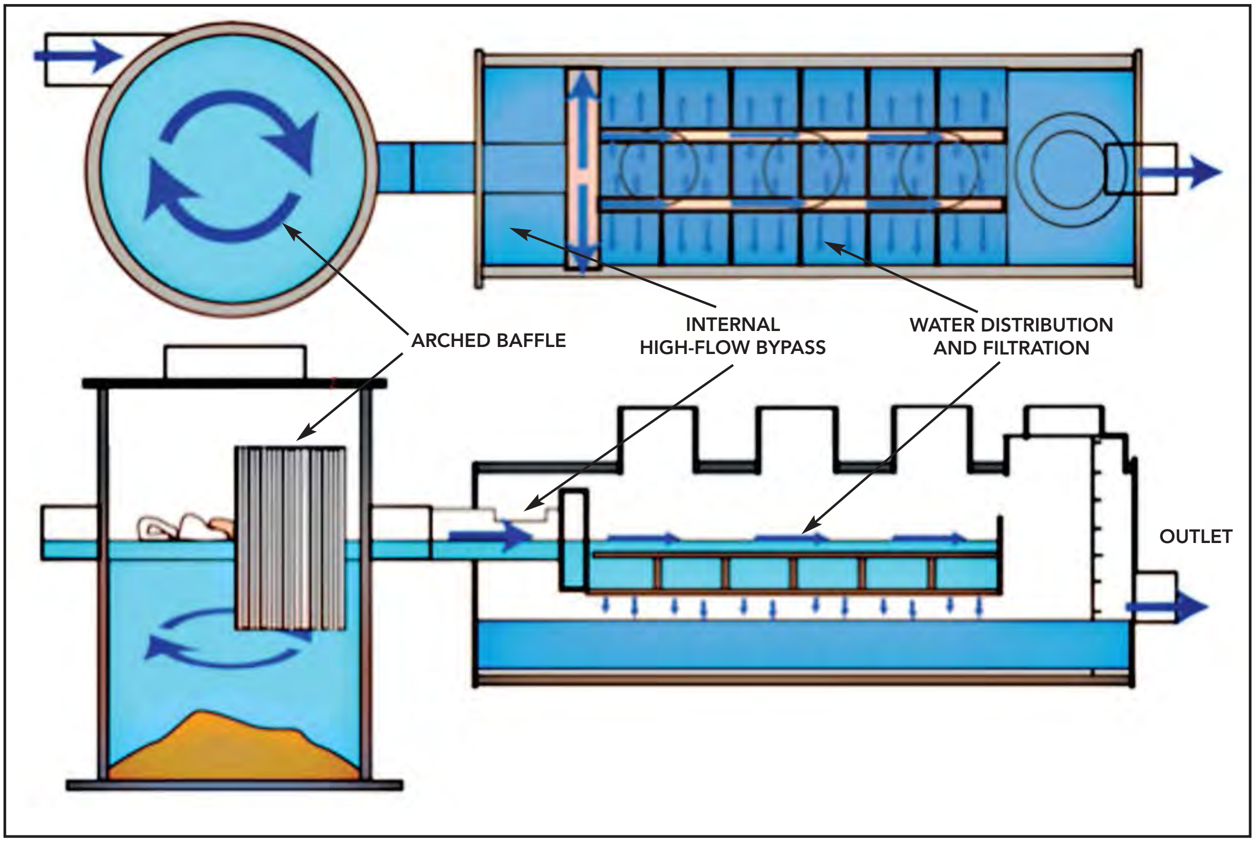

Figure 8-29 Example of Manufactured Filter System

Manufactured storage, or detention, systems can be installed below or above ground, providing the added advantage for a given space to be dual function. An example of this is providing underground detention cells below a parking lot or alley. Pollutants in stormwater runoff conveyed to these systems settle out over time, similar to the function of a typical extended detention structural BMP. Similar to extended detention structural BMP, manufactured storage systems can be used as downstream components in a treatment train if sized accordingly. Regular inspection of the outlet structure and at key points in the system susceptible to clogging is critical for the long-term functioning of this BMP. An example of a manufactured storage system is shown in Figure 8-30.

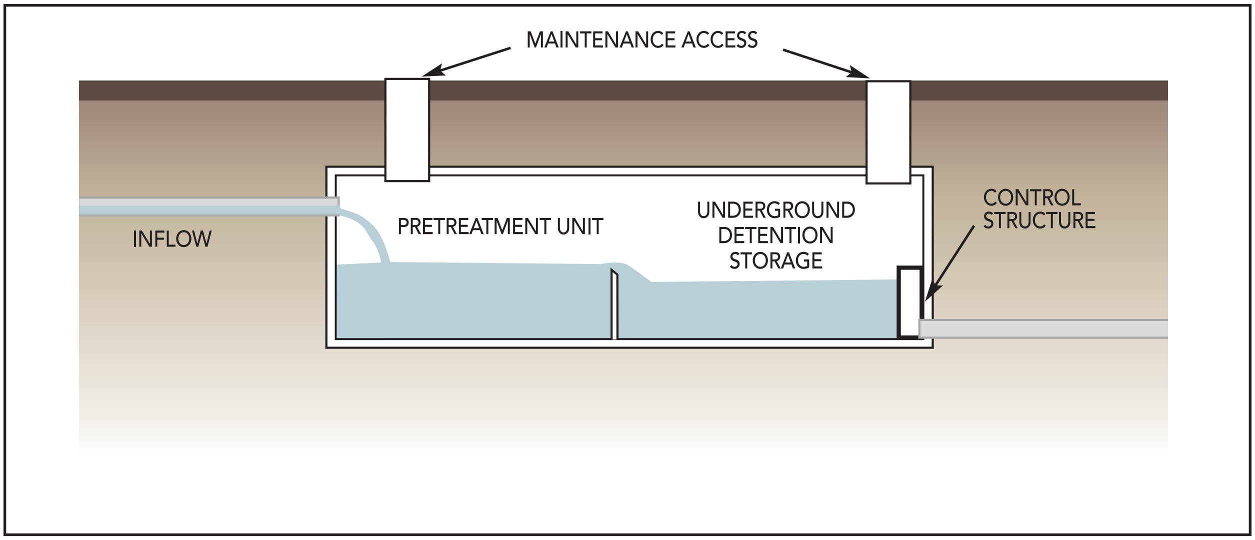

Figure 8-30 Example of Manufactured Storage System

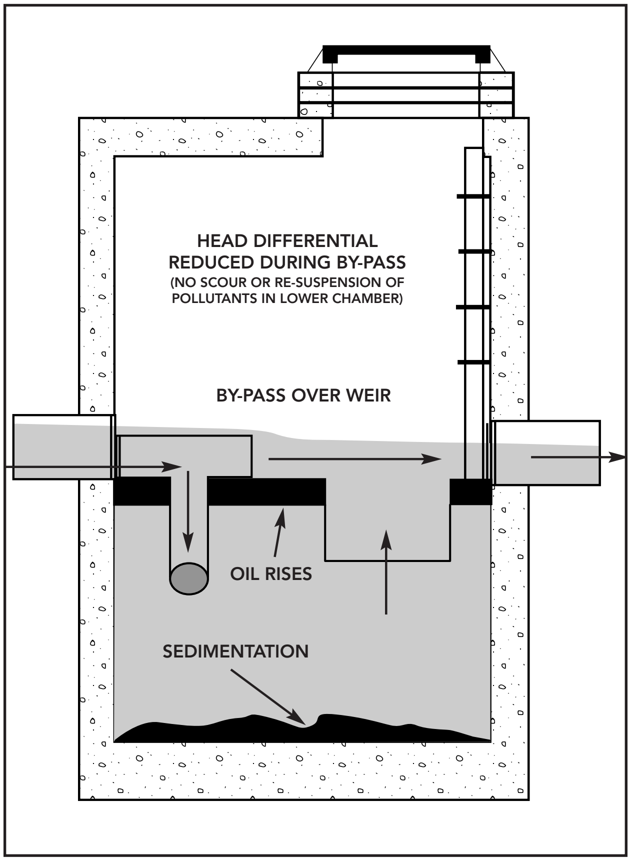

Figure 8-31 Example of Manufactured Separator System, Chamber Configuration (Adapted from Virginia Stormwater Management Handbook, 1999)

Separator systems filter flow via system hydraulics. These systems are typically used to treat stormwater using gravitational settling or circular flow to remove sediment and pollutants. They can provide pre-treatment of stormwater runoff before discharging downstream to either a typical conveyance system, or another structural BMP (as part of a treatment train). Applications of separators can be stand-alone (part of new construction) or can be used in retro-fit situations. Continual maintenance is critical for these systems to continue functioning at a high level of service. An example of a chambered system is shown in Figure 8-31 and an example of a hydrodynamic system is shown in Figure 8-32.

Vortechs Stormwater Treatment System - Model # 9000

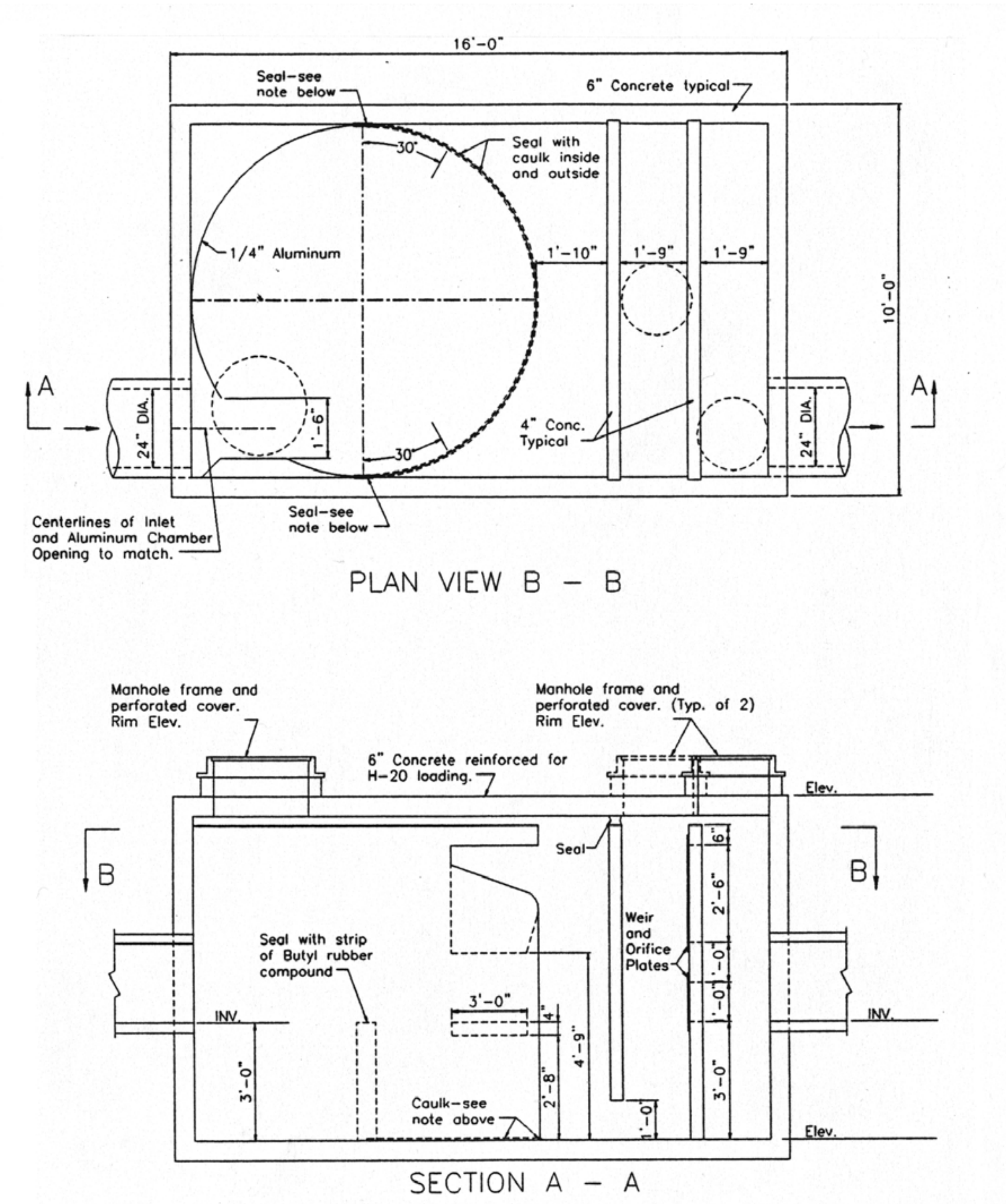

Figure 8-32 Example of Manufactured Separator System, Vortex Configuration (Adapted from Virginia Stormwater Management Handbook, 1999)

8.6.6.2 Advantages and Disadvantages

Advantages	Disadvantages
Manufactured systems can be designed to target removal of specific pollutants.	Design volumes are often limited to smaller drainage areas/runoff volume applications.
Opportunity for dual-use of a respective area (i.e. a parking lot can have an underground storage manufactured system)	Dependent on routine, scheduled maintenence for maximum system function.
Retrofit systems available.	Subsurface installations are not readily inspected, and typically lack provisions to warn of impending failure.
Typically do not require a large footprint for construction; ideal for applications in urban areas with minimal open space.	Little long-term maintenance data available to establish the life-span and long term needs of these systems.
Various options are available from manufacturers to find the "best fit" for an application.	
Quick to install; less room for error during installation	
Manufacturers provide recommended installation instructions and specifications.	
Can be cheaper than traditional technologies for stormwater treatment.	

8.6.6.3 Design Requirements and Considerations

Because each manufactured system varies in function, application, and manufacturer (or vendor), design requirements and considerations are presented in a generalized fashion. Each of these requirements and considerations, along with the appropriate design calculations, should be evaluated for the manufactured system to be installed at a given site. It is appropriate to request the design information for filter systems, detention/storage systems, and separators.

Design Flow Rate

Manufactured systems that are sized using a flow rate, including filter systems and separators, must be designed using the Q_{WQ} as discussed in Section 8.3.2. These systems provide little to no storage.

Volume

Manufactured systems that include a storage volume component must be sized to treat and/or store a volume of stormwater greater than or equal to the WQCV. Manufactured systems may be designed to reduce the peak flow rate for the 2-year event to meet pre-development peak flow rate; however, flows beyond the 2-year event peak flow rate should bypass the facility.

Pollutant Removal Characteristics

The specific pollutant removal characteristics of a manufactured system should be clearly specified. This includes listing all pollutants treated by the system with estimates of median effluent concentration.

For separators, if stormwater has the potential of containing hydrocarbons (i.e. gasoline, oil, petrochemicals) the system should be sized to contain a spill of up to 60 gallons (City of Elizabethton, Tennessee [Elizabethton], 2006). In addition, separators must actively remove floatable debris.

For any proposed installation of a manufactured system, monitoring may be required to verify the installed performance related to pollutant removal.

Overflow or Bypass

An overflow or bypass must be provided and/or specified as part of each manufactured system installation. This overflow or bypass must be designed to convey flows in excess of the manufactured system design. It is recommended that the overflow or bypass point convey excess flow at a point upstream of the manufactured system, rather than at the system itself, therefore conveying flow around the BMP. The overflow or bypass cannot convey flow in excess of the downstream system capacity. All overflow or bypass from the manufactured system should not re-suspend and release material that may already be trapped in the system.

While diversion of flows in excess of the WQCV should occur upstream of all manufactured systems, provisions should still be made at the system itself to safely overflow or bypass stormwater runoff should clogging, a blockage, or failure occur (Elizabethton, 2006).

On-line and Off-line

All filter systems or separators must be constructed off-line, meaning that runoff in excess of the WQCV must bypass the system through an upstream diversion. Storage or detention manufactured systems may be constructed on-line, and be designed for volumes in excess of the WQCV.

Tailwater Effects

For any manufactured system installation, hydraulic design should consider the effects of tailwater from downstream waterways or facilities. The effects of tailwater flooding on the system's hydraulic functionality should be considered.

Subsurface Devices

All subsurface installations of manufactured systems should consider dead and live loads that may be imposed on the structure. Sufficient and suitable access must be provided for each chamber in a manufactured system for inspection and maintenance activities. In addition, the designer should ensure that adequate clearance is available at the installation site for any operations and maintenance equipment. A structural engineering or geotechnical review may be required, depending on the installation.

Operation and Maintenance Plan

To retain a well functioning manufactured system, regular and continual inspections and maintenance is critical. Detailed operations and maintenance requirements that are critical to the manufactured system's continual functionality should be evaluated. Maintenance responsibilities should be defined prior to installation. Considerations and priority should be made for points in the manufactured system susceptible to clogging, any filter cleaning/disposal requirements, and frequency of vac-truck cleaning.

8.6.6.4 Inspection and Maintenance

Maintenance activities for manufactured systems depend on the system installed. All activities are classified as continual and should occur following rainfall or quarterly.

After rainfall equaling or exceeding 0.5 in.

1. Inspect the manufactured system. Check all filters, outlets, and overflow points in the system.
2. If sediment, debris, or other items have accumulated in the system, remove.
3. Clean filters if needed. Unclog or repair outlets and overflow points as needed.

4. Identify inspection/maintenance activities specific to the manufactured system that are critical following rainfall. Note the manufacturer's specifications for the maximum levels of pollutant accumulation allowed before removal is required.

Quarterly:

1. Inspect the manufactured system. Check all filters, outlets, and overflow points in the system.

2. If sediment, debris, or other items have accumulated in the system, remove. Clean the system with a vac-truck, as appropriate.

3. Clean filters if needed. Unclog or repair outlets and overflow points as needed.

4. Identify inspection/maintenance activities specific to the manufactured system that are critical on a biannual basis. Note the manufacturer's specifications for the maximum levels of pollutant accumulation allowed before removal is required.

5. Inspect structural components of the system for cracking, subsidence, spalling, erosion, and deterioration.

8.6.6.5 Submittal Requirements

For review purposes prior to construction, the following minimum submittal requirements are recommended.

1. Drainage area map, specifically outlining drainage area to the manufactured system.

2. Stormwater plan/profile for site and/or drainage area; stormwater routing/conveyance to manufactured system should be clearly delineated.

3. Manufactured system plan, profile, and detailed sections. Each component of the manufactured system should be clearly labeled with dimensions.

4. If retrofit installation, plan, profile, and detailed sections for the retrofit installation should be included.

5. If manufactured system is to be installed either below or above another site component (i.e. parking lot with underground manufactured storage system or building with manufactured Green Roof system), appropriate dead and live load calculations must be submitted, signed and sealed by a professional structural engineer.

6 Manufacturer's specifications for installation.

7. Manufacturer's specifications for maintenance.

8. An as-built survey of the manufactured system is recommended to confirm actual construction/installation adheres to approved construction plans.

9. A long-term inspection/maintenance plan.

8.6.6.6 References

Elizabethton. 2006. Commercial/Industrial Development Stormwater BMP Guidance:
http://www.elizabethton.org/business/BMP%20Design%20Guidance%20Final.pdf

MSD. 2009. Proprietary Water Quality Products and the Metropolitan St. Louis Sewer District's Stormwater Management Program:
http://www.stlmsd.com/portal/page/portal/engineering/planreview/PlanReviewInformation/ProprietaryBMPs/MSDProprietaryBMPProgramGuidance-080213rev090105.pdf

Virginia. 1999. Virginia Stormwater Management Handbook, Volumes 1 and 2, First Edition:
http://www.dcr.virginia.gov/stormwater_management/documents/Chapter_3-15.pdf

8.6.7 Permeable Pavement

Permeable pavement systems are comprised of a pavement surface which allows the infiltration of water into multiple subsurface layers. Depending on the specific design of this BMP, it has the potential to capture and temporarily store stormwater runoff, and filter and infiltrate stormwater runoff into the subsoil. There are several types of pavement surfaces, including:

1. Pervious Concrete – composed of water, coarse aggregate, cement, and little to no fine aggregate. This concrete has large void spaces, allowing water to rapidly infiltrate through it. Pervious concrete applications should conform to the requirements of the American Concrete Institute (ACI) 522.1, Specification for Pervious Concrete Pavement, published by the American Concrete Institute, Farmington Hills, Michigan. The specification should be reviewed by a qualified engineer and modified for the proposed pervious concrete application, as needed.

2. Porous Asphalt – a mixture of asphalt cement, coarse aggregate, and admixtures. As with pervious concrete, little to no fine aggregate is used, producing large void spaces which allow water to rapidly infiltrate to subsurface layers.

3. Permeable Pavers – a system of interlocking blocks which are placed with spaces between them. These spaces then allow for the rapid infiltration of water. A permeable paver can be comprised of openings up to 20-percent of the overall area.

4. Porous Gravel – used in place of traditional gravel drives. This system has a greater depth of gravel than a traditional application and includes a filter material.

5. Reinforced Grass – a system of plastic or concrete pavers which have large openings intended for the placement of aggregate or turf.

Underneath each of these pavement surfaces, a crushed stone aggregate base layer. The aggregate should be clean, washed, and free of fines. This aggregate layer serves as a reservoir, and holds the WQCV until it can be fully infiltrated into the subsoil. An underdrain system is included to ensure the aggregate reservoir drains properly for storm events producing runoff volumes larger than the WQCV. Site conditions may also call for use of perimeter barriers to prevent lateral infiltration.

Design Considerations	
Location characteristics (Slope, Soil Type)[1]	Minimum Slope: 0% Maximum Slope: 5% Soil Type: A, B for maximum infiltration C, D for lower infiltration
Contributing drainage area	The contributing drainage area should never exceed 5 times the surface area of the permeable pavement.
Design size	No restrictions
Detention time for WQCV treatment[1]	48 to 72 hours
Median Effluent Concentrations[2]	TSS =17 mg/L, TP =0.09 mg/L, Cu =3 µg/L
Implementation and Maintenance Considerations	
Potential for use with other BMPs	BMPs with high sediment removal capacities may be located immediately upstream to prevent clogging of pores and decrease maintenance; may be used in combinations with other BMPs to provide full treatment of the design volume.
Maintenance	**High** - Sediment/debris removal

[1] Chicago Stormwater Ordinance Manual, 2011 and USEPA Pervious Concrete Pavement, September 2009

[2] Median effluent concentrations apply to events with measured discharge. Geosyntec Consultants and Wright Water Engineers, Inc 2008

8.6.7.1 General Application

Permeable pavement systems should be sited at locations which are low-speed, low-traffic areas, such as parks, driveways, parking stalls, and pedestrian paths. They should not be located in a place where stormwater could convey large amounts of sediment to it, as this would clog pores and reduce infiltration rates. In addition, runoff from construction activities upstream of a permeable pavement system must be carefully controlled to prevent clogging. As this BMP provides high rates of stormwater infiltration, it must not be placed where contaminants such as pesticides, fertilizers, or other soluble contaminants may be conveyed to the groundwater table.

Figure 8-33 Example of a Permeable Paver Installation

Permeable concrete installations can be sited for higher traffic areas. Such sites require a greater thickness for the concrete pavement layer than installations in low traffic areas. An engineer should specify the thickness of the concrete on a site-by-site basis. If a permeable pavement system is sited next to an existing or a proposed structure, including buildings or other infrastructure, the impact of the increased infiltration on the structure's foundation must be considered.

Figure 8-33 shows an example of a permeable paver installation.

8.6.7.2 Advantages and Disadvantages

Advantages	Disadvantages
Has the ability to provide a large amount of volume reduction, depending on specific design and site conditions	Easily clogged with suspended sediment. As with all filtering systems, maintenance is key to performance.
Provides benefit to water quality	Higher construction and maintenance costs compared to traditional pavement However, some of this cost is offset with the elimination of traditional drainage infrastructure.
Has dual use as road/path infrastructure	Is ineffective when used in areas with a high water table
Suitable for cold-climate applications	Special consideration is required during design phase to ensure infiltration does not affect surrounding structures, if applicable
Reduces impervious area in a watershed	
Contributes to groundwater recharge	
Reduced maintenance in winter due to less frequent occurrences of melting and refreezing.	

8.6.7.3 Design Requirements and Considerations

Overall Design Guidance

1. Permeable pavement should not be constructed until the entire drainage area is permanently stabilized against erosion or a pre-treatment practice is implemented, nor should any activities be completed which could cause large sediment loads to be conveyed to the permeable pavement, such as staging of landscape mulch or soil on or near the pavement. Heavy sediment loads to the pavement will reduce infiltration rates and require additional maintenance to restore the infiltration rate to design levels.

2. Permeable pavement should not be sited where infiltration into the soil at the bottom of the aggregate reservoir could cause damage to surrounding structures due to expansive soils and/or bedrock. The aggregate reservoir drains primarily through infiltration, and would not function properly if not allowed to do so.

3. Coordination and communication between all parties involved, including, but not limited to, the City, the engineer, and the installer, is important in construction of a permeable pavement system. Prior to the construction phase, a meeting between all involved parties should be conducted to communicate the design process and procedures and to establish lines of communication.

4. The aggregate reservoir should be designed to capture at a minimum the required V_D. The design volume is equal to the WQCV unless routing of impervious areas to pervious areas (i.e. cascading planes) occurs within the drainage area of the permeable pavement system. The WQCV is based on 0.5 in. of runoff. If cascading planes are present, the design volume can be reduced because a portion of the WQCV from the impervious area is infiltrated. Refer to Section 8.3 to determine the design volume to use for sizing the permeable pavement system.

5. The design volume should be drained from the system within 48 hrs.

6. Subsurface investigations and the design of the subsurface system should be completed by a qualified engineer.

7. A qualified engineer with experience in the design of both conventional and permeable pavements should complete the pavement design when it will carry vehicular traffic. The engineer should ensure that the subgrade is properly designed, and should complete inspections both during and after construction to ensure that the system is constructed properly and can support traffic loads.

8. For permeable asphalt and concrete applications, a test panel of the pavement should be provided by the installer prior to construction using the proposed design mix and the specification. This panel should have had 30 days to cure.

9. After construction, the infiltration rate of the permeable pavement installation should be tested using the process outlined in ASTM C1701 for pervious concrete and ASTM D5093 for permeable pavers and the results formally reported to the City.

10. The most current ACI 522.1 specification shall be utilized for each installation.

11. Special consideration should be given to ensure that settlement of the pavement is accounted for. An increase in the pavement elevation of up to one-quarter in. may be required to account for the effects of settlement.

Excavation and Subsurface Investigations

1. Excavation is required to construct the aggregate reservoir and/or the underdrain system.

2. A desktop review of available geologic and geotechnical information should be completed prior to any field tests to determine the suitability of a proposed site for a permeable pavement application.

3. If the desktop analysis does not reveal any issues preventing permeable pavement from being constructed on a proposed site, a geotechnical engineer should scope and perform a subsurface study. Table 8-18 outlines the subsurface investigations which should be considered. The geotechnical engineer may modify the recommendations in Table 8-18 or require additional testing depending on site conditions.

Table 8-18

Subsurface Investigations Guideline for Permeable Pavement Applications

Type of Investigation	Goals	Recommendations[1]
Exploratory Borings/Pits	Characterize subsurface conditions Develop subgrade preparation requirements	At least one boring for every 40,000 square feet of permeable pavement, with a minimum of two borings for each installation Extend boring/pit at least 5 feet below proposed bottom of base Extend boring/pit to at least 20 feet below proposed bottom of base when expansive soils or bedrock could be encountered Temporary monitoring wells may be considered for placement in the borings/pits at sites with shallow groundwater which is encountered or believed to exist
Laboratory Tests	Characterize the subgrade Evaluate infiltration rates Assess subgrade for supporting traffic loads	The following tests may be considered: Moisture content (ASTM D2216) Dry Density (ASTM D2936) Atterburg Limits (ASTM D4318) Gradation (ASTM D6913) Swell Consolidation (ASTM D4546) Subsoil infiltration rate (ASTM D3385) Subgrade Support Hydraulic Conductivity

[1] *UDFCD,* 2010

Aggregate Reservoir

The aggregate reservoir will vary in depth and should be composed of American Association of State Highway and Transportation Officials (AASHTO) No. 57 coarse aggregate with all fractured faces. Stone should be clean with no small particles to clog soils. Additional depth may be used to provide additional storage greater than the WQCV, if site conditions allow. Testing of the aggregate should be completed using the Los Angeles Abrasion test as specified by ASTM C131-06. The results of the LA Abrasion test should be submitted to the City for approval prior to construction of the permeable pavement installation. A porosity of 40-percent or less should be used to calculate storage capacity. The bottom of the aggregate layer should be 2 ft. above the normal groundwater table. Disturbance of the subgrade soil by construction activities should be avoided. A nonwoven geotextile fabric should be placed at the bottom and sides of all aggregate reservoirs, unless a perimeter barrier is required to prevent lateral exfiltration. If placement of pavement does not occur immediately following aggregate installation, the aggregate reservoir should be protected by erosion and sediment control to ensure that sediment is not carried to the reservoir as a result of other construction activities.

The ability of a permeable pavement system to capture water varies depending on if it is installed on a flat or a sloped subgrade. A flat installation, shown in Figure 8-34, is preferred as it has a simpler design and maximizes the volume of water the aggregate reservoir can store per unit area of permeable pavement. By comparison, sloped installations require large partitions or flow barriers. As shown in Figures 8-35 and 8-36, these flow barriers are required to fully utilize the aggregate reservoir for storage and filtration of the WQCV. The ability of the pavement to infiltrate the WQCV is reduced as the velocity of water on the pavement surface increases and potentially exceeds the infiltration rate of the pavement. Because of this, sloped installations with longitudinal slopes greater than 1 percent should be designed for only rain falling directly on the pavement surface. No contributing drainage area should be allowed to drain to the pavement surface for such installations. Flat installations with 1 percent or less longitudinal slopes can receive stormwater flow from adjoining drainage areas in combination with the pavement surface.

A qualified engineer should evaluate the aggregate reservoir design to ensure that it has structural integrity for the traffic loadings required at the permeable pavement site.

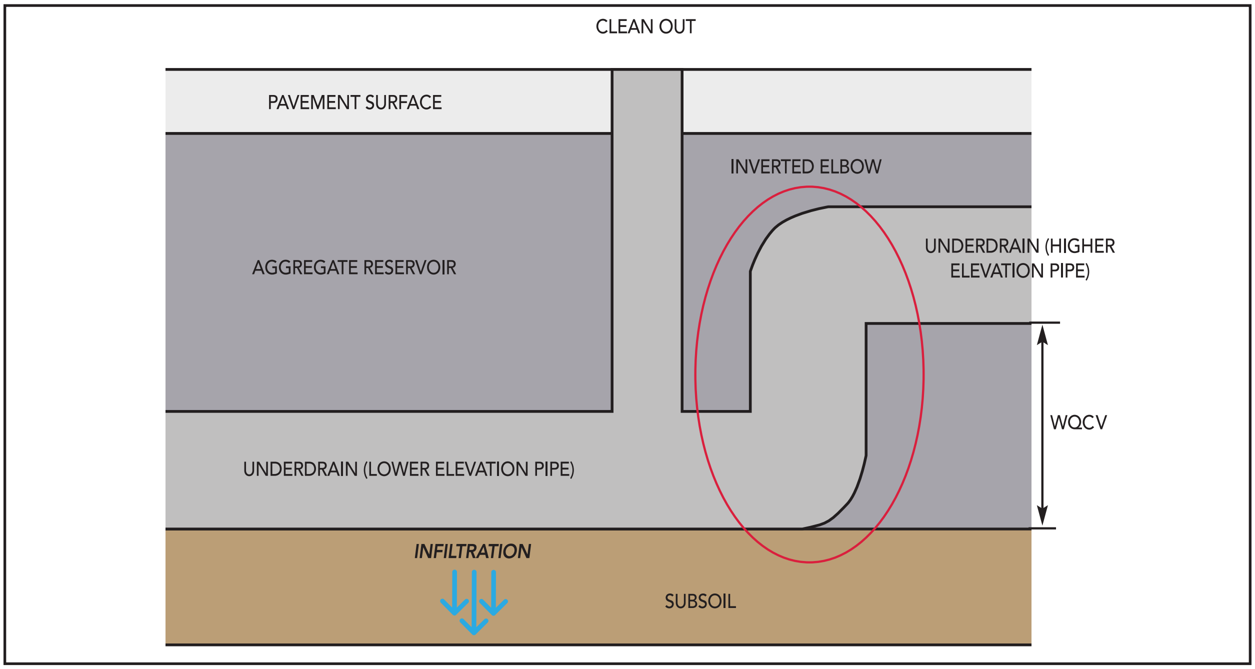

Figure 8-34 Profile View of a Flat Permeable Pavement System

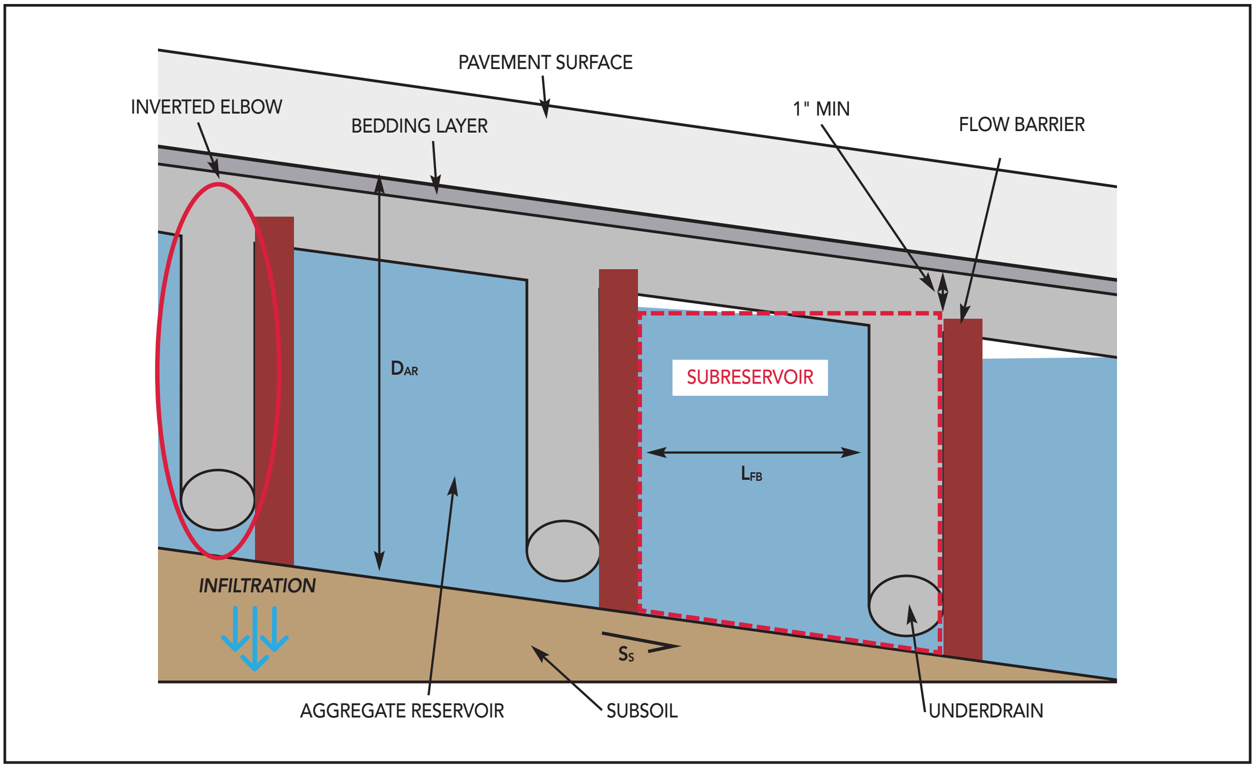

Figure 8-35 Profile View of a Sloped Permeable Pavement System

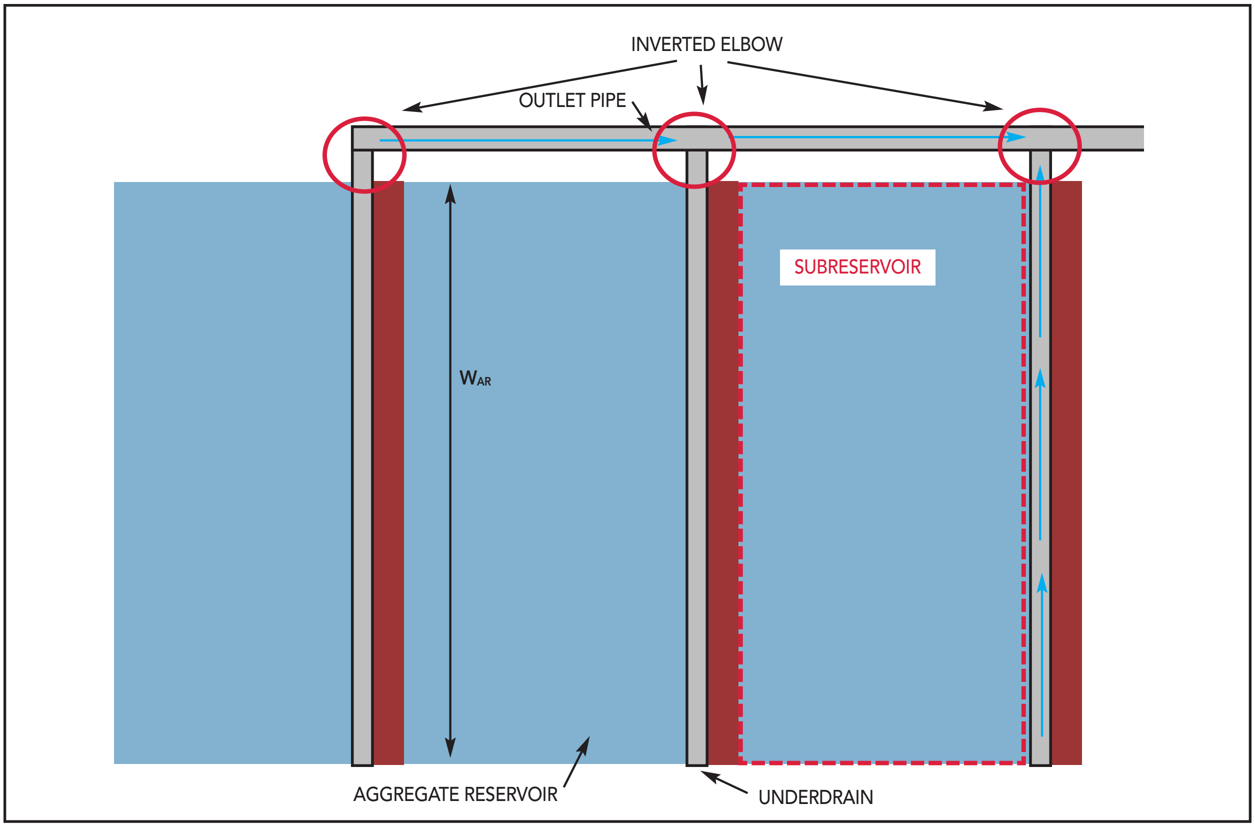

Figure 8-36 Plan View of a Sloped Permeable Pavement System

Perimeter Barriers and Flow Barriers

A perimeter barrier is required for sites where the geotechnical engineer has deemed lateral infiltration a risk to surrounding structures due to expansive soils and/or bedrock. An example of such a scenario would be when the permeable pavement installation is surrounded by conventional pavement. The perimeter barrier should completely surround and contain the permeable pavement system. It should extend from below the aggregate layer to the edge of the installation.

Flow barriers should be provided for sloped permeable pavement installations, as shown in Figure 8-36 These barriers should be buried into the subsoil and extend up into the aggregate base. At least 1-in. of clearance between the top of the barrier and the bottom of the permeable pavement must be maintained. These barriers must be impermeable to keep water from flowing to the lowest point in the aggregate reservoir. If a proprietary system is used for either perimeter or flow barriers, such as an impermeable geomembrane liner, the manufacturer's instructions and specifications for its installation should be followed.

Underdrain System and Outlet Pipe

An underdrain system should be included in the permeable pavement system to ensure that the inflow of stormwater volume is greater than the WQCV or design volumes are conveyed from the aggregate reservoir. The underdrain should run the entire length of the installation so that the invert of the pipe rests on the subgrade soil. Immediately before the pipe leaves the downstream end of the installation, an inverted elbow should be installed, as shown in Figure 8-34. The inverted elbow is a vertical portion of pipe which connects the pipe at the bottom of the aggregate reservoir to a pipe at a higher elevation. The higher elevation pipe should be placed so that its invert allows the WQCV to be stored in the aggregate base, as shown in Figure 8-34.

The underdrain should be made of slotted Polyvinyl Chloride (PVC) pipe meeting the dimensions given below in Table 8-19. The inverted elbow and higher elevation pipe should be made of normal PVC pipe with no slots. The designer should consider requirements to limit peak flow rates to predevelopment conditions (Chapter 2) when sizing the underdrain.

Table 8-19
Slotted Pipe Dimensions

Pipe Diameter	Length Between Slots	Maximum Slot Width	Slot Centers	Open Area Per Foot of Pipe
4 inches	1-1/16 inches	0.032 inches	0.413 inches	1.90 square inches
6 inches	1-3/8 inches	0.032 inches	0.516 inches	1.98 square inches

Note: Variations in these values are expected from available pipe diameters; however, the maximum slot width should not exceed 0.032 inches, and the ability of the pipe to completely drain the reservoir within 48 to 72 hours should be evaluated if large deviations in open area per foot of pipe are encountered.

For sloped permeable pavement installations, an underdrain pipe should be placed in each subreservoir which runs parallel to the flow barrier along the base of the barrier. These should connect to an outlet pipe which spans the entire length of the permeable pavement, as shown in Figure 8-35. For a sloped installation, an inverted elbow is required for each subreservoir, as shown in Figures 8-35 and 8-36. The higher invert outlet pipe has no restrictions and can be constructed using conventional methods with any material pipe normally used for stormwater drainage, so long as it has capacity to drain the aggregate reservoir according to the calculations described in Section 8.6.7.6. The outlet pipe should be constructed using conventional methods, and no material layer is required to surround it.

A cleanout should be placed near the bend of the inverted elbow on the lower elevation pipe in both sloped and flat installations, as shown in Figure 8-34. This will allow for maintenance of the lower elevation pipe.

High Flow Conveyance

High flow conveyance must be provided to divert stormwater away from permeable pavement during large storm events. This conveyance can be located upstream of the pavement or be a structure which conveys overflow from the aggregate reservoir, as with the underdrain system and outlet pipe. It can direct flows to downstream BMPs as part of a treatment train, or discharge to a stormwater conveyance system. The high flow conveyance system should be sized such that all criteria for maximum allowable street encroachment by stormwater, as discussed in Chapter 3: Storm Drainage System, is maintained.

Installation of Concrete Section around Perimeter

Where permeable pavement is installed, a concrete section is required to be installed around the perimeter of the pavement to ensure the pavements are held tightly together under repeated traffic loading. Exceptions can be made in non-vehicular applications subject to City approval. Use of a normal curb section is acceptable in most cases. The bottom of the concrete section should extend to at least the bottom depth of the pavement.

8.6.7.4 Inspection and Maintenance

Maintenance activities for permeable pavements are vital and should be performed at the frequencies indicated below.

As needed

1. Maintain pre-treatment measures (vegetated strips, swales, mechanical devices) to prevent sediment and soil from being carried to the permeable pavement.
2. Monitor to determine if the aggregate reservoir drains properly after typical events via infiltration and underdrain.
3. Remove vegetation growing in the permeable pavement.
4. Ensure surface is free of sediment and clean surface if clogging is observed.

Biannual

1. Clean entire surface by broom, blower, rotary brush, or sweeping.
2. Repair and/or replace joint aggregate after cleaning (for permeable paver applications).
3. Inspect and clean outlet structures.
4. Inspect surface for deterioration or settling.

Every Five Years

Vacuum the entire surface and replace the joint aggregate. For pervious concrete, powerwashing can be completed before vacuuming to loosen sediment. Powerwashing is not recommended for permeable paver systems and vacuuming is the only recommended maintenance procedure. Alternatively, vacuuming could be completed after a rainfall in lieu of powerwashing.

Winter Conditions

Permeable pavements (except for porous gravel) can be snowplowed. Mechanical removal of ice and snow is preferred. Sand should not be placed on permeable pavement, as it can cause clogging. In addition, deicers should be used on a limited basis, as they will flow through the pavement and into groundwater.

8.6.7.5 Submittal Requirements

For review purposes prior to construction, the following minimum submittal requirements are recommended:

1. Drainage area map, including drainage area to the permeable pavement system.
2. Existing contour map with elevations referenced to NAVD 88 and proposed grading layout.
3. Results of geotechnical investigation of site.
4. Plan view with aerial photography of the drainage area with any long term sources of sediment identified, flow paths from these sources to the permeable pavement system, and any pretreatment used to mitigate sediment.
5. Stormwater plan/profile for site.
6. Permeable pavement system plan view and profile view with all components clearly labeled with dimensions.
7. All design calculations (refer to Design Example). If pretreatment is used, all design calculations for the device or devices should be submitted.
8. Detail of proposed underdrain, outlet, and/or high flow conveyance structures with dimensions for construction. Include appropriate design calculations (refer to Design Example).
9. A stormwater control plan which identifies appropriate erosion control measures should be included.
10. Documentation of the infiltration rate of the permeable pavement as determined by ASTM C1701.
11. An as-built survey of the permeable pavement system is recommended to confirm actual construction adheres to approved construction plans.
12. Long-term inspection/maintenance plan.

8.6.7.6 Design Calculations

A short summary of the design calculations is presented below. A detailed design example is outlined in Section 8.6.7.7.

Step 1 Conduct a subsurface investigation to characterize subgrade conditions. The testing should be completed by a geotechnical engineer. If the results of the investigation indicate that an impermeable barrier and/or a perimeter barrier is necessary, the type and material of the barrier(s) should be chosen and the barriers designed.

Step 2 Calculate the WQCV and the V_D. The WQCV is based on 0.5 in. of runoff. Refer to Section 8.3.1 for guidance in calculating the WQCV. If routing of impervious area to pervious area (i.e. cascading planes) occurs within the drainage area of the permeable pavement, the design volume of the permeable pavement can be reduced because a portion of the WQCV from the impervious area is infiltrated. Refer to Section 8.3.4 to determine the reduced WQCV to use the V_D for cascading planes.

V_D = WQCV or if cascading planes exist in permeable pavement drainage area, see Section 8.3.4 for calculation of V_D.

Step 3 Size the depth of the aggregate reservoir. The depth of the aggregate reservoir is based on the design volume (V_D) according to Equation 8-20 for a flat installation and Equations 8-21, 8-22, and 8-23 for sloped installations. Equation 8-20 also accounts for 1-in. of clearance between the top of the flow barrier and the bottom of the permeable pavement surface.

$$D_{AR} = \left(\frac{V_D/_{0.9}}{W_{AR} * L_{AR}} + \frac{1}{12}\right) \quad (8\text{-}20)$$

Where:

D_{AR} = Depth of the aggregate reservoir for flat installations (ft.)
V_D = Design volume (cu. ft.)
W_{AR} = Width of the aggregate reservoir (ft.)
L_{AR} = Length of the aggregate reservoir (ft.)

For a sloped permeable pavement system where the slope of the subsoil is approximately equal to the slope of the permeable pavement surface, subreservoirs with equal storage volume are created. The length between flow barriers and total number of the subreservoirs created by the flow barriers must be determined before the depth of the aggregate reservoir can be determined. Equation 8-21 is used to find the length between flow barriers.

$$L_{FB} < \frac{1.5 * V_D}{s_S * A_{pp} * p} \quad (8\text{-}21)$$

Where:

L_{FB} = Length between flow boundaries (ft.)
V_D = Design volume (cu. ft.)
s_S = Slope of the subsoil (ft./ft.)
A_{pp} = Area of the permeable pavement (sq. ft.)
p = Porosity of the aggregate reservoir, less than or equal to 0.4

Equation 8-22 is then used to determine the number of subreservoirs. When the number of equally sized subreservoirs is not an integer, this signifies that a subreservoir with a smaller volume than the others will be created.

$$n_r = \frac{L_{AR}}{L_{FB}+W_{FB}} \quad (8\text{-}22)$$

Where:

n_r = Number of equally sized subreservoirs
L_{AR} = Length of the aggregate reservoir (ft.)
L_{FB} = Length between flow barriers (ft.)
W_{FB} = Width of the flow boundaries, measured in the direction of flow (ft.)

After calculation of the length between flow barriers and the resulting number of subreservoirs, Equation 8-23 is used to determine the depth of the aggregate reservoir. This equation allows for 1-in. of clearance between the top of the flow barrier and the bottom of the permeable pavement surface.

$$D_{AR} = \left[\frac{V_D}{0.9 * L_{FB} * W_{AR} * \mathrm{P}_{AR} * n_r} + 0.5 * s_S * L_{FB} + \frac{1}{12}\right] \quad (8\text{-}23)$$

Where:

D_{AR} = Depth of the aggregate reservoir for sloped installations (ft.)
V_D = Design volume (cu. ft.)
L_{FB} = Length between flow boundaries (ft.)
W_{AR} = Width of the aggregate reservoir (ft.)
P_{AR} = Porosity of the aggregate reservoir, less than or equal to 0.4
n_r = Number of equally sized subreservoirs
s_s = Slope of the subsoil (ft./ft.)

If a permeable pavement system is designed in which the soil slope does not match the slope of the permeable pavement, the calculation of the depth of aggregate required to store the design volume is not straightforward. This is because the heights of the flow barriers will vary, creating subreservoirs with different storage volumes. Should such an installation be proposed, a depth of aggregate reservoir should be assumed and calculations completed as described in Step 4 for this situation.

If a permeable pavement system is proposed which has a permeable pavement slope that is adverse to the subsoil slope, the height of the flow barriers must allow for 1 in. of freeboard between the bottom of the pavement and the maximum water surface in the subreservoir.

Step 4 Calculate volume reduction (if conditions allow). Further volume reduction can be achieved by increasing the depth of the aggregate reservoir. Once the desired aggregate depth has been determined, find the new V_D based on this depth. Equation 8-24 shows the design volume calculation for a flat installation, and Equation 8-25 shows the calculation for a sloped installation.

$$V_D = 0.9 * \left[\left(D_{AR} - \frac{1}{12}\right) * L_{AR} * W_{AR} * \mathrm{p}\right] \qquad (8\text{-}24)$$

Where:

D_{AR} = Depth of the aggregate reservoir for flat installations (ft.)
V_D = Design volume, flat installation (cu. ft.)
W_{AR} = Width of the aggregate reservoir (ft.)
L_{AR} = Length of the aggregate reservoir (ft.)
p = Porosity of the aggregate reservoir, less than or equal to 0.4

$$V_D = 0.9 * \left[0.5 * s_S * L_{FB} + (D_{AR} - s_s * L_{FB}) - \frac{1}{12}\right] * L_{FB} * W_{AR} * p * n_r \qquad (8\text{-}25)$$

Where:

V_D = Design volume, sloped installations (cu. ft.)
n_r = Number of equally sized subreservoirs
D_{AR} = Depth of the aggregate reservoir for sloped installations (ft.)
W_{AR} = Width of the aggregate reservoir (ft.)
L_{FB} = Length between flow boundaries, ensure that Equation 8-21 is satisfied for the resulting design volume (ft.)
s_s = Slope of the subsoil (ft./ft.)
p = Porosity of the aggregate reservoir, less than or equal to 0.4

As previously described, where the soil slope does not match the pavement slope, calculation of the storage volume of the proposed aggregate reservoir is not straightforward. To calculate the storage volume, Equation 8-25 should be modified by dropping the term n_r and then it should be used to calculate the storage volume of each subreservoir. The design volume is then the sum of the volumes stored in all subreservoirs. The result is then compared to the WQCV to see if adequate storage volume is provided by the assumed depth of aggregate reservoir. If there is not, then a larger depth should be assumed and the calculations completed again.

Step 5 Size the underdrain and outlet pipe. Size the underdrain to drain the aggregate reservoir within 48 to 72 hrs. and design the connection to existing stormwater infrastructure. Equation 8-27 gives the pipe size for a flat installation which has one outlet pipe. Equation 8-27 is also used to size outlet pipes for sloped installation subreservoirs, where V_S is the volume stored in each subreservoir, and not the total design volume. Calculation of V_S is given in Equation 8-26. The pipe diameter should be rounded up to the standard 4-in. or 6-in. PVC pipe sizes listed in Table 8-19. If one 6-in. pipe is not large enough, multiple outlet pipes should be used.

For a sloped installation, Equation 8-26 is used to find the volume stored in each subreservoir when they are all equally sized.

$$V_s = \frac{V_D}{n_r} \qquad (8\text{-}26)$$

Where:

V_S = Volume stored in each subreservoir (cu. ft.)
n_r = Number of equally sized subreservoirs

For sloped installations where n_r is not an integer, a subreservoir with a volume smaller than the others will be created. To determine the volume stored in this smaller subreservoir, Equation 8-26 should first be used to determine the volume stored in the equally sized subreservoirs. The volume of the smaller reservoir is then calculated as the V_S calculated in Equation 8-26 multiplied by the difference between n_r calculated in Equation 8-22 and n_r rounded down to the nearest integer.

Equation 8-27 is used to size the outlet pipes. For the diameter of an outlet pipe from a flat installation or the main outlet pipe from a sloped installation, the volume used to size the pipe is the design volume, V_D. For the subreservoir outlet pipes in a sloped installation, the volume used is the volume stored in each subreservoir, V_S. Equation 8-27 will be used twice in a sloped installation to size the subreservoir outlet pipes and the main outlet pipe from the subreservoir.

$$D_p = 12 * \left(3.47 * 10^{-4} \frac{V * n}{\sqrt{s_p}}\right)^{3/8} \qquad (8\text{-}27)$$

Where:

D_P = Diameter of the outlet pipe (in.)
V = Design volume (V_D) for flat installation to size main outlet pipe receiving flow from subreservoir outlets; or, Volume stored in each subreservoir (V_S) for a sloped installation subreservoir outlet pipe (cu. ft.)
n = Manning's n value for pipe material, 0.009 – 0.011 for PVC
s_p = Slope of the outlet pipe, minimum 0.005 (ft./ft.)

For a sloped installation, the outlet pipe from a subreservoir smaller than the equally sized subreservoirs should be the same size as is required in the equally sized subreservoirs.

Step 6 Size overflow conveyance. Size overflow conveyance to pass large flows up to the 100-year event and to maintain the peak discharge rates during the two-year storm event to existing conditions. If the outlet pipe is to be used for this purpose, recalculate the required diameter of the outlet pipe using other means.

8.6.7.7 Example

Design a permeable pavement system BMP that will be used as a pedestrian path. The permeable pavement system will be 100-ft. long with a 6-ft. width and will intercept flow from 1,050-sq. ft. of drainage area. The drainage area is highly urban with 85-percent impervious area. The pavement will have a longitudinal slope of 3 percent, as prior approval from the City was obtained, and the subsoil slope will match the pavement slope.

Step 1 Conduct a subsurface investigation to characterize subgrade conditions. Testing was completed by a geotechnical engineer. The results of the investigation indicate that an impermeable barrier and/or a perimeter barrier is necessary, the type and material of the barrier(s) should be chosen and the barriers designed to prevent lateral movement of water.

Step 2 Calculate the WQCV and Design Volume (V_D). The drainage area, A_T, is 1,050 sq. ft., or 0.024 ac. The WQCV is based on 0.5 in. of runoff. No routing of impervious area to pervious area (i.e. cascading planes) occurs within the drainage area of the permeable pavement. Refer to Section 8.3.1 for guidance in calculating the WQCV.

$$V_D = \frac{0.5\ in}{12\ in/ft} * 1{,}050\ ft^2 = 43.75\ ft^3$$

Pretreatment

Runoff from the highly urbanized drainage area is likely to carry high sediment loads. Thus, a pretreatment device is strongly recommended. Vegetated filter strips and vegetated swales work to reduce the velocity of runoff and promote settling of suspended sediments. In situations where area is limited, utilize underground manufactured devices to detain and slow runoff (MARC, 2009). For this example, it is assumed that the pretreatment is implemented properly and that all runoff volume is translated completely to the permeable pavement system.

Step 3 Size the depth of the aggregate reservoir. Because this system will be constructed on a sloped surface, flow barriers will be required. The length between flow barriers must be calculated first. Equation 8-21 is used to calculate the maximum length between flow barriers. A porosity of 0.3 is assumed for the aggregate reservoir.

$$L_{FB} < \frac{1.5 * 43.75 ft^3}{0.03\frac{ft}{ft} * 600 ft^2 * 0.3} = 12.15\ ft$$

For this example, it is assumed that a length between flow barriers of 10 ft. is ideal due to constructability constraints and will be used. Because this is less than the calculated 12.15 ft., it satisfies the condition required by Equation 8-21.

Next, the number of subreservoirs is calculated using Equation 8-22. For this example, the permeable pavement length of 100 ft. and a flow barrier with a width of 0.5 ft. is assumed.

$$n_r = \frac{100ft}{10ft + 0.5ft} = 9.5$$

To calculate the depth of the aggregate reservoir, Equation 8-23 is used.

$$D_{AR} = \left[\frac{43.75ft^3}{0.9 * 10ft * 6ft * 0.3 * 9.5} + \left(0.5 * 0.03\frac{ft}{ft} * 10ft\right) + \frac{1}{12}\right] = 0.52ft = 6.2\ in$$

The minimum allowable depth for an aggregate reservoir is 12 in., so a D_{AR} of 12 in. is used.

Step 4 Calculate volume reduction. For this example, volume reduction is attained because the D_{AR} of 12 in. is higher than the 6.2 in. depth required to store the WQCV. Because this is a sloped installation, the volume of water the aggregate reservoir stores, is the total volume captured in each subreservoir. To calculate the total volume of storage capacity in the entire aggregate reservoir, Equation 8-25 is used.

$$V_D = 0.9 * \left[0.5 * 0.03\frac{\text{ft}}{\text{ft}} * 10\text{ ft} + \left(1 - 0.03\frac{\text{ft}}{\text{ft}} * 10\text{ ft}\right) - \frac{1}{12}\right] * 10\text{ ft} * 6\text{ ft} * 0.3 * 9.5 = 118\text{ ft}^3$$

Step 5 Size the underdrain and outlet pipe. For this example, the underdrains for the subreservoirs must be sized, as well as the outlet pipe taking flow from each of the subreservoir underdrains. Equation 8-27 is used to find the diameters for both types of pipes. For the subreservoir outlet pipes, the volume in each subreservoir is used in the equation, as calculated using Equation 8-26.

$$V_s = \frac{118\text{ft}^3}{9.5} = 12.4\text{ ft}^3$$

This value is then used in Equation 8-27 to find the size of the subreservoir outlet pipes. The minimum allowed slope for the pipes is 0.5%.

$$D_p = 12\left(3.47 * 10^{-4}\frac{12.4\text{ ft}^3 * 0.01}{\sqrt{0.005\frac{\text{ft}}{\text{ft}}}}\right)^{3/8} = 0.75\text{ in}$$

The calculated pipe diameter of 0.75 in. is rounded up to 4-in., in accordance with Table 8-19. The sizing of the outlet pipe uses the total design volume and the longitudinal slope of 3% in Equation 8-27:

$$D_p = 12\left(3.47 * 10^{-4}\frac{12.4\text{ ft}^3 * 9.5 * 0.01}{\sqrt{0.03\frac{\text{ft}}{\text{ft}}}}\right)^{3/8} = 1.2\text{ in}$$

The calculated pipe diameter of 1.2 in. is rounded up to 4 in.

Step 6 Size overflow conveyance. Overflow conveyance is sized to pass flows up to the 100-year event using control structures upstream of the permeable pavement installation. In addition, peak discharge rates are maintained during the two-year storm event to match existing conditions.

8.6.7.8 References

City of Chicago, Illinois. 2012. *Stormwater Management Ordinance Manual*: http://www.cityofchicago.org/dam/city/depts/water/general/Engineering/SewerConstStormReq/2012StormManual.pdf

Geosyntec Consultant and Wright Water Engineers, Inc. 2008. Overview of Performance by BMP Category and Common Pollutant Type: ISBMPD (1999-2008): http://www.bmpdatabase.org/Docs/Performance%20Summary%20Cut%20Sheet%20June%202008.pdf

MARC. 2009. Manual of Best Management Practices for Stormwater Quality, Section Edition. http://kcmetro.apwa.net/chapters/kcmetro/specs/APWA_BMP_ManualAUG09.pdf.

City of Omaha. 2006. Omaha Regional Stormwater Design Manual: http://www.ci.omaha.ne.us/pw/for-contractors-a-consultants

UDFCD. 2010. Urban Storm Drainage Criteria Manual, Best Management Practices Vol. 3. Denver, Colorado: http://www.udfcd.org/downloads/down_critmanual.htm (listings by volume)

8.6.8 Retention Wet Ponds

The primary components of a retention wet pond include the permanent pool, the littoral bench surrounding the permanent pool, and the live storage volume above the permanent pool. The live volume is sized such that the WQCV displaces a portion of the permanent pool and is released within 12 hrs. of a storm event. The hydraulic residence time of the permanent pool is typically two weeks or more. The primary pollutant removal mechanism is settling as stormwater runoff resides in the permanent pool, but pollutant uptake, particularly of nutrients, also occurs to some degree through biological and chemical activity in the pond (CASQA, 2003). Wet ponds are a highly utilized stormwater BMP practice due to community acceptance and amenity value (Schuler et al., 2007). Retention wet ponds should be used for drainage areas of 10 ac. or more and are typically not used in retrofits due to their typically large area requirement.

Design Considerations	
Location characteristics (Slope, Soil Type)	Slope: Sites < 15% Soil type C, D or a liner may be used
Contributing drainage area	Greater than 10 acres
Design Size	1-3% Drainage area[1] Minimum (L:W) is 3:1
Median Effluent Concentrations[2]	TSS = 13 mg/L, TP = 0.12 mg/L, TN = 1.43 mg/L, Cu = 6.4 µg/L, Fecal Coliform = 133 cfu / 100 mL
Implementation and Maintenance Considerations	
Potential for use with other BMPs	Downstream of source control BMPs, or swales and filter strips
Maintenance	Low – periodic sediment/debris removal, vegetation maintenance

[1] Department of Environmental Protection – Bureau of Watershed Management (DEP), 2006
[2] Geosyntec Consultants and Wright Water Engineers, Inc 2008

8.6.8.1 General Application

Retention wet ponds can be used to improve stormwater runoff quality from roads, parking lots, residential neighborhoods, commercial areas, and industrial sites. A retention wet pond is more applicable to treat larger tributary areas than other BMPs, and can be utilized as a second BMP in a treatment train. Retention wet ponds may be used for a smaller site if the drainage area is sufficient for sustaining a permanent pool. Wet ponds may also be incorporated into an extended storage or a detention pond design for flow control (Metro Council, 2001) and work well in conjunction with other BMPs such as upstream source controls.

Under the proper conditions, retention wet ponds can satisfy multiple objectives, including water quality improvement, erosion protection, creation of wildlife and aquatic habitats, and recreational and aesthetic provision (UDFCD, 2005). Wet ponds are generally ineffective at reducing runoff volumes by themselves (Metro Council 2001) but can be used to reduce runoff flow rates if additional flood control volume is provided above the permanent pool (UDFCD, 2005). Wet ponds also provide some volume reduction through evaporation, typically less than 5-percent (Strecker et al., 2004 as referenced by Schuler et al., 2007).

8.6.8.2 Advantages and Disadvantages

Advantages	Disadvantages
Cost-effective for large drainage areas	Large land area requirement
Removal of both solid and soluble pollutants (Metropolitan Council, 2001)	Inadequate baseflow could result in high salts, nutrients and algae in effluent
Highly effective at nutrient removal	Large storm events could cause low dissolved oxygen or sediment re-suspension
Minimal risk of groundwater contamination	Attract waterfowl, which may increase downstream nutrient loading and bacteria
Sediment removal is less frequent than other BMPs (Metropolitan Council, 2001)	Minimal impact on runoff volume reduction
May provide recreation, wildlife habitat, aesthetics and/or open space	Not suitable for small drainage areas or most retrofits
	Thermal pollution may occur

8.6.8.3 Design Requirements and Considerations

Previous studies have shown that 90-percent of pollutant removal in a wet pond occurs between rainfall events (MD DEQ, 1986 as cited in Metro Council, 2001), and modeling results indicate that two-thirds of the sediment, nutrients, and trace metal loads are removed within the first 24 hrs. after a storm event (Metro Council, 2001). Correct permanent pool storage volume, live storage volume, basin configuration, and outlet sizing are thus very important.

The procedure for designing a retention wet pond is outlined in the following sub-sections. The design components are described in the order of construction starting with excavation for construction of the permanent pool storage area, pretreatment forebay, and inlet/outlet structures.

Overall Design Guidance

- Retention wet ponds should not be constructed until the entire drainage area is permanently stabilized against erosion and sedimentation, or a pre-treatment practice is implemented. Heavy sediment loads to the pond will reduce effectiveness and require premature dredging of the pond to restore its performance.

- To maintain baseflow to the permanent pool in between rainfall events, the minimum drainage area to the detention wet pond should be at least 10 ac. Other environmental conditions such as average ET rates and soil infiltration rates should be considered. High ET and infiltration rates are undesirable for a detention wet pond. Infiltration should be prevented in more conductive soils with a liner to sustain a permanent pool.

Basin Configuration

- To encourage settling/sedimentation, designers should maximize the horizontal and vertical flowpath between the inlet and outlet and avoid “dead zones” in the basin design (Metro Council, 2001). A minimum length to width ratio of 3:1 is recommended. Other ways to avoid short-circuiting include a wedge-shaped pond with inflows on the shallow end (DEP, 2006).

Permanent Pool Storage Area & Live Volume (WQCV)

- Retention wet ponds should be designed such that the live volume (WQCV) is released over 12 hrs. (EPA, 2006).

- The pond depth is an important design factor as it controls sediment deposition. The optimum pond depth should range from 2 to 3 ft. minimum, up to 12 ft. maximum, with an average depth of 4 to 8 ft. Shallow wet ponds tend to have more effective solids removal than their deeper counterparts. However, in pools less than 2 ft. deep, wind will likely re-suspend particles (Metro Council, 2001). If the permanent pool is designed to support fish, sufficient permanent pool depth should be maintained.

- Side slopes of the retention wet pond should be no greater than 4:1. Embankment side slopes may be 3:1 with site-specific approval.
- Design of the permanent pool volume should allow for 14 days hydraulic residence time to allow for particulate settling and nutrient uptake. A longer hydraulic residence time will encourage better settling and sedimentation. This is accomplished by sizing the pool using regional precipitation data and characteristics of the tributary area. These considerations are illustrated in the design example at the end of this section.

Inlet

1. Typical inlet structures include, but are not limited to, drop manholes, rundown chutes, baffle chutes, and pipes with impact basins (Muthukrishnan et al., 2006).

2. All inlets should include some type of energy dissipater to reduce sediment resuspension (MARC, 2009).

Forebay/Pretreatment

1. Wet pond design should include pretreatment to capture sediment. For ponds greater than 4,000 cu. ft. (Metro Council, 2001), a forebay is recommended. For smaller ponds, the design should include a filtration BMP, such as swale or filter strip.

2. The forebay should be a 4 to 6 ft. deep cell delineated by a barrier and should be sized to contain at least 10 percent of the design volume (MARC, 2009).

3. The minimum length to width ratio of the forebay should be greater than 2:1 to prevent short-circuiting (Muthukrishnan et al., 2006).

Littoral Bench

1. The littoral bench slopes should be no steeper than 2:1 (Metro Council, 2001).

2. The littoral bench should extend inward at least 10 ft. from the perimeter of the permanent pool and should be between 6 in. to 12 in. below the permanent pool surface (CASQA, 2003; UDFCD, 2005).

3. The slope of the littoral bench should not exceed 6:1. The bench should be planted with native wetland vegetation to promote biological uptake of nutrients and dissolved pollutants and reduce the formation of algal mats. To maximize biological uptake but prevent plants from encroaching on the open water surface, the vegetated littoral bench should comprise 25 percent to 50 percent of the permanent pool surface area (Nashville Metropolitan-Davidson County [Nashville], 2006).

Outlet Structure

1. Outlet control devices should be designed to prevent clogging, allow maintenance and provide temperature benefits. This can be achieved with a reverse sloped outlet where the invert of the outlet is at the permanent pool elevation, but the water enters the outlet 2 to 7 ft. below the normal water surface.

2. Outlet devices are generally multistage structures with pipes, orifices, or weirs for flow control. Orifices, if used, should be at least 4 in. in diameter and should be protected from clogging by using a trash rack, well screen or other method (DEP, 2006).

3. Outlet devices should be installed in the embankment for accessibility. If possible, outlet devices should enable the normal water surface to be varied. This allows the water level to be adjusted (if necessary) seasonally, as the wet pond accumulates sediment over time, if desired grades are not achieved, or for mosquito control (DEP, 2006).

4. An emergency drain to completely drain the permanent pool for maintenance within 24 hrs. should be incorporated into the design (DEP, 2006).

Siting Considerations

1. Do not locate on fill sites or on/near steep slopes. Depending on soils, bottom modifications can include compaction, incorporating clay into the soil or an artificial liner (Nashville, 2006)

2. The design water surface depth should be a minimum of 20 ft. away from property lines and building structures or per agency specification. A greater distance may be necessary when the retention facility may compromise foundations or slope stability (KC Metro APWA, 2006)

3. For public safety considerations, fences and landscaping should be used to impede access to the facility. The facility should be contoured to eliminate drop-offs or other hazards.

8.6.8.4 Inspection and Maintenance

Maintenance activities for retention wet pond include short-term and long-term maintenance tasks.

Short Term: Year 1 – Year 3 (Post-Installation)

1. Water young plants and seedlings a minimum of weekly for the first three months. Watering may be required more frequently during the summer months (June through August) during the first year. Try to maintain at least a 70-percent vegetation density to ensure stability.

2. Eliminate weeds using spot application of herbicide throughout the first year.

3. Check for signs of erosion or instability and make sure that aesthetics are maintained throughout the BMP footprint

4. After rainfall equaling or exceeding 0.5 in.:

    a. Ensure that vegetation and other erosion stabilizing mechanisms are intact and check inlet/outlet structures and surrounding area for signs of erosion or instability

    b. Inspect all inlet/outlets and repair or restore clogged flow structures as needed

    c. Remove sediment and debris from pretreatment BMP or Forebay

    d. Confirm drainage system functions and bank stability.

5. At one year after installation, inspect vegetation and all other supporting structure. Replace dead plants and remove invasive plant species.

6. Removed sediments should be tested for toxicants and should comply with local disposal requirements.

Long Term: Year 3 – later

1. In early spring, mow or trim vegetation to an approximate height of 6 in. above grade. Remove accumulated debris.
2. Inspect vegetation one to two times each year and remove weeds and invasive species.
3. Trim back or remove overgrown vegetation.
4. Repair or restore clogged high flow structures as needed.
5. At least twice a year, check for subsidence, erosion, tree growth on the embankment, sediment accumulation around the outlet, and erosion within the basin and banks.
6. Removed sediments should be tested for toxicants and should comply with local disposal requirements.

8.6.8.5 Submittal Requirements

For review purposes prior to construction, the following minimum submittal requirements are recommended:

1. Drainage area map, including drainage area to the retention wet pond.
2. Existing and proposed contour map of site (1-ft. contours recommended). Additional spot elevations may be helpful.
3. Geotechnical investigation of site (soil borings, water table location).
4. Stormwater plan/profile for site.
5. Retention wet pond plan view and profile view. Components clearly labeled with dimensions.
6. Hydrologic calculations (refer to Design Example) and average annual water budget analysis.
7. Detail of any proposed outlet and overflow structures with dimensions for construction. Include appropriate design calculations (refer to Design Example).
8. Vegetation plan with schedule for installation and initial maintenance. Appropriate erosion control measures should be included.
9. An as-built survey of the retention wet pond is recommended to confirm actual construction adheres to approved construction plans.
10. Long-term inspection/maintenance plan with responsible party and dedicated funding source.

8.6.8.6 Design Calculations

A short summary of design calculations is presented below. A detailed design example is outlined in Section 8.6.8.7.

Step 1 Determine the WQCV and retention wet pond design live-storage volume (V_D). The WQCV is based on 0.5 in. of runoff. If routing of impervious area to pervious area (i.e. cascading planes) occurs within the drainage area of the retention wet pond, the design volume of the retention wet pond can be reduced because a portion of the WQCV from the impervious area is infiltrated. Refer to Section 8.3 to determine the reduced WQCV to use for sizing the retention wet pond.

V_D= WQCV or if cascading planes exist in EDDB drainage area, see Section 8.3.4 for calculation of V_D.

Step 2 Determine the Rational runoff coefficient for the tributary area.

$$C = 0.3 + 0.6 * (\frac{I}{100}) \quad (8\text{-}28)$$

Where:

C = Rational runoff coefficient (unitless)
I = Percent Imperviousness of Drainage Area (unitless)

Step 3 Determine the permanent pool volume. Determine the permanent pool volume required to provide a minimum detention time of 14 days.

$$V = \frac{C * A_T * R_{14}}{12\ in} \quad (8\text{-}29)$$

Where:

V = Permanent pool volume (ac.-ft.)
C = Rational runoff coefficient (unitless)
A_T = Tributary area (ac.)
R_{14} = 14-day wet season rainfall for Omaha, NE (1.6 in.)

Step 4 Size the outlet. Determine the outlet type and size such that the V_D is detained and released over 12 hrs. Outlet design must also consider facility dimensions and site constraints. For sizing all retention wet pond outlets, first calculate the average discharge rate for the V_D using Equation 8-30.

Average Discharge Rate

$$Q_{AVG} = \frac{V_D * 43{,}560 \frac{ft^2}{acre}}{12\ hrs * 3{,}600 \frac{sec}{hr}} \quad (8\text{-}30)$$

Where:

Q_{AVG} = Average discharge rate for the V_D (cfs)
V_D = Design live-storage volume for retention wet pond (ac.-ft.)

Next the Q_{AVG} is used to calculate dimensions for a single orifice or v-notch weir outlets.

Single Orifice

$$D_O = 2\left(\frac{Q_{AVG}}{C_O \times \pi \times (2 \times g \times H_{avg})^{0.5}}\right)^{0.5} * \frac{12\ in}{ft} \quad (8\text{-}31)$$

Where:

D_O = Orifice diameter (in.)
Q_{AVG} = Average discharge rate for the V_D (cfs)
V_D = Design live-storage volume for retention wet pond (ac.-ft.)
C_O = Orifice discharge coefficient, Where C_O = 0.66 for weir plate thickness ≤ orifice diameter, and 0.80, otherwise
g = acceleration due to gravity (32.2 ft./s.)
H_{avg} = Average head of V_D(ft.)

V-notch Weir

Dimensions of the V-notch weir outlet include the V-notch weir angle and the top width of the V-notch opening.

$$\theta = 2 * \frac{180}{\pi} * \tan^{-1}\left(\frac{Q_{AVG}}{C_V * H_{avg}^{5/2}}\right)$$ ** Note: set angles to radians on calculators and spreadsheets *(8-32)*

$$W_V = 2 * Z_{max} * \tan\left(\frac{\theta * \pi}{2 * 180}\right)$$ ** Note: set angles to radians on calculators and spreadsheets *(8-33)*

Where:

θ	=	Required V-notch weir angle, 20° minimum (degrees)
Q_{AVG}	=	Average discharge rate for the V_D (cfs)
C_V	=	V-notch weir coefficient (2.5)
H_{2yr}	=	Average head of V_D volume over orifice invert (ft.)
W_V	=	Top width of V-notch weir (ft.)
Z_{max}	=	Max V_D depth above outlet (ft.)

Step 5 Size Outlet Protection to avoid clogging. If the chosen outlet structure discharges to a closed system, or if debris in the outlet works would be difficult to remove, determine the appropriate outlet protection to avoid clogging. Outlet protection to avoid clogging may include trash racks, hoods, or reversed slope pipes. Follow guidance in Chapter 6 Storage Facilities to estimate the minimum trash rack size versus outlet diameter or minimum dimensions.

Step 6 Determine the forebay volume. The minimum forebay volume should be 10 percent of the design volume (V_D).

Step 7 Determine the littoral bench dimensions. Determine littoral bench dimensions based on permanent pool volume and littoral bench design guidelines.

8.6.8.7 Example

Design retention wet pond to accept runoff from an 18-ac., single-family residential development (30% impervious). The developer would like to design a wet pond with a single orifice outlet.

Step 1 Determine the WQCV and retention wet pond design live-storage volume (V_D). The drainage area to the retention wet pond is 18 ac. Using 0.5 in. of runoff, the WQCV is calculated as:

$$WQCV = \frac{0.5\ inches}{12\ inches} * 18\ acres = 0.75\ acre - feet$$

Routing of impervious area to pervious area (i.e. cascading planes) reduces the design volume of the retention wet pond because a portion of the runoff from the impervious area is infiltrated. When cascading planes are used, estimate the retention wet pond design volume using Section 8.3.4. For this example, no cascading planes are present so the design live-storage volume (V_D) is equal to the WQCV.

$$V_D = WQCV = 0.75\ acre - feet$$

Step 2 Determine the Rational Runoff Coefficient for the tributary area. To calculate the permanent pool volume, the rational runoff coefficient must first be calculated. Using Equation 8-28:

$$C = 0.3 + 0.6 * \left(\frac{30}{100}\right) = 0.48$$

Step 3 Determine the permanent pool volume. Determine the permanent pool volume required to provide a minimum detention time of 14 days. Using Equation 8-29, the permanent pool volume is:

$$V = \frac{0.48 * 18\ acres * 1.6\ inches}{12\ inches} = 1.15\ acre - feet$$

Step 4 Size the outlet. The developer would like to install a single orifice outlet for this particular wet pond. To size the outlet, first the water quality discharge should be calculated using Equation 8-30.

$$Q_{AVG} = \frac{0.75\ acre - ft * 43{,}560 \frac{ft^2}{acre}}{12\ hrs * 3{,}600 \frac{sec}{hr}} = 0.76\ cfs$$

Then, the orifice diameter should be calculated using Equation 8-31. The desired average depth of the V_D above the outlet is 2 ft.

$$D_O = 2\left(\frac{0.76\ cfs}{0.66 * \pi * (2 * 32.2 * 2\ ft)^{0.5}}\right)^{0.5} * \frac{12\ in}{ft} = 4.3\ inches$$

Step 5 Size Outlet Protection to avoid clogging. For this example, the orifice outlet discharges to a closed system; therefore, a trash rack is provided. The openings for the trash rack should be calculated based on the orifice diameter calculated. The purpose of sizing openings for the trash rack is to find the optimal size of the openings to let the required discharge pass while protecting the outlet from clogging. First the area of the orifice opening is calculated.

$$A_{ot} = \frac{1}{4}\pi * 4.3^2 = 14.5\ in^2$$

Next, using Figure 6-13 in Chapter 6, the minimum area that the trash rack should cover around the outlet is calculated:

$$A_t = 14.5 * 77e^{-0.124 * 4.3} = 655\ in^2, or\ 4.5\ ft^2$$

Step 6 Determine the forebay volume. The minimum volume of the forebay is equal to 10-percent of the design volume (V_D). With a design volume of 0.75 ac.-ft. the forebay volume is 0.075 ac.-ft. The minimum length to width ratio should be greater than 2:1.

Step 7 Determine the littoral bench dimensions. The littoral bench slopes should be no steeper than 2:1 and should extend inward at least 10 ft. from the perimeter of the permanent pool. The benches should be between 6 in. to 12 in. below the permanent pool surface.

8.6.8.8 References

CASQA. 2003. *California Stormwater Quality Association Stormwater Best Management Practice Handbook*: http://www.dot.ca.gov/hq/construc/stormwater/manuals.htm

DEP. 2006. Pennsylvania Stormwater Best Management Practices Manual-Section 6.6.2: Wet Pond/Retention Basin. Document Number: 363-0300-002: http://www.jonestownship.com/Stormwater%20BMP.pdf

USEPA. 2006. National Pollutant Discharge Elimination System Fact Sheet Series – Wet Ponds: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=68

Geosyntec Consultant and Wright Water Engineers, Inc. 2008. Overview of Performance by BMP Category and Common Pollutant Type: ISBMPD (1999-2008): http://www.bmpdatabase.org/Docs/Performance%20Summary%20Cut%20Sheet%20June%202008.pdf

KC Metro APWA. 2006. Division V Section 5600 Storm Drainage Systems and Facilities

Metro Council. 2001. Minnesota Urban Small Sites BMP Manual-Retention Systems: Wet Ponds. St. Paul, MN. Pgs. 3-251 to 3-265: http://www.metrocouncil.org/environment/water/bmp/manual.htm

MARC. 2009. Manual of Best Management Practices for Stormwater Quality –Second Edition. Section 8.10 Extended Wet Detention. http://kcmetro.apwa.net/chapters/kcmetro/specs/APWA_BMP_ManualAUG09.pdf

Muthukrishnan, S. Field, R. and Sullivan, D. 2006. The use of best management practices (BMPs) in urban watersheds (ed. 1, 118-124) Field, R., Tafuri, A., Muthukrishnan, S., Acquisto, B., and Selvakumar, A. (Eds.), Pennsylvania, U.S.: Destech Publications

Nashville. 2006. Stormwater Management Manual Volume 4: Best Management Practices: http://www.nashville.gov/stormwater/regs/SwMgt_ManualVol04_2009.asp

Schuler, T.; Hirschman, D.; Novotney, M.; and Zielinski, J. 2007.. Urban Subwatershed Restoration Manual No. 3 – Urban Stormwater Retrofit Practices. Volume 1.0. Office of Wastewater Management Center for Watershed Protection

UDFCD. 2010. Urban Storm Drainage Criteria Manual, Best Management Practices Vol. 3. Denver, Colorado: http://www.udfcd.org/downloads/down_critmanual.htm (listings by volume).

8.6.9 Soil Conditioning

Soil conditioning is a post-construction practice intended to improve disturbed and low organic soils through mechanical compaction reduction and compost amendment in order to increase macroporosity and improve water retention. This practice is intended to reduce the generation of runoff from the area where it is implemented.

Design Considerations	
Location characteristics (Slope, Soil Type)	Slope: Sites < 10% Soil type: All Outside of tree dripline. Water table > 1.5 feet from surface Greater than 10 feet from building foundation.
Contributing drainage area	This BMP is not designed to control runoff from other areas. It is designed to control the rainfall falling on it.
Design Size	Soil depth of at least 6 inches.
Pollutant Removal Efficiency[1,2]	TSS = 65%, TKN = 72%, NH4-N = 54%, TP = 20-76% Dissolved P = 89%
Implementation and Maintenance Considerations	
Potential for use with other BMPs	Upstream of structural BMPs
Maintenance	Vegetation establishment, maintenance, and weed management.

[1] Median Effluent Concentrations were not available for this BMP.

[2] Tyler, et.al. 2010.

8.6.9.1 General Application

Soil conditioning is acceptable for any pervious area where the soils have lost their inherent infiltration and water storage capacity through compaction and disturbance. This BMP will be most applicable for large site areas proposed for turfgrass, low maintenance lawn, or nature prairie plantings. It can also be applied to areas within landscape beds given all specifications are met for soil conditioning and tilling within the bed areas, and the beds are not bermed with slopes greater than 10%. Soil conditioning for the purpose of stormwater management should be used:

1. When slopes are less than 10%
2. Outside the dripline of a tree, to avoid damaging the root system
3. When existing soils are not saturated or seasonally wet
4. Greater than ten (10) ft. of the foundation of a building
5. When the water table is greater than 1.5 ft. of the soil surface
6. Where runoff velocities will not damage or undermine vegetation

8.6.9.2 Advantages and Disadvantages

Advantages	Disadvantages
Reduces runoff peaks and volumes for small storm events and the initial rainfall of larger events.	Compost must meet specifications or performance may be diminished
Simple design, construction, and maintenance	If compaction occurs on soil conditioned area performance will be diminished
Encourages healthy plant growth	Cannot be used to control runoff from off-site areas.
Increases biological diversity and activity in the soil complex	

8.6.9.3 Design Requirements and Considerations

The following steps should be followed to properly condition disturbed soils for stormwater management.

- Step 1 – Ensure site conditions are dry prior to beginning the soil conditioning process to avoid further compacting soils.
- Step 2 – Remove existing vegetation, including turf, and till the ground to a minimum depth of 6 in.
- Step 3 – Place a 3-in. deep layer of specified compost on top of the tilled ground and till compost into a depth of 6 in. of existing soil. See Table 8-20 for compost specifications.
- Step 4 –Fine grade the site with minimum equipment passes (no more than two (2) passes) to reduce the potential for soil compaction. Finalizing all preliminary critical spot elevation, slopes and positive drainage criteria for the site should be completed as much as possible prior to finish grading in order to ensure that equipment compaction is minimized after soil is worked an amended.
- Step 5 – Firm soil using one pass of a 50-pound roller if vegetative cover will be drill seeded or plugged to help ensure successful plant establishment.
- Step 6 – Establish vegetative cover immediately after finish grading and take steps to prevent erosion during establishment, including but not limited to installing erosion control blankets, silt fence or straw waddles. Vegetation may be sodded, seeded, or plugged. For seeding or plugging, all standard procedures shall be followed for the appropriate mulching of bare soil surface areas until vegetation is fully established. Expectations of early plant performance must be understood (i.e. – there may be a short period of plant stress due to nutrient cycling in compost) and incorporated into the management plan (see Step 7).
- Step 7 – A management plan is required in the PCSMP for all areas that have undergone soil conditioning. The plan must be followed during the first two years of plant establishment. Components include weed management, spot reseeding, maintaining moisture during germination and initial establishment, inspection and intensive rainfall events, and the removal of erosion control measures as needed.

Compost Specifications

The compost used in soil conditioning shall be derived from plant material, and the result of biological degradation and transformation of plant derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stabilized with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the criteria presented in Table 8-20, as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor. OmaGro is a locally produced compost product that is acceptable for use in soil conditioning.

Table 8-20
Compost Criteria for Soil Conditioning

Compost Criteria
One hundred percent of the material must pass through a half inch screen
The pH of the material shall be between 6 and 8
Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0%by weight.
Organic matter should be between 35 and 65 %
Soluble salt content shall be less than 6.0 mmhos/cm
Maturity should be greater than 80 %
Stability shall be 7 or less
Carbon/nitrogen ratio shall be less than 25:1
Trace metal test result = “pass”
The compost must have a dry bulk density ranging from 40 to 50 lbs/ft^3.

Vegetation

Perennial grasses are usually specified and native grasses are preferred. A range of plant material can be used in conditioned soils areas including legumes, deep rooted grasses, shrubs, and trees.

8.6.9.4 Inspection and Maintenance

Short Term: Year 1 – Year 3 (Post-Installation)

1. Water vegetation a minimum of weekly for the first three months. Watering may be required more frequently during the summer months (June through August) during the first year. Try to maintain at least a 70% vegetation density to ensure stability.

2. Eliminate weeds manually or by using spot application of herbicide throughout the first year.

3. Check for signs of erosion or instability and make sure that aesthetics are maintained throughout the soil conditioned area.

4. After rainfall equaling or exceeding 0.5 in., ensure that vegetation and other erosion stabilizing mechanisms are intact.

5. At one year after installation, inspect vegetation and all other supporting structures. Replace dead plants and remove invasive plant species.

Long Term: Year 3 – later

1. In early spring, mow or trim vegetation to a height no less than 6 in. Remove accumulated debris.

2. Inspect vegetation one to two times each year and remove weeds and invasive species.

3. Trim back or remove overgrown vegetation.

4. At least twice a year, check for subsidence, erosion, and sediment accumulation.

8.6.9.5 Submittal Requirements

For review purposes prior to construction, the following minimum submittal requirements are recommended:

1. Area of proposed soil conditioning and any proposed or existing downstream BMPs.
2. Existing and proposed contour map of site (1-ft. contours with elevations tied to NAVD 1988 datum recommended). Additional spot elevations may be helpful.
3. Geotechnical investigation of site (soil borings, water table location).
4. Vegetation plan with schedule for installation and initial maintenance. Appropriate erosion control measures should be included.
5. Long-term inspection/maintenance plan with responsible party and dedicated funding source.

8.6.9.6 Design Calculations

Equation 8-31 can be used to calculate the volume of compost required for an area proposed for soil conditioning.

$$V_{compost} = A_{SC} * d_{compost} * \frac{1\,ft}{12\,inches} * \frac{1\,yd^3}{27\,ft^3} \qquad (8\text{-}34)$$

Where:

$V_{compost}$ = volume of compost needed for soil conditioning, yd.^{3}
A_{SC} = Area of proposed soil conditioning, ft.^{2}
$d_{compost}$ = depth of compost, in.

8.6.9.7 Example

Calculate the volume of compost necessary to implement 5,000 ft.^{2} of soil conditioning, to be planted with turf grass. Use the recommended compost depth of 3 in.

$$V_{compost} = 5{,}000\,ft^2 * 3\,inches * \frac{1\,ft}{12\,inches} * \frac{1\,yd^3}{27\,ft^3} = 46.3\ yards\ of\ compost$$

8.6.9.8 References

Tyler, Rodney. Marks, Alexander. Faucette, Britt.2010. The Sustainable Site – The Design Manual for Green Infrastructure and Low Impact Development.

Virginia Department of Conservation and Recreation. 2010. Design Specification No. 4 Soil Compost Amendment Version 1.7.

8.7 Lot-Level/Homeowner Non-Structural Best Management Practices

Stormwater pollution is the untreated contaminated water that drains from lawns, parking lots and streets through the municipal storm drain system. When harsh chemicals from lawns and toxic substances from spills enter waterways, harmful pollutants kill fish, destroy wildlife habitats, decrease aesthetic value and contaminate the water people use as a source for drinking, boating and swimming. Non-structural BMPs that help reduce the quantity of pollutants from reaching the waterways include but are not limited to; using sustainable methods of lawn care and landscape maintenance, reducing trash and pet waste, and sweeping and cleaning impervious surfaces (University of Nebraska-Lincoln Water, 2011).

8.7.1 Lawn Care and Landscape Maintenance

Stormwater runoff from a healthy dense lawn (with up to medium dense soil) rarely occurs, except during intense rainfall events (University of Minnesota, 2006: Bierman, et al., 2010). In order to maintain a healthy lawn, it is important to select lawns that are adapted to the region's climate. The Nebraska Master Gardener Program, hosted by the University of Nebraska-Lincoln, provides a link to a sustainable urban landscape website hosted by the University of Minnesota. The University of Minnesota website contains links to assist in lawn management and sustainable landscape design. Additionally, maintenance is important to keep a healthy lawn system. Maintenance techniques that support a healthy lawn include; soil care, method of fertilizing, and method of mowing.

8.7.1.1 Soil Care

Soil is the foundation for a healthy lawn and landscape. Soil should be tested to determine the soil's compaction. Soil testing can be done by pushing a screwdriver into the soil. If the screwdriver requires pounding to enter the soil, the soil is compacted (Center for Watershed Protection, 2000). Soil preservation and amendments are discussed in previous Sections. Soil that is compacted can be treated using a hand corer or a mechanical aerator. Compost can be applied to existing lawns to improve soil compaction (Center for Watershed Protection, 2000).

8.7.1.2 Reduce Turf Area

Conversion of lawns to groundcover, trees, shrubs or meadow plantings can greatly reduce the quantity of stormwater runoff as well as reduce the cost, time and effort needed to maintain turf based yard (Center for Watershed Protection, 2000). Areas that are not suited for lawn are best for conversion. These areas include frost pockets, exposed areas, shaded areas, steep areas and wet areas (Center for Watershed Protection, 2000). Additionally areas that are difficult or dangerous to mow are good candidates for conversion. Areas that are difficult to fertilize or water evenly are also good conversion candidates. Refer to Section 8.5.1 Rain Gardens in Residential Areas for possible replacement landscape designs.

8.7.1.3 Fertilizer Methods

Test soil's pH and fertility level, prior to adding any fertilizers, as many soils do not need additional fertilizers to support a healthy lawn. The USDA provides a soil quality test guide. Nebraska Department of Agriculture provides a list of soil and plant testing laboratories that are in compliance with the Nebraska Soil and Plant Analysis Laboratory Act Regulations. Additionally many home improvement and hardware stores carry inexpensive soil testing kits, in their lawn and garden departments.

Leaving grass clippings or mulch/mowing typically provides adequate levels of nitrogen and phosphorus to maintain a healthy lawn. If a commercial fertilizer is used it is best to use a minimal amount of fertilizer with encapsulated nitrogen and no or low phosphorus. The use of slow release (encapsulated) nitrogen and low or no phosphorus fertilizer helps reduce stormwater pollutant loads. Unless a soil test indicates otherwise, phosphorous is only needed during the first year of establishment of the lawn. When applying common off the shelf commercial fertilizer use half the manufacturer's recommended rate, as studies have found most lawns do not require high doses of fertilizer (Center for Watershed Protection, 2000). Additionally when to apply fertilizer is equally important: cool season grasses are best fertilized once in the fall and warm season grasses are best fertilized in several small doses during the summer (Center for Watershed Protection, 2000). By applying fertilizers during the correct season the turf utilizes more of the nutrients which relates to a more cost effective method of maintaining the turf as well as helping to reduce the amount of pollutants in stormwater runoff.

In order to keep the fertilizer on the lawn and plants where it provides its benefits and to keep the fertilizer out of waterways, avoid using fertilizer just before it rains.

8.7.1.4 Lawn Care

Follow the three in. rule: never cut your lawn shorter than three in. By increasing the mowing height the health of the turf is improved as it helps prevent the grass crowns from being exposed to sunburn. Taller grass also keeps the soil from being exposed to sunlight which can cause weed seeds to germinate. Increased mowing height encourages deeper root growth which in turns causes the grass to be healthier. Cutting the grass at a taller height also helps retain the moisture during drier seasons.

8.7.2 Trash and Pet Waste Reduction

Litter disposed of in a storm drain can choke, suffocate and disable aquatic life. Dispose of litter by throwing it in a trash can or recycling it.

8.7.2.1 Trash Reduction

Cleaning products and other household chemicals should never be dumped outside, down the sink or down a storm drain. You can dispose of your household chemicals for free at Under the Sink, the City's household hazardous waste disposal facility. Check their website for drop off information.

Landscape waste while organic can still be problematic to waterways; the problem occurs as this waste contributes to higher levels of nutrients entering the waterways which in turn encourage algae and rooted plants to grow in lakes and streams (Janssen and Barrow, 2008). Methods to reduce yard waste include utilizing lawn care tips listed in Section 8.7.1.4 and composting in backyards. University of Nebraska-Lincoln Extension provides a website (Stormwater Management: Yard Waste Management) with information regarding how to start composting and other waste reduction tips.

8.7.2.2 Pet Waste Reduction

Pet waste dumped in storm drains goes straight into rivers and lakes, contaminating the water. Pet waste left on lawns can cause harmful bacteria and viruses to enter waterways, causing pollutant damage. It is best to dispose of pet waste in the trash or flush it down the toilet. The waste will be properly treated in the landfill or wastewater treatment plant. When taking your dog for a walk, remember to take some plastic bags to clean up after them. Do not throw the bag down the storm drain. Stormwater runoff is not treated.

Incorporate pet waste stations in multi-family and apartment complex common areas and public parks and trail systems.

8.7.3 Sweeping and Cleaning of Impervious Areas

Do not leave grass clippings and leaves on impervious areas (such as driveways and streets) when you are doing yard work. This debris can enter the storm drain and cause clogs and pollute the water. Decaying leaves deplete water's oxygen levels which can harm aquatic organisms.

Pick up any spilled chemicals, fertilizers, oils, etc as rainwater can pick these pollutants up and deposit them into the waterways. Use cat litter or other absorbents to soak up liquid spills and then sweep up and properly dispose of the used absorbent.

8.7.4 References

Bierman, P.M., Horgan, B.P., Rosen, C.J., Hollman, A.B. and Pagliari P.A. 2010. Phosphorus Runoff from Turfgrass as Affected by Phosphorus Fertilization and Clipping Management. *Journal of Environmental Quality*. 39:282-292.

Center for Watershed Protection. 2000. Toward a low input lawn. *Protection Techniques.* 1(5), 254-264.

City of Omaha. 2003. Under the sink: Household Hazardous Waste Collection Facility: http://www.underthesink.org/

Janssen, D. and Barrow, T. 2008. Stormwater Management: Yard Waste Management. University of Nebraska – Lincoln Extension, Water/Property Design and Management NebGuide: http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=1010

Nebraska Department of Agriculture. 2008. Nebraska Soil and Plant Testing Laboratories: http://www.agr.state.ne.us/division/lab/soil_plant_testing_labs.pdf

USDA. 2001. Soil Quality Test Kit Guide: http://soils.usda.gov/sqi/assessment/files/test_kit_complete.pdf

University of Minnesota. 2006. Sustainable Urban Landscape Information Series (SULIS): http://www.sustland.umn.edu/maint/benefits_1.html

University of Nebraska-Lincoln Extension. 2011. Nebraska Master Gardener Program. http://mastergardener.unl.edu/home

University of Nebraska- Lincoln Extension. 2011. UNL Water. http://water.unl.edu/web/landscapes/home

8.5 References

Arendt, Randall G. 1998. Better Site Design: A Handbook for Changing the Development Rules in Your Community. *Center for Watershed Protection and Conservation Design for Subdivisions.* Ellicott City, MD: Center for Watershed Protection.

Caltrans Storm Water Website. 2011: http://www.dot.ca.gov/hq/oppd/stormwtr/

Center for Watershed Protection: http://www.cwp.org

Chow, Ven Te; Maidment, David R.; and Mays, Larry W. 1988. Applied Hydrology.

City of Lenexa. Municipal Code: http://www.lenexa.com/LenexaCode/codetext.asp?section=001

City of Omaha. Municipal Code: http://library.municode.com/index.aspx?clientID=10945&stateID=27&statename=Nebraska

City of Omaha, 2011. Post Construction Stormwater Management Planning Guidance: http://www.omahastormwater.org/images/stories/Development/pcsmp%20guidance%20document%20revised%20nov%202011.pdf

City of Omaha. 2009. Long Term Control Plan for the Omaha Combined Sewer Overflow Control Program Vol 1:

City of Omaha. 2007. Green Streets of Omaha Part 3, Chapter V Installation and Maintenance Standards. http://www.cityofomaha.org/planning/urbanplanning/design-guidelines (listings by part)

USEPA. 2011. SWMM: http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/ , Accessed July 2011

USEPA. 2008. Municipal Handbook, Managing Wet Weather with Green Infrastructure: Green Streets: http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_green_streets.pdf

Farnsworth, Richard K. and Thompson, Edwin S. 1982. NOAA Technical Report NWS 34 Mean Monthly, Seasonal, and Annual Pan Evaporation for the U.S. Office of Hydrology National Weather Service Washington, D.C.

Geosyntec Consultant and Wright Water Engineers, Inc. 2011. Technical Summary Volume Reduction. ISBMPD http://www.bmpdatabase.org/Docs/Volume%20Reduction%20Technical%20Summary%20Jan%202011.pdf

Geosyntec Consultant and Wright Water Engineers, Inc. 2008a. Analysis of Treatment System Performance: ISBMPD (1999-2008): http://www.bmpdatabase.org/Docs/Performance%20Summary%20June%202008.pdf

Geosyntec Consultant and Wright Water Engineers, Inc. 2008b. Overview of Performance by BMP Category and Common Pollutant Type: ISBMPD (1999-2008): http://www.bmpdatabase.org/Docs/Performance%20Summary%20Cut%20Sheet%20June%202008.pdf

Guo; James C. Y.; Blackler, Gerald E.; Earles, T. Andrew; and MacKenzie, Ken. 2010. Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs. ASCE Journal of Environmental Engineering.

LID Center, Inc. 2008. LID Center – Green Streets:
http://www.lowimpactdevelopment.org/greenstreets/background.htm

MARC. 2009. Manual of Best Management Practices for Stormwater Quality – Second Edition. Section 8.10 Extended Wet Detention. http://kcmetro.apwa.net/chapters/kcmetro/specs/APWA_BMP_ManualAUG09.pdf.

National Climatic Data Center. Omaha Eppley Airfield Station rain gauge:
http://www.srh.noaa.gov/data/obhistory/KOMA.html

Natural Resources Conservation Service WETS Station. 2005. Omaha Eppley Field, NE6255:
http://www.wcc.nrcs.usda.gov/ftpref/support/climate/wetlands/ne/31055.txt

Nebraska Department of Environmental Quality. Section 303d List of Impaired Waterbodies:
http://www.deq.state.ne.us/SurfaceW.nsf/Pages/TMDL

North Carolina DOT Stormwater Best Management Practices Toolbox, 2008:
http://www.ncdot.org/doh/preconstruct/highway/hydro/pdf/StormwaterBMPMarch08.pdf

Papillion Creek Partnership. 2009. Final Papillion Creek Watershed Management Plan:
http://www.papiopartnership.org/resources/documents/090430_Final_Drainage_Plan_BodyReport_Compilied.pdf

Rodie, Steve, Hartsig, Ted and Szatko, Andy. 2010. Sustainable Landscapes - Rain Gardens, Bioswales and Xeric Gardens: A Manual for Homeowners and Small Properties in Omaha. University of Nebraska – Lincoln Extension, Water/Property Design and Management Website:
http://water.unl.edu/web/propertydesign/publications (listings by chapter)

The Rouge River Project: http://www.rougeriver.com/proddata/wmm.html

UDFCD. 2010. Urban Storm Drainage Criteria Manual, Best Management Practices Vol. 3. Denver, Colorado:
http://www.udfcd.org/downloads/down_critmanual.htm (listings by volume)

USACE. 1998. WRP-Technical Note HY-DE-4.1 Methods to Determine the Hydrology of Potential Wetland Sites.

Washington Organic Recycling Council. 2010. Building Soil Guidelines and Resources for Implementing Soil Quality and Depth BMP T5.13 Stormwater Management Manual for Western Washington. Soils for Salmon:
http://www.soilsforsalmon.org/pdf/Soil_BMP_Manual.pdf

WinSLAMM: http://www.winslamm.com/winslamm_updates.html

Wisconsin Department of Natural Resources. 2004. Conservation Practice Standards 1002: Site Evaluation for Stormwater Infiltration.

Appendix 8-A

Simple Method to Calculate Urban Stormwater Pollutant Loads and BMP Performance

(This page was intentionally left blank)

Appendix 8-A
Simple Method to Calculate Urban Stormwater Pollutant Loads and BMP Performance

Estimating the expected annual pollutant loads from the developed area will assist in determining target pollutants. Estimating BMP pollutant removal performance helps in selecting post-construction BMPs that are most effective in removing the targeted constituents from site runoff.

Estimating Annual Pollutant Loads from Developed Areas

To quickly calculate the expected pollutant load from an urban area, the Stormwater Center's Simple Method to Calculate Urban Stormwater Pollutant Loads[1] can be used. The Stormwater Center has summarized event mean concentrations (EMCs) of pollutants from different land uses. A summary of the Stormwater Center data is shown in Table A-1. EMCs for bacteria have also been published by the Papillion Creek Partnership and are shown in Table A-2.

Table A-1
Simple Method Model Default Value EMC

Pollutant	Land Use			
	Residential	Commercial	Roadway	Industrial
Total Nitrogen (mg/l)	2.2	2	3	2.5
Total Phosphorus (mg/l)	0.4	0.2	0.5	0.4
Total Suspended Solids (mg/l)	100	75	150	120

Source: Stormwater Center Website, accessed July 2011.

The Simple Method estimates pollutant loads for chemical constituents as a product of annual runoff volume and EMC, as:

$$L = 0.226 \times R \times C \times A$$ *Equation A-1*

Where:

L = Annual load (lbs)
R = Annual runoff (inches)
C = EMC (mg/L)
A = Area (acres)
0.226 = Unit conversion factor

For bacteria, the equation is slightly different, to account for the differences in units. The modified equation for bacteria is:

$$L = 1.03x10^{-3} \times R \times C \times A$$ *Equation A-2*

Where:

L	=	Annual load (Billion Colonies)
R	=	Annual runoff (inches)
C	=	EMC bacteria (Colony Forming Units (CFU)/100 ml)
A	=	Area (acres)
1.03 * 10-3	=	Unit conversion factor

The annual runoff in inches is calculated as a product of annual runoff volume, and a runoff coefficient (Rv). Runoff volume is calculated as:

$$R = P \times P_j \times R_v$$ *Equation A-3*

Where:

R	=	Annual runoff (inches)
P	=	Annual rainfall (inches) Table A-3
P_j	=	Fraction of annual rainfall events that produce runoff (usually 0.9)
R_v	=	Runoff Coefficient

$$R_v = 0.05 + 0.9 \times I_a$$ *Equation A-4*

Where:

I_a	=	Impervious fraction

Table A-2
Possible Sources and Concentrations of Fecal Coliform and E. coli in the Papillion Creek Drainage Basin

Land Use Category	Effective Percent Impervious	Fecal Coliform Bacteria (CFU/100 mL)	Equivalent E. Coli Bacteria Loading (CFU/100 mL)
Agriculture	Varies	88,400	55,700
Parks and Open Areas	5%	11,600	7,300
Rural Estate (Homes on 3 to 10 acres)	10%	17,100	10,800
Low Density Residential (Homes on 1 to 3 acres)	16%	23,700	14,900
Medium Density Residential (Homes on approx. 0.25 Acres)	38%	48,100	30,300
Churches, Schools, and Civic	50%	61,300	38,600
High Density Residential (Multi-Family Apartment Complexes)	65%	77,900	49,100
Industrial Areas	72%	85,600	53,900
Commercial and Retail Businesses	85%	100,000	63,000

Source: Papillion Creek Partnership. 2009. Final Papillion Creek Watershed Management Plan.

Table A-3
Annual rainfall for Municipalities within the Omaha Region

City	NRCS (30 year average)
Blair	30.06
Boys Town	28.89
Chalco	28.89
Elkhorn	30.15
Gretna	29.69
Las Vista	28.89
Omaha	30.26
Papillion	28.89
Ralston	28.89
Waterloo	30.15

[1]Rain gauge information for Douglas and Washington County for NRCS based on time frame of 1971-2000

[2]Rain gauge information for Sarpy County (Ashland) for NRCS based on time frame of 1961-1990

Once the pollutant load from a particular land use is estimated, the BMP performance can also be estimate. The pollutant load leaving a BMP is a function of the volume of water leaving the BMP and the effluent concentration. The Simple Method to Calculate BMP Performance (Simple Method) can be used to estimate the pollutant removal effectiveness of BMP types. The Simple Method provides an estimate of BMP performance; **actual pollutant removal performance for a particular BMP can only be verified using post-construction monitoring data.**

Simple Method to Calculate BMP Performance

BMP performance can be estimated by comparing the pollutant load entering the BMP to the pollutant load exiting the BMP. The International BMP database recommends using effluent concentrations and outflow volumes to measure BMP performance. The reasons for this recommendation are summarized in the Percent Removal Factsheet[2].

The pollutant load entering the BMP is estimated using Equation A-1 or A-2. The pollutant load exiting the BMP is estimated using Equation A-5 which multiplies the median effluent concentration based on BMP type and by the outflow volume.

$$E = 0.226 \times O \times C \times A$$ *Equation A-5*

Where:

E = Effluent Pollutant Load (lbs)
O = Outflow Volume in Watershed Inches (inches)
C = Median Effluent Concentration of BMP (mg/l)
A = Area (acres)
0.226 = Unit conversion factor

---

http://www.stormwatercenter.net/monitoring%20and%20assessment/simple%20meth/simple.htm

For BMPs that do not provide significant reduction in stormwater volume, then the outflow volume is equal to the inflow volume. The International BMP Database indicated that volume reduction is most significant in filter strips, grassed swales and bioretention BMPs. Volume percent removal estimates for these BMPs are provided in Table A-4.

Table A-4
International Stormwater BMP Database Percent Volume Reduction

BMP Category	25th Percentile	Median	75th Percentile	Average
Biofilter – Grass Strips	18%	34%	54%	38%
Biofilter – Grass Swales	35%	42%	65%	48%
Bioretention	45%	57%	74%	61%
Detention Basins – Surface Grass Lined	26%	33%	43%	33%

Relative Volume Reduction = Study total Inflow Volume – Study Total Outflow Volume / Study Total Inflow Volume

Source: Wright Water Engineers and Geosyntec Consultants, 2011

The International BMP Database also publishes median effluent concentrations for several BMP types. A summary of the BMP Database information on median effluent concentrations for common pollutants (except bacteria) is provided in Table A-5. Table A-6 shows the median effluent concentrations of select BMPs for bacteria

Table A-5
Structural BMP Median Influent and Effluent Concentrations from the International BMP Database

Constituents	Sample Location	Detention Pond (n=25)[1]	Wet Pond (n=46)[1]	Wetland Basin (n=19)[1]	Biofilter (n=57)[1]	Media Filter (n=38)[1]	Porous Pavement (n=6)[1]
Suspended Solids (mg/L)	Influent	72.65	34.13	37.76	52.15	43.27	
	Effluent	31.04	13.37	17.77	23.92	15.86	16.96
Total Cadmium (µg/L)	Influent	0.71	0.49	0.36	0.54	0.25	
	Effluent	0.47	0.27	0.24	0.30	0.19	xx
Dissolved Cadmium (µg/L)	Influent	0.24	0.19		0.25	0.16	
	Effluent	0.25	0.11	xx	0.21	0.13	xx
Total Copper (µg/L)	Influent	20.14	8.91	5.65	31.93	14.57	
	Effluent	12.10	6.36	4.23	10.66	10.25	2.78
Dissolved Copper (µg/L)	Influent	6.66	7.33		14.15	7.75	
	Effluent	7.37	4.37	xx	8.40	9.00	xx
Total Chromium (µg/L)	Influent	7.36	6.00		5.63	2.18	
	Effluent	3.18	1.44	xx	4.64	1.48	xx
Total Lead (µg/L)	Influent	25.01	14.36	4.62	19.53	11.32	
	Effluent	15.77	5.32	3.26	6.70	3.76	7.88
Dissolved Lead (µg/L)	Influent	1.25	3.40	0.50	2.25	1.44	
	Effluent	2.06	2.48	0.87	1.96	1.18	xx
Total Zinc (µg/L)	Influent	111.56	60.75	47.07	176.71	92.34	
	Effluent	60.20	29.35	30.71	39.83	37.63	16.60
Dissolved Zinc (µg/L)	Influent	26.11	47.46		58.31	69.27	
	Effluent	25.84	32.86	xx	25.40	51.25	xx
Total Phosphorus (mg/L)	Influent	0.19	0.21	0.27	0.25	0.20	
	Effluent	0.19	0.12	0.14	0.34	0.14	0.09
Dissolved Phosphorus (mg/L)	Influent	0.09	0.09	0.10	0.09	0.09	
	Effluent	0.12	0.08	0.17	0.44	0.09	xx
Total Nitrogen (mg/L)	Influent	1.25	1.64	2.12	0.94	1.31	
	Effluent	2.72	1.43	1.15	0.78	0.76	xx
Nitrate-Nitrogen (mg/L)	Influent	0.70	0.36	0.22	0.59	0.41	
	Effluent	0.58	0.23	0.13	0.60	0.82	xx
TKN (mg/L)	Influent	1.45	1.26	1.15	1.80	1.52	
	Effluent	1.89	1.09	1.05	1.51	1.55	1.23

1 Actual number of BMPs reporting a particular constituent may be greater or less than the number reported in this table, which was based on number of studies reported in database based on BMP category. Notes: xx- Lack of sufficient data to report median and confidence interval. Values in parenthesis are the 95% confidence intervals about the median. Differences in median influent and effluent concentrations does not necessarily indicate that there was a statistically significant difference between influent and effluent. See "Analysis of Treatment System Performance, International Stormwater BMP Database (1997-2007) (Geosyntec and Wright Water Engineers and Geosyntec Consultants 2007) for more detailed information. Source: International Stormwater BMP Database June 2008 (www.bmpdatabase.org)
2Source: Wright Water Engineers and Geosyntec Consultants, Pollutant Category Summary: Fecal Indicator Bacteria, December 2010

Table A-6
Structural BMP Median Influent and Effluent Concentrations from the International BMP Database.

Constituent	Sample Location	Detention Pond (n=11)	Wet Pond (n=6,7)	Grass Swale/Strip (n=9)	Media Filter (n=12,14)
Fecal Coliform (CFU per 100 mL)[2]	Influent	749	1971	2628	605
	Effluent	813	133	4724	216

[2]Source: International Stormwater BMP Database, *Pollutant Category Summary: Fecal Indicator Bacteria*, December 2010

The section below provides an example of calculating pollutant removal effectiveness of two BMP options.

Example Calculation of Pollutant Removal Effectiveness

Compare the Fecal Coliform bacteria removal effectiveness of an extended dry detention BMP and a retention wet pond BMP for a medium density residential development. The TMDL for bacteria requires discharge from the drainage area to be below 23 Billion Colonies of Fecal Coliform. The drainage area to the BMP is 10 acres with percent imperviousness of 40-percent.

Step 1: Calculate the expected annual pollutant load from the development.

Use Equation A-2 to calculate the annual load of bacteria from the residential development. The EMC for bacteria from medium density residential land use is 48,100 CFU / 100 mL as shown in Table A-2. The annual precipitation total for Omaha is 30.26 inches (Table A-3).

$$L = 1.03x10^{-3} \times R \times C \times A$$

Where:

L	=	Annual load (Billion Colonies)
R	=	Annual runoff (inches)
C	=	EMC bacteria (CFU/100 ml)
A	=	Area (acres)
$1.03 * 10^{-3}$	=	Unit conversion factor

Use Equation A-4 to estimate the runoff coefficient for the residential development.

$$R_v = 0.05 + 0.9 \times .40 \ = 0.41$$

The runoff coefficient is used in Equation A-3 to calculate the annual runoff volume (R) in inches.

$$R = 30.26 \times \ 0.9 \times 0.41 = 11.2 \, inches$$

The runoff volume is used in Equation A-2 to estimate the bacteria load from the residential development.

$$R = 30.26 \times \ 0.9 \times 0.41 = 11.2 \, inches$$

Table A-6
Structural BMP Median Influent and Effluent Concentrations from the International BMP Database.

Constituent	Sample Location	Detention Pond (n=11)	Wet Pond (n=6,7)	Grass Swale/Strip (n=9)	Media Filter (n=12,14)
Fecal Coliform (CFU per 100 mL)[2]	Influent	749	1971	2628	605
	Effluent	813	133	4724	216

[2]Source: International Stormwater BMP Database, *Pollutant Category Summary: Fecal Indicator Bacteria*, December 2010

The section below provides an example of calculating pollutant removal effectiveness of two BMP options.

Example Calculation of Pollutant Removal Effectiveness

Compare the Fecal Coliform bacteria removal effectiveness of an extended dry detention BMP and a retention wet pond BMP for a medium density residential development. The TMDL for bacteria requires discharge from the drainage area to be below 23 Billion Colonies of Fecal Coliform. The drainage area to the BMP is 10 acres with percent imperviousness of 40-percent.

Step 1: Calculate the expected annual pollutant load from the development.

Use Equation A-2 to calculate the annual load of bacteria from the residential development. The EMC for bacteria from medium density residential land use is 48,100 CFU / 100 mL as shown in Table A-2. The annual precipitation total for Omaha is 30.26 inches (Table A-3).

$$L = 1.03x10^{-3} \times R \times C \times A$$

Where:

L	=	Annual load (Billion Colonies)
R	=	Annual runoff (inches)
C	=	EMC bacteria (CFU/100 ml)
A	=	Area (acres)
$1.03 * 10^{-3}$	=	Unit conversion factor

Use Equation A-4 to estimate the runoff coefficient for the residential development.

$$R_v = 0.05 + 0.9 \times .40 \ = 0.41$$

The runoff coefficient is used in Equation A-3 to calculate the annual runoff volume (R) in inches.

$$R = 30.26 \times \ 0.9 \times 0.41 = 11.2 \ inches$$

The runoff volume is used in Equation A-2 to estimate the bacteria load from the residential development.

$$L = 1.03x10^{-3} \times 11.2 \ inches \times 48{,}100 \frac{CFU}{100mL} \times 10 \ acres = 5{,}550 \ Billion \ Colonies$$

Step 2: Calculate the expected annual pollutant load from a dry pond BMP.

Use Equation A-6 to calculation the annual bacteria load from a dry pond BMP. The dry pond receives the full annual runoff volume from the residential development and the median effluent concentration from Table A-6 is used. Dry pond BMPs are expected to reduce annual runoff volumes between 26 and 43 percent. The median percent reduction in volume is 33 percent.

Calculate the outflow volume (O) as a portion of the inflow volume (R).

$$O\ inches = Inflow - Inflow\frac{Reduction\ \%}{100} = 11.2\ inches - 11.2\ inches\ \frac{33}{100} = 7.5\ inches$$

$$E = 1.03x10^{-3} \times 7.5\ inches \times 813\frac{CFU}{100mL} \times 10\ acres = 62.8\ Billion\ Colonies$$

Step 3: Calculate the expected annual pollutant load from a retention wet pond BMP.

Use Equation A-6 to calculate the annual bacteria load from a wet pond BMP. The wet pond receives the full annual runoff volume from the residential development and the median effluent concentration from Table A-6 is used. The wet pond is not expected to significantly reduce runoff volumes; therefore, the outflow volume is equal to the inflow volume.

$$E = 1.03x10^{-3} \times 11.2\ inches \times 133\frac{CFU}{100mL} \times 10\ acres = 15.3\ Billion\ Colonies$$

Step 4: Evaluate BMP alternatives.

The expected annual pollutant load from the extended dry detention basin is 62.8 Billion Colonies of Fecal Coliform bacteria which is greater than the limit of 23 Billion Colonies allowed by the TMDL. If an extended dry detention basin is used for this site, additional treatment of the extended detention basin effluent may be required to reduce Fecal Coliform bacteria to the TMDL limit. However, if a retention wet pond is used, the annual pollutant load is 15.3 Billion Colonies of Fecal Coliform which is below the TMDL limit. This analysis gives an estimate of pollutant loads. Actual pollutant loads can only be verified using monitoring data once the BMP has been constructed and is operating. This type of analysis is useful when planning BMP selection to determine the greatest likelihood of achieving downstream water quality goals.

Appendix 8-B

USEPA Class V Well Memorandum

(This page was intentionally left blank)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 1 3 2008

OFFICE OF
WATER

MEMORANDUM

SUBJECT: Clarification on which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" wells by the Underground Injection Control Program

TO: Water Division Directors, Regions 1-10

FROM: Linda Boornazian, Director
Water Permits Division (MC 4203M)

Steve Heare, Director
Drinking Water Protection Division (MC 4606M)

Over the past several years stormwater infiltration has become an increasingly effective tool in the management of stormwater runoff. Although primary stormwater management responsibilities within EPA fall under the Clean Water Act (CWA), the infiltration of stormwater is, in some cases, regulated under the Safe Drinking Water Act (SDWA) with the goal of protecting underground sources of drinking water (USDWs). Surface and ground water protection requires effective integration between the overlapping programs. This memorandum is a step forward in that effort and is meant to provide clarification on stormwater implementation and green infrastructure, in particular under the CWA, which is consistent with the requirements of the SDWA's Underground Injection Control (UIC) Program.

In April 2007, EPA entered into a collaborative partnership with four national groups (the Association of State and Interstate Water Pollution Control Administrators, the Low Impact Development Center, the National Association of Clean Water Agencies, and the Natural Resources Defense Council) to promote green infrastructure as a cost-effective, sustainable, and environmentally friendly approach to stormwater management. The primary goals of this collaborative effort are to reduce runoff volumes and sewer overflow events through the use of green infrastructure wet weather management practices.

Within the context of this collaborative partnership, green infrastructure includes a suite of management practices that use soils and vegetation for infiltration, treatment, and evapotranspiration of stormwater. Rain gardens, vegetated swales, riparian buffers and porous pavements are all common examples of green infrastructure techniques that capture and treat stormwater runoff close to its source. Green infrastructure management practices typically do not include commercially manufactured or proprietary infiltration

Internet Address (URL) • http://www.epa.gov
Recycled/Recyclable • Printed with Vegetable Oil Based Inks on Recycled Paper (Minimum 30% Postconsumer)

devices or other infiltration practices such as simple drywells, which do not provide for pre-treatment prior to infiltration.

The partnership is promoting green infrastructure as an effective approach to stormwater management because these practices are associated with a number of environmental benefits. In addition to reducing and delaying runoff volumes, green infrastructure approaches can also reduce pollutant levels in stormwater, enhance ground water recharge, protect surface water from stormwater runoff, increase carbon sequestration, mitigate urban heat islands, and increase wildlife habitat.

Given the multiple benefits that green infrastructure can provide, EPA and its partners have increased efforts to incorporate green infrastructure techniques into stormwater management strategies nationwide. In recent years, public support for these practices has gradually increased. For more information on green infrastructure, please visit www.epa.gov/npdes/greeninfrastructure.

There are cases where stormwater infiltration practices are regulated as Class V wells under the UIC program, and State and local stormwater managers report that some developers are hesitant to incorporate green infrastructure practices because they fear regulatory approvals will slow the process and increase costs. EPA believes those fears are unfounded and notes that most green infrastructure practices do not meet the Class V well definition and can be installed without regulatory oversight by the UIC Program. However, EPA remains committed to the protection of USDWs and emphasizes the need for UIC program compliance (per 40 CFR 144).

To provide clarification on which stormwater infiltration techniques meet EPA's UIC Class V well definition, EPA's Office of Water has developed the attached "Class V Well Identification Guide." State or Regional stormwater and nonpoint source control programs, developers, and other interested parties are requested to contact the State or Regional UIC Program Director with primary authority for the UIC Class V program when considering the use of practices that have been identified, or potentially identified, as Class V wells. UIC program managers should consider the proximity to sensitive ground water areas when looking at the suitability of stormwater infiltration practices. Depending on local conditions, infiltration without pretreatment may not be appropriate in areas where ground waters are a source of drinking water or other areas identified by federal, state, or local governments as sensitive ground water areas, such as aquifers overlain with thin, porous soils.

Please share this memo and the attached guide with your State and Regional stormwater, nonpoint source control, UIC and other ground water managers, as well as with appropriate green infrastructure contacts. These programs are encouraged to coordinate on stormwater management efforts when sensitive ground water issues arise.

Attachment

Underground Injection Control (UIC) Program Class V Well Identification Guide

This reference guide can be used to determine which stormwater infiltration practices/technologies have the potential to be regulated as “Class V” wells. Class V wells are wells that are not included in Classes I through IV. Typically, Class V wells are shallow wells used to place a variety of fluids directly below the land surface. By definition, a well is “any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system” and an “injection well” is a “well” into which “fluids” are being injected (40 CFR §144.3). Federal regulations (40 CFR §144.83) require all owners/operators of Class V wells to submit information to the appropriate regulatory authorities including the following:

1. Facility name and location
2. Name and address of legal contact
3. Ownership of property
4. Nature and type of injection well(s)
5. Operating status of injection well(s)

For more information on Class V well requirements, please visit http://www.epa.gov/safewater/uic/class5/comply_minrequirements.html. For more information on green infrastructure, please visit http://www.epa.gov/npdes/greeninfrastructure.

The stormwater infiltration practices/technologies in rows A through I below are generally not considered to be wells as defined in 40 CFR §144.3 because typically they are not subsurface fluid distribution systems or holes deeper than their widest surface dimensions. If these practices/technologies are designed in an atypical manner to include subsurface fluid distribution systems and/or holes deeper than their widest surface dimensions, then they may be subject to the Class V UIC regulations. The stormwater infiltration practices/technologies in rows J through K however, depending upon their design and construction probably would be subject to UIC regulations.

	Infiltration Practice/Technology	Description	Is this Practice/Technology Generally Considered a Class V Well?
A	Rain Gardens & Bioretention Areas	Rain gardens and bioretention areas are landscaping features adapted to provide on-site infiltration and treatment of stormwater runoff using soils and vegetation. They are commonly located within small pockets of residential land where surface runoff is directed into shallow, landscaped depressions; or in landscaped areas around buildings; or, in more urbanized settings, to parking lot islands and green street applications.	No.
B	Vegetated Swales	Swales (e.g., grassed channels, dry swales, wet swales, or bioswales) are vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff. As stormwater runoff flows along these channels, vegetation slows the water to allow sedimentation, filtering through a subsoil matrix, and/or infiltration into the underlying soils.	No.
C	Pocket Wetlands & Stormwater Wetlands	Pocket/Stormwater wetlands are structural practices similar to wet ponds that incorporate wetland plants into the design. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake. Several design variations of the stormwater wetland exist, each design differing in the relative amounts of shallow and deep water, and dry storage above the wetland.	No.
D	Vegetated Landscaping	Self-Explanatory.	No.
E	Vegetated Buffers	Vegetated buffers are areas of natural or established vegetation maintained to protect the water quality of neighboring areas. Buffer zones slow stormwater runoff, provide an area where runoff can infiltrate the soil, contribute to ground water recharge, and filter sediment. Slowing runoff also helps to prevent soil and stream bank erosion.	No

	Infiltration Practice/Technology	Description	Is this Practice/Technology Generally Considered a Class V Well?
F	Tree Boxes & Planter Boxes	Tree boxes and planter boxes are generally found in the right-of-ways alongside city streets. These areas provide permeable areas where stormwater can infiltrate. The sizes of these boxes can vary considerably.	No.
G	Permeable Pavement	Permeable pavement is a porous or pervious pavement surface, often built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil. Permeable pavement is an environmentally preferable alternative to traditional pavement that allows stormwater to infiltrate into the subsoil. There are various types of permeable surfaces, including permeable asphalt, permeable concrete and even grass or permeable pavers.	No.
H	Reforestation	Reforestation can be used throughout a community to reestablish forested cover on a cleared site, establish a forested buffer to filter pollutants and reduce flood hazards along stream corridors, provide shade and improve aesthetics in neighborhoods or parks, and improve the appearance and pedestrian comfort along roadsides and in parking lots.	No.
I	Downspout Disconnection	A practice where downspouts are redirected from sewer inlets to permeable surfaces where runoff can infiltrate.	In certain circumstances, for example, when downspout runoff is directed towards vegetated/pervious areas or is captured in cisterns or rain-barrels for reuse, these practices generally would not be considered Class V wells.
J	Infiltration Trenches	An infiltration trench is a rock-filled trench designed to receive and infiltrate stormwater runoff. Runoff may or may not pass through one or more pretreatment measures, such as a swale, prior to entering the trench. Within the trench, runoff is stored in the void space between the stones and gradually infiltrates into the soil matrix. There are a number of different design variations.	In certain circumstances, for example, if an infiltration trench is "deeper than its widest surface dimension," or includes an assemblage of perforated pipes, drain tiles, or other similar mechanisms intended to distribute fluids below the surface of the ground, it would probably be considered a Class V injection well.

	Infiltration Practice/Technology	Description	Is this Practice/Technology Generally Considered a Class V Well?
K	Commercially Manufactured Stormwater Infiltration Devices	Includes a variety of pre-cast or pre-built proprietary subsurface detention vaults, chambers or other devices designed to capture and infiltrate stormwater runoff.	These devices are generally considered Class V wells since their designs often meet the Class V definition of subsurface fluid distribution system.
L	Drywells, Seepage Pits, Improved Sinkholes.	Includes any bored, drilled, driven, or dug shaft or naturally occurring hole where stormwater is infiltrated.	These devices are generally considered Class V wells if stormwater is directed to any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or has a subsurface fluid distribution system.

Appendix 8-C

PCWP Stream Setback Policy

(This page was intentionally left blank)

PAPILLION CREEK WATERSHED
STORMWATER MANAGEMENT POLICIES

POLICY GROUP #3: LANDSCAPE PRESERVATION, RESTORATION, AND CONSERVATION

ISSUE: Natural areas are diminishing, and there is a need to be proactive and integrate efforts directed toward providing additional landscape and green space areas with enhanced stormwater management through restoration and conservation of stream corridors, wetlands, and other natural vegetation.

"ROOT" POLICY: Utilize landscape preservation, restoration, and conservation techniques to meet the multi-purpose objectives of enhanced aesthetics, quality of life, recreational and educational opportunities, pollutant reduction, and overall stormwater management.

SUB-POLICIES:

1) Incorporate stormwater management strategies as a part of landscape preservation, restoration, and conservation efforts where technically feasible.
2) Define natural resources for the purpose of preservation, restoration, mitigation, and/or enhancement.
3) For new development or significant redevelopment, provide a creek setback of 3:1 plus 50 feet along all streams as identified in the Papillion Creek Watershed Management Plan and a creek setback of 3:1 plus 20 feet for all other watercourses.
4) All landscape preservation features as required in this policy or other policies, including all stormwater and LID strategies, creek setbacks, existing or mitigated wetlands, etc., identified in new or significant redevelopment shall be placed into an out lot or within public right of way or otherwise approved easement.

REFERENCE INFORMATION

DEFINITIONS

1) Creek Setback. See Figure 1 below and related definitions in Policy Group #5. A setback area equal to three (3) times the channel depth plus fifty (50) feet (3:1 plus 50 feet) from the edge of low water on both sides of channel shall be required for any above or below ground structure exclusive of bank stabilization structures, poles or sign structures adjacent to any watercourse defined within the watershed drainage plan. Grading, stockpiling, and other construction activities are not allowed within the setback area and the setback area must be protected with adequate erosion controls or other Best Management Practices, (BMPs). The outer 30 feet adjacent to the creek setback limits may be credited toward meeting the landscaping buffer and pervious coverage requirements.

   A property can be exempt from the creek setback requirement upon a showing by a licensed professional engineer or licensed landscape architect that adequate bank stabilization structures or slope protection will be installed in the construction of said structure, having an estimated useful life equal to that of the structure, which will provide adequate erosion control conditions coupled with adequate lateral support so that no portion of said structure adjacent to the stream will be endangered by erosion or lack of lateral support. In the event that the structure is adjacent to any stream which has been channelized or otherwise improved by any agency of government, then such certificate providing an exception to the creek setback requirement may take the form of a certification as to the adequacy and protection of the improvements installed by such governmental agency. If such exemption is granted, applicable rights-of-way must be provided and a minimum 20 foot corridor adjacent thereto.

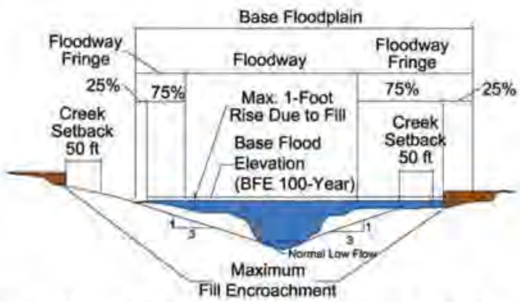

Figure 1 – Floodway Fringe Encroachment and Creek Setback Schematic

DEFINITIONS

1) Base Flood. The flood having a one percent chance of being equaled or exceeded in magnitude in any given year (commonly called a 100-year flood). *[Adapted from Chapter 31 of Nebraska Statutes]*
2) Floodway. The channel of a watercourse and the adjacent land areas that are necessary to be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than one foot. *[Adapted from Chapter 31 of Nebraska Statutes].* The Federal Emergency Management Agency (FEMA) provides further clarification that a floodway is the central portion of a riverine floodplain needed to carry the deeper, faster moving water.
3) Floodway Fringe. That portion of the floodplain of the base flood, which is outside of the floodway. *[Adapted from Chapter 31 of Nebraska Statutes]*
4) Floodplain. The area adjoining a watercourse, which has been or may be covered by flood waters. *[Adapted from Chapter 31 of Nebraska Statutes]*
5) Watercourse. Any depression two feet or more below the surrounding land which serves to give direction to a current of water at least nine months of the year and which has a bed and well-defined banks. *[Adapted from Chapter 31 of Nebraska Statutes]*
6) Low Chord Elevation. The bottom-most face elevation of horizontal support girders or similar superstructure that supports a bridge deck.
7) Updated Flood Hazard Maps. The remapping of flooding sources within the Papillion Creek Watershed where Digital Flood Insurance Rate Maps (DFIRMs) are based on 2004 or more recent conditions hydrology and full-build out conditions hydrology. West Papillion Creek and its tributaries are currently under remapping and will become regulatory in 2009. Updating flood hazard maps for Big Papillion Creek and Little Papillion Creek are planned to be completed in the future.
8) New Development. New development shall be defined as that which is undertaken to any undeveloped parcel that existed at the time of implementation of this policy.

PAPILLION CREEK WATERSHED
STORMWATER MANAGEMENT POLICIES

POLICY GROUP #5: FLOODPLAIN MANAGEMENT

ISSUE: Continued and anticipated development within the Papillion Creek Watershed mandates that holistic floodplain management be implemented and maintained in order to protect its citizens, property, and natural resources.

"ROOT" POLICY: Participate in the FEMA National Flood Insurance Program, update FEMA floodplain mapping throughout the Papillion Creek Watershed, and enforce floodplain regulations to full build-out, base flood elevations.

SUB-POLICIES:

1) Floodplain management coordination among all jurisdictions within the Papillion Creek Watershed and the Papio-Missouri River Natural Resources District (P-MRNRD) is required.
2) Flood Insurance studies and mapping throughout the Papillion Creek Watershed shall be updated using current and full-build out conditions hydrology.
3) Encroachments for new developments or significant redevelopments within floodway fringes shall not cause any increase greater than one (1.00) foot in the height of the full build-out base flood elevation using best available data.
4) Filling of the floodway fringe associated with new development within the Papillion Creek System shall be limited to 25% of the floodway fringe in the floodplain development application project area, unless approved mitigation measures are implemented. The remaining 75% of floodway fringe within the project area shall be designated as a floodway overlay zone. For redevelopment, these provisions may be modified or waived in whole or in part by the local jurisdiction.
5) The low chord elevation for bridges crossing all watercourses within FEMA designated floodplains shall be a minimum of one (1) foot above the base flood elevation for full-build out conditions hydrology using best available data.
6) The lowest first floor elevation of buildings associated with new development or significant redevelopment that are upstream of and contiguous to regional dams within the Papillion Creek Watershed shall be a minimum of one (1) foot above the 500-year flood pool elevation.

<u>REFERENCE INFORMATION</u>

DEFINITIONS (See Figure 1 below and related definitions in Policy Group #3: Landscape Preservation, Restoration, and Conservation).

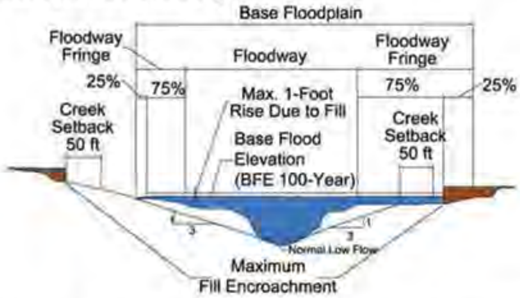

Figure 1 – Floodway Fringe Encroachment and Creek Setback Schematic

PAPILLION CREEK WATERSHED
STORMWATER MANAGEMENT POLICIES

1) Base Flood. The flood having a one percent chance of being equaled or exceeded in magnitude in any given year (commonly called a 100-year flood). *[Adapted from Chapter 31 of Nebraska Statutes]*
2) Floodway. The channel of a watercourse and the adjacent land areas that are necessary to be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than one foot. *[Adapted from Chapter 31 of Nebraska Statutes].* The Federal Emergency Management Agency (FEMA) provides further clarification that a floodway is the central portion of a riverine floodplain needed to carry the deeper, faster moving water.
3) Floodway Fringe. That portion of the floodplain of the base flood, which is outside of the floodway. *[Adapted from Chapter 31 of Nebraska Statutes]*
4) Floodplain. The area adjoining a watercourse, which has been or may be covered by flood waters. *[Adapted from Chapter 31 of Nebraska Statutes]*
5) Watercourse. Any depression two feet or more below the surrounding land which serves to give direction to a current of water at least nine months of the year and which has a bed and well-defined banks. *[Adapted from Chapter 31 of Nebraska Statutes]*
6) Low Chord Elevation. The bottom-most face elevation of horizontal support girders or similar superstructure that supports a bridge deck.
7) Updated Flood Hazard Maps. The remapping of flooding sources within the Papillion Creek Watershed where Digital Flood Insurance Rate Maps (DFIRMs) are based on 2004 or more recent conditions hydrology and full-build out conditions hydrology. West Papillion Creek and its tributaries are currently under remapping and will become regulatory in 2009. Updating flood hazard maps for Big Papillion Creek and Little Papillion Creek are planned to be completed in the future.
8) New Development. New development shall be defined as that which is undertaken to any undeveloped parcel that existed at the time of implementation of this policy.

BASIC FEMA REQUIREMENTS

On March 1, 2003, FEMA became part of the U.S. Department of Homeland Security (DHS). In order for a community to participate in the FEMA National Flood Insurance Program, it must first define base flood elevations and adopt a floodway for all its major streams and tributaries. Once a community adopts its floodway, the requirements of *44 CFR 60.3(d)* must be fulfilled. The key concern is that each project in the floodway must receive an encroachment review; i.e., an analysis to determine if the project will increase flood heights or cause increased flooding downstream. Note that the FEMA regulations call for preventing any increase in flood heights. Projects, such as filling, grading or construction of a new building, must be reviewed to determine whether they will obstruct flood flows and cause an increase in flood heights upstream or adjacent to the project site. Further, projects, such as grading, large excavations, channel improvements, and bridge and culvert replacements should also be reviewed to determine whether they will remove an existing obstruction, resulting in increases in flood flows downstream. *[Adapted from Federal Emergency Management Agency guidance]*

Appendix 8-D
Derivation of Peak Flow Rate
for the Water Quality Storm

(This page was intentionally left blank)

Appendix 8-D
Derivation of Peak Flow Rate for the Water Quality Storm

The current policy outlined in the City of Omaha Post-Construction Stormwater Management Planning Guidance for selecting a design storm for flow-through BMPs is:

"For stormwater BMPs that provide treatment based on a flow rate, the Designer may submit calculations that demonstrate water quality flow rates that are equivalent to treating the first one-half inch (0.5 inches) of stormwater runoff. On sites where the Rational Method is suitable and the time of concentration is 5 minutes, designers may estimate i using the 1-yr IDF curve with 20-minute duration. Designers may also use WinTR-55 to estimate flow rate, however, the model must show a correlation to a 0.5 inches runoff depth in the output report. Proprietary stormwater BMPs shall be pre-approved for use by the City of Omaha Public Works Department."

The variable "i" is the rainfall intensity in inches per hour for storms with duration equal to the time of concentration of the site. Use of the Rational Method requires the designer to select a value for the runoff coefficient (C) which represents a ratio of runoff to rainfall for future land-use conditions. BMPs sized using the City's volume criteria are sized with 0.5 inches of runoff regardless of the future land use conditions.

To provide an approach for sizing of flow-through BMPs that is consistent with the City's volume design criteria, CDM Smith's NetSTORM program was run using approximately 61 years of rainfall data collected within the Omaha Region. The results of the NetSTORM analysis were used to create capture curves for a BMP with a 24-hour draindown time (Figure D-1).

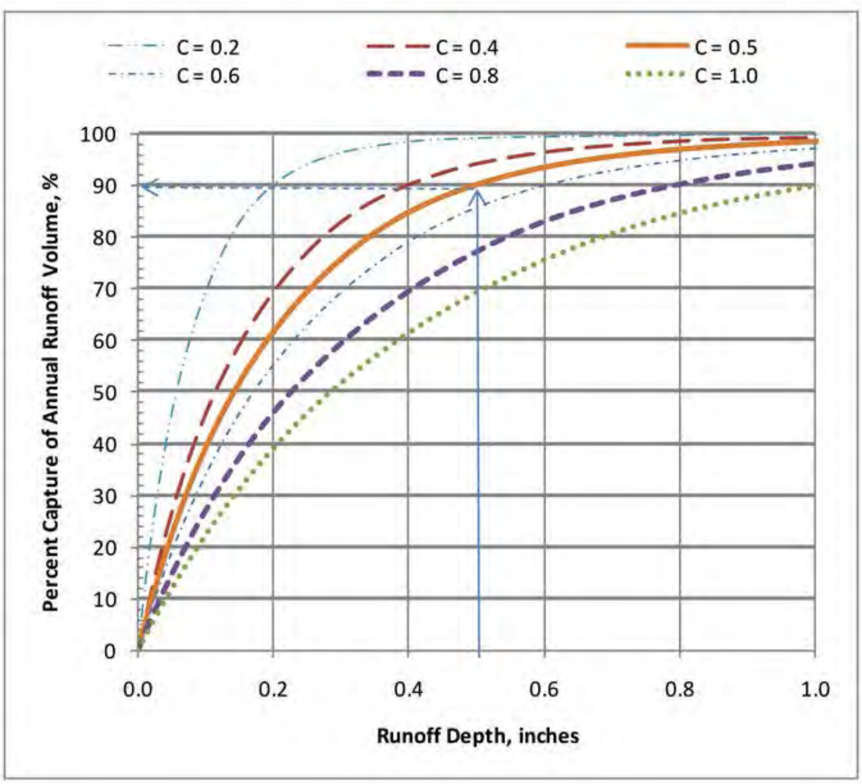

Figure D-1 Capture Curves for Omaha, Nebraska for BMP with 24-hour draindown time.

Figure D- 1 shows that a BMP sized for 0.5 inches of runoff and a 24-hour draindown captures and treats between 70 to greater than 95 percent of annual runoff events depending upon the runoff coefficient (C) applied to the development. If we apply a 90-percent treatment criteria to flow through BMPs (equal to a site with C = 0.5 capturing 0.5 inches of runoff), the 90-percent intensity can be used to calculate a peak flow rate per acre required for treatment.

NetSTORM was used to separate the rainfall depths into event of 1-hour, 6-hour, and 24-hour duration and the 90-percent rainfall intensity was calculated. Figure D-2 shows the resulting plot for the 90-percent along with that of the 1-year return interval storm event. Values for durations other than 1-, 6-, and 24-hours were estimated using the slope of the 1-year intensity curve.

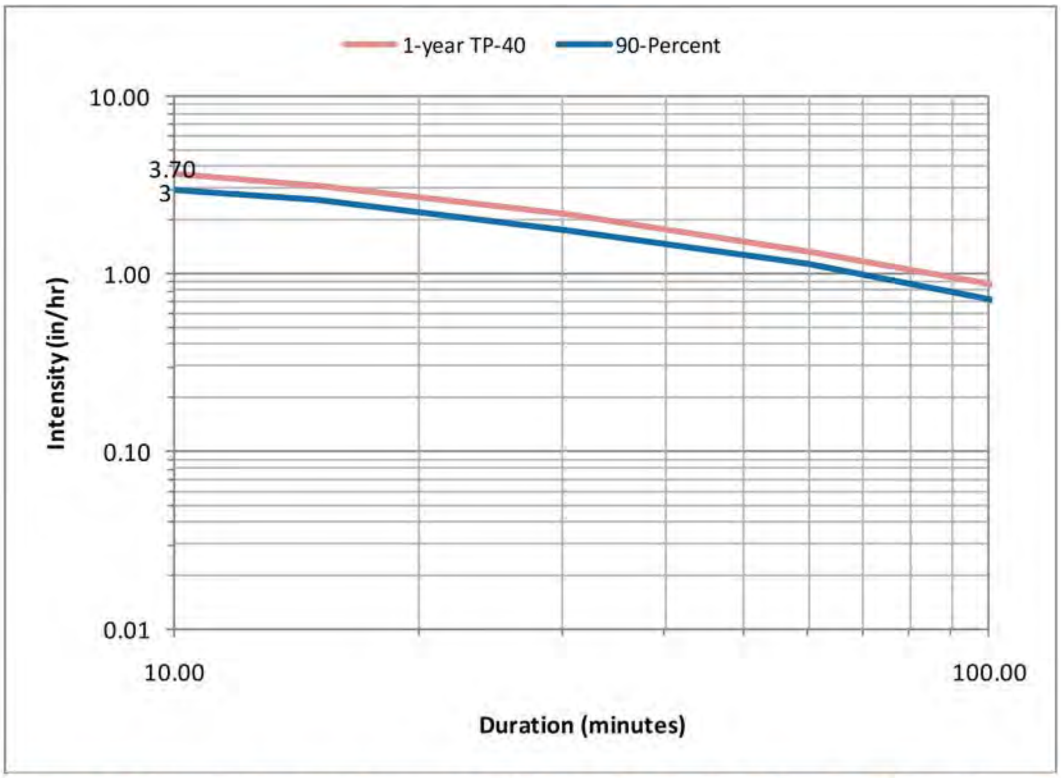

Figure D-2 Intensity-Duration-Frequency (IDF) Curves for Omaha, Nebraska. (Adapted from TP-40).

The 90-percent curve in Figure D-2 can be used to estimate the rainfall intensity to be used in the Rational equation for flow-through BMPs. The 90-percent rainfall intensities are less than those for the 1-year return interval; however, they can be related back to a 0.5 inches runoff capture, and the 90-percent intensity curve can be used for multiple durations.

To remain consistent with the City's ordinance on the 0.5 inches of runoff, CDM Smith calculated the peak flow per acre of drainage area for a variety of storm durations based on a C = 0.5 as shown in Figure D-3. The graph in Figure D-3 can be used to determine a required peak flow rate for flow through BMPs. Using Figure D-3 to determine a peak flow rate is consistent with the BMP sizing criteria of capturing 0.5 inches of runoff, regardless of subarea runoff coefficient.

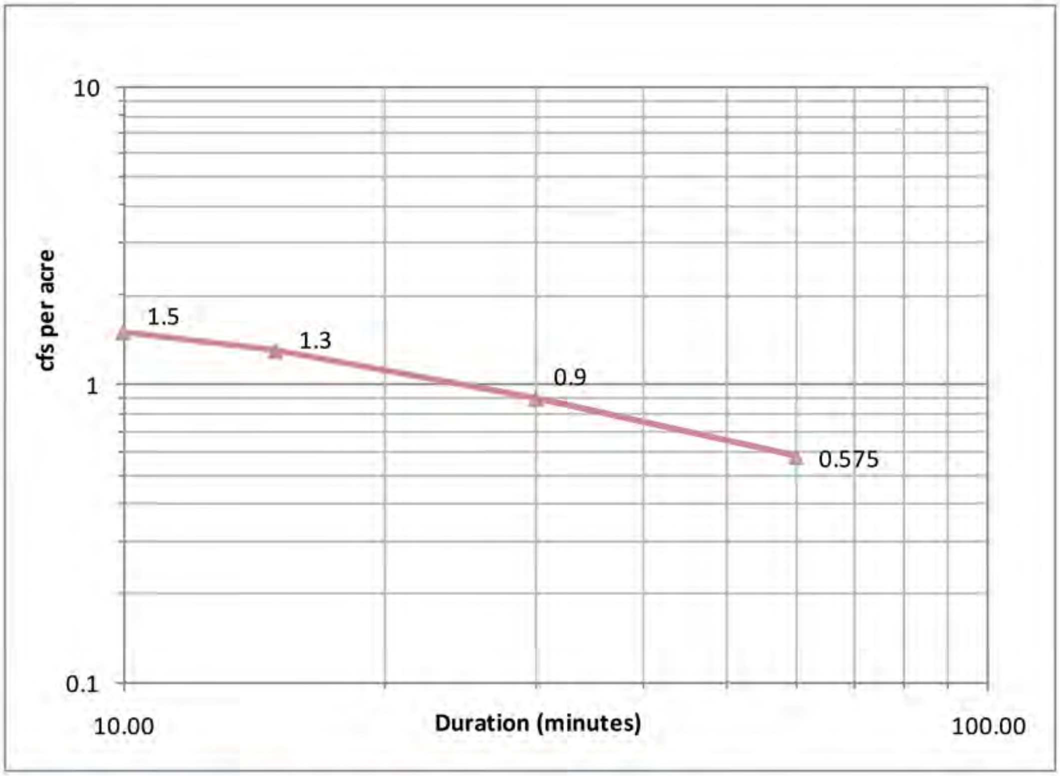

Figure D-3 CFS Per Acre for C=0.5 and 90-Percent Intensity

Alternatively, flow-through BMPs perform best when applied to small drainage areas that have a small time of concentration. Therefore, the City could decide to simplify the design standard by choosing an estimated time of concentration and design duration, for example: 10 minutes, and require all flow-through BMPs be sized using the corresponding cubic feet per second (cfs) per acre (1.5 cfs per acre for 10-minute duration).

(This page was intentionally left blank)

Appendix 8-E

Background Information on Cascading Planes

(This page was intentionally left blank)

Appendix 8-E
Background Information on Cascading Plane

When stormwater that is generated as runoff from impervious areas is conveyed through pervious areas (through swales, strips, turf areas, etc.) the runoff volume and peak flow rate is reduced[1]. When pervious areas receive runoff from impervious areas the concept is known as cascading planes.[2] When pervious areas receive runoff from impervious areas the concept is known as cascading planes.[3] Figure E-1 provides an illustration of the cascading planes concept.

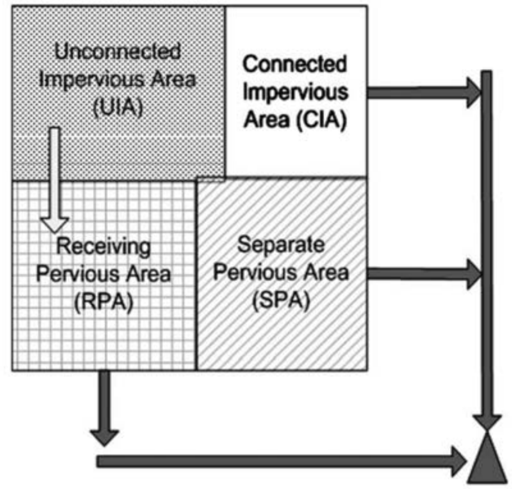

Figure E-1 Schematic of Cascading Planes Concept. Source: Guo, et.al. Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs. ASCE Journal of Environmental Engineering December 2010.

Effective impervious (I_E) can be used to represent the runoff volume reduction due to cascading planes. The Urban Drainage and Flood Control District of Denver uses the concept of effective impervious to account for runoff volumes that are reduced by using LID conveyance BMPs such as grass swales, vegetated buffers, disconnection of roof drains and other impervious areas draining to pervious areas.[4] The effective impervious area concept is described in Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs by Guo, et.al.[5]

The paragraphs below describe using the relationships described in Guo, 2010 as a method of estimating volume reduction for site developments that use LID conveyance BMPs in the City of Omaha. The reduction in the design volume of the downstream structural BMP is based on the idea that a portion of the 0.5 inches of runoff is "captured and controlled" within the conveyance BMP or pervious area. The amount controlled is calculated using the following equation:

Depth of Runoff Controlled, inches = 0.5 - 0.5 x K Equation E-1

Where:

K	=	$e^{[-0.0052(100-I_A)f/i]}$ = pavement-area-reduction factor (PARF), equation provided by Guo, 2010.
I_A	=	area-weighted imperviousness percent for cascading plane = UCIA / (UCIA + RPA)
UCIA	=	unconnected impervious area, acres
RPA	=	receiving pervious areas, acres
f	=	infiltration rate on the pervious surface, in/hr
i	=	average rainfall intensity, in/hr = 0.6 inches per hour for the City of Omaha (Figure 3-1 from Urban Drainage and Flood Control District Urban Storm Drainage Criteria Manual Volume 3, November 2010)

---

[1] Guo, et.al. Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs. ASCE Journal of Environmental Engineering December 2010.
[2] Guo, et.al. Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs. ASCE Journal of Environmental Engineering December 2010.
[3] Guo, et.al. Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs. ASCE Journal of Environmental Engineering December 2010.
[4] Urban Drainage and Flood Control District Urban Storm Drainage Criteria Manual, Vol. 3 November 2010, page 3-15
[5] Guo, et.al. Incentive Index Developed to Evaluate Storm-Water Low-Impact Designs. ASCE Journal of Environmental Engineering December 2010.

Table E-1 shows the results of Equation E-1 for varying percent imperviousness of cascading planes and soil infiltration rates. An example application using Table E-1 is provided below.

Table E-1
Depth of Runoff Controlled (in inches) by Cascading Planes

Percent Impervious of Cascading Planes, %	f, in/hr[1]								
	0.12	0.16	0.26	0.34	0.43	0.83	1.04	1.92	5.85
	Soil Texture Classification								
	Clay	Sandy Clay	Clay Loam	Sandy Clay Loam	Loam	Silt Loam	Sandy Loam	Loamy Sand	Sand
1	0.049	0.064	0.100	0.127	0.154	0.255	0.295	0.404	0.497
10	0.045	0.059	0.092	0.116	0.142	0.238	0.278	0.388	0.495
20	0.040	0.053	0.082	0.105	0.129	0.219	0.257	0.368	0.491
30	0.035	0.046	0.073	0.093	0.115	0.198	0.234	0.344	0.486
40	0.030	0.040	0.063	0.081	0.100	0.175	0.209	0.316	0.476
50	0.025	0.033	0.053	0.068	0.085	0.151	0.181	0.282	0.460
60	0.025	0.027	0.043	0.056	0.069	0.125	0.151	0.243	0.434
70	0.015	0.020	0.033	0.042	0.053	0.097	0.118	0.196	0.391
80	0.010	0.014	0.022	0.029	0.036	0.067	0.082	0.142	0.319
90	0.005	0.007	0.011	0.015	0.018	0.035	0.043	0.077	0.199
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[1]Values for conveyance-based BMPs from Urban Drainage and Flood Control District Urban Storm Drainage Criteria Manual Volume 3, page 3-17

Example Application

Consider a 10-acre site with future impervious area of 70-percent. The ordinance requires the capture and treatment of the first 0.5 inches of runoff equating to a WQCV of 5 acre-inches or 0.417 acre-feet.

Scenario 1- Traditional Development

The 7 acres of impervious area is directed to the storm drain. There is no contribution of runoff from the impervious areas to the pervious areas. In this scenario, the design water quality volume for the site is 0.417 acre-feet as there is no allowance for reducing runoff volume.

Scenario 2- LID Conveyance Development

In Scenario 2, 6 of the 7 acres of impervious area is directed to the storm drain. The remaining 1 acre of impervious area flows to one acre of turf lawn on sandy-clay-loam soil with infiltration rates of 0.34 inches per hour. The volume runoff from the 1 acre of impervious area which flows to the pervious areas is reduced. First the percent imperviousness of the cascading planes is calculated.

I_A = UCIA / (UCIA + RPA) = (1 acre / (1 acre + 1 acres) = 50%

Then, using Table E-1, the WQCV allowance for I_A = 50 percent and f = 0.34 inches per hour is 0.068 inches.

The design WQCV is reduced to 0.432 inches (0.5 inches – 0.068 inches) for the 2 acres of cascading planes and the remainder of the site does not qualify for a reduction in WQCV. If a structural BMP is placed downstream of the cascading planes, then it will be sized using the 0.432 inches of runoff. If a structural

BMP is placed at the downstream end of the entire site, the WQCV allowance applies only to the cascading planes portion. Therefore, the design volume for the BMP would be the area weighted total calculated as:

$$WQCV_{site} = 0.432\ inches * \frac{1\ ft}{12\ inches} * 2\ acres + 0.5\ inches * \frac{1\ ft}{12\ inches} * 8\ acres = 0.405\ acre - feet$$

Table E-2
WQCV Allowance Summary

Scenario	Area	Description	Site WQCV
Scenario 1	10 Acres	Typical Site Design – 70% Impervious	0.417 acre-feet
Scenario 2	10 Acres	LID Design – 70% Impervious 1 acre of UCIA drains to 1 acre of RPA	0.405 acre-feet

(This page was intentionally left blank)

Appendix 8-F

Example Bioretention Facility Specifications

(This page was intentionally left blank)

Appendix 8-F
Example Bioretention Facility Specification

BIORETENTION GARDENS

9003.1 Description

Bioretention gardens are small landscaped basins intended to provide water quality management by filtering stormwater runoff before release into storm drain systems or natural channels. This work shall consist of installing bioretention gardens as specified in the Contract Documents, including all materials, equipment, labor and services required to perform the work.

9003.2 Materials

A. Bioretention Soil Mixture: The Bioretention Soil Mixture (BSM) is composed of the following materials:

Item	Composition By Volume	Reference
Organic Compost	50%	See below.
Sand	50%	ASTM C33 Fine Aggregate

The BSM shall be a uniform mix, free of plant residue, stones, stumps, roots or other similar objects larger than two inches excluding mulch. No other materials or substances shall be mixed or dumped within the bioretention garden that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations.

B. Organic Compost: The compost used in the BSM and soil conditioned areas shall be derived from plant material, and the result of biological degradation and transformation of plant derived materials under conditions that promote anaerobic decomposition. The material shall be well composted, free of viable weed seeds, and stabilized with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the criteria presented below as reported by the U.S. Composting Council STA Compost Technical Data Sheet provided by the vendor. OmaGro is a locally produced compost product that is acceptable for use in bioretention gardens.

Compost Criteria
One hundred percent of the material must pass through a half inch screen
The pH of the material shall be between 6 and 8
Manufactured inert material (plastic, concrete, ceramics, metal, etc.) shall be less than 1.0% by weight.
Organic matter should be between 35 and 65 %
Soluble salt content shall be less than 6.0 mmhos/cm
Maturity should be greater than 80 %
Stability shall be 7 or less
Carbon/nitrogen ratio shall be less than 25:1
Trace metal test result = “pass”
The compost must have a dry bulk density ranging from 40 to 50 lbs/ft^3.

C. Other Materials

Material	Specification
No. 57 Aggregate	ASTM D448
No. 7 Aggregate	ASTM D448
4-inch HDPE Plastic Pipe Underdrain	AASHTO M252
Geotextile Fabric	AASHTO M288
Mulch, 2x Shredded Hardwood Bark	See below
Water	See below.

Shredded Hardwood Mulch: Shredded hardwood mulch shall be aged a minimum of 6 months and consist of the bark and wood (50/50) from hardwood trees which has been milled and screened to a maximum 4-inch particle size and provide a uniform texture free from sawdust, clay, soil, foreign materials, and any artificially introduced chemical compounds that would be detrimental to plant or animal life.

Aggregate: No. 7 and No. 57 Aggregate shall be double-washed to reduce suspended solids and potential for clogging. The aggregate shall be placed as shown in the Contract Drawings.

Water: Water used in the planting, establishing, or caring for vegetation shall be free from any substance that is injurious to plant life.

9003.3 Construction

The underdrain or BSM shall not be placed until all contributing drainage areas are permanently stabilized against erosion and sedimentation as shown on the Contract Plans and to the satisfaction of the Engineer. Any discharge of sediment that affects the performance of the cell will require reconstruction of the cell to restore its defined performance. No heavy equipment shall operate within the perimeter of a bioretention garden during underdrain placement, backfilling, planting, or mulching of the garden.

A. Excavation: If the bioretention garden is to be used as a temporary sediment basin the bioretention garden shall be excavated to the dimensions, side slopes, and ***6 inches above*** the bottom of the BSM elevations shown on the Contract Plans. Any sediment from construction operations deposited in the bioretention garden shall be completely removed from the garden after all vegetation, including landscaping within the drainage area of the bioretention garden, has been established. The excavation limits shall then be final graded to the dimensions, side slopes, and ***final*** elevations shown on the Contract Plans. Excavators and backhoes, operating on the ground adjacent to the bioretention garden, shall be used to excavate the garden if possible, by low ground-contact pressure equipment or, if approved by the engineer, by excavators and/or backhoes operating on the ground adjacent to the bioretention garden. Low ground-contact pressure equipment is preferred on bioretention gardens to minimize disturbance to established areas around perimeter of cell. No heavy equipment shall be used within the perimeter of the bioretention garden before, during, or after the placement of the BSM.

Excavated materials shall be removed from the bioretention garden site. Excavated materials shall be used or disposed of in conformance with the project specifications.

B. Roto-tilling: After placing the underdrain and aggregate and before the BSM, the bottom of the excavation shall be roto-tilled to a minimum depth of 6 inches to alleviate any compaction of the garden bottom. Any substitute method for roto-tilling must be approved by the Engineer prior to use. Any ponded water shall be removed from the bottom of the garden and the soil shall be friable before roto-tilling. The roto-tilling shall not be done where the soil supports the aggregate bed underneath the "Underdrain for Bioretention". (See "Underdrain for Bioretention" specifications below.)

C. Underdrain for bioretention: The underdrain system, aggregate bed, and geotextile fabric shall be placed according to dimensions shown on the Contract Plans.

D. Observation wells/cleanouts of 4-inch non-perforated HDPE pipe shall be placed vertically in the bioretention garden as shown on the Contract Plans. The wells/cleanouts shall be connected to the perforated underdrain with the appropriate manufactured connections as shown on the Contract Plans. The wells/cleanouts shall extend 6 inches above the top elevation of the bioretention garden mulch, and shall be capped with a screw cap.

E. Placement of the BSM: The BSM shall be placed and graded using <u>low ground-contact pressure equipment</u> or, if approved by the engineer, by excavators and/or backhoes operating on the ground adjacent to the bioretention garden. Low ground-contact pressure equipment is preferred on bioretention gardens to minimize disturbance to established areas around perimeter of cell. No heavy equipment shall be used within the perimeter of the bioretention garden before, during, or after the placement of the BSM. The BSM shall be placed in horizontal lifts in depths not exceeding 12 inches for the entire area of the bioretention garden. The BSM shall be pre-mixed, with a moisture content low enough to prevent clumping and compaction during placement. If the BSM becomes contaminated during the construction of the garden, the contaminated material shall be removed and replaced with uncontaminated material at the Contractor's expense. Final grading of the BSM shall be performed after a 24-hour settling period. Upon final grading the surface of the BSM shall be roto-tilled to a depth of 6". Final elevations shall be within 2 inches of elevations shown on the Contract Plans.

F. Soil Conditioning of Ponding Area: Ensure there is no standing water within the ponding area prior to beginning the soil conditioning process to avoid further compacting soils. Existing vegetation, including turf, shall be removed and the ground shall be tilled to a minimum depth of 6 inches. A 3-inch deep layer of specified compost shall be placed on top of the tilled ground and tilled into a depth of 6 inches of existing soil. Fine grading of the site shall be completed with a minimum number of equipment passes (no more than two (2) passes) to reduce the potential for soil compaction. Finalizing all preliminary critical spot elevation, slopes and positive drainage criteria for the site shall be completed as much as possible prior to finish grading in order to ensure that equipment compaction is minimized after soil is worked an amended. Soil shall be firmed using one pass of a 50-pound roller if vegetative cover will be seeded or plugged to help ensure successful plant establishment. Vegetative cover shall be established immediately after finish grading and erosion shall be prevented during establishment, including but not limited to installing erosion control blankets, silt fence or straw waddles. Vegetation may be sodded, seeded, or plugged. For seeding or plugging, all standard procedures shall be followed for the appropriate mulching of bare soil surface areas until vegetation is fully established.

G. Mulching: Once grading is complete, the entire surface of the BSM shall be mulched to a uniform thickness of 3 inches. Mulching shall be complete within 24 hours to reduce the potential of silt accumulation on the surface. Well aged shredded hardwood bark mulch is the only acceptable mulch. Mulching shall be done immediately after grading to reduce potential of any silt accumulation on the surface.

H. Plant Installation: Trees, shrubs, and other plant materials specified for Bioretention Gardens shall be planted as specified in the Contract Plans and applicable landscaping standards with the exception that pesticides, herbicides, and fertilizer shall not be applied during planting under any circumstances. Furthermore, pesticides, fertilizer, and any other soil amendments shall not be applied to the bioretention garden during landscape construction, plant establishment, or maintenance.

9003.4 Method of Measurement

Bioretention gardens will be measured by the square foot and will be paid for at the Contract Unit Price.

9003.5 Basis of Payment

The payment will be full compensation for all material, labor, equipment, tools, and incidentals necessary to satisfactorily complete the work. Biological plantings will be paid for separately under other items of the contract.

References:

MARC and APWA. 2009. Manual of Best Management Practices for Stormwater Quality.

Wisconsin Department of Natural Resources (WDNR).November 2010. Bioretention for Infiltration (1004). http://dnr.wi.gov/topic/stormwater/documents/Bioretention1004.pdf