

December 2013

Public Improvement Specifications Chapter 14: Stormwater Quality Management

Introduction:

This Chapter shall be applicable to all subdivision or site plan applications that disturb one acre or more per KYR10 and are located within the City limits or within the Phase II boundary of Daviess County unless eligible for an exemption or granted a waiver by the City of Owensboro or Daviess County under the specifications of the Stormwater Ordinance and the OMPC Public Improvement Specifications.

This Chapter also applies to sites disturbing less than one acre within the City limits that meet one or both of the following criteria:

- Results in an increase in impervious surface* of ¼ acre or greater, OR
- Will result in an increase in runoff rate of one (1) cfs or more from the previous condition

***NOTE:** areas of permeable pavement may be counted as 50% pervious and 50% impervious.

This Chapter also applies to land development activities that are located within the City limits or within the Phase II boundary of Daviess County that are smaller than one (1) acre, if such activities are part of a larger common plan of development. A map of the City/County Phase II boundary can be found at <http://www.Owensboro.org/engineering/stormwater>

Site development plans submitted as a redevelopment project as defined in the applicable Stormwater Ordinance, are subject to permitting and on-site stormwater requirements as determined by the City of Owensboro or Daviess County. Each redevelopment project shall have no net increase in imperviousness without an approved development plan or site plan.

No excavation, cut or fill of earth or debris shall be undertaken unless an Excavation, Cut or Fill permit is issued by the City or County Engineer.

(a) Post construction stormwater quality management in new development, redevelopment, and existing systems

Post-Construction Stormwater Management is a key element of the MS4 permit and the Nation's and Commonwealth's strategy for achieving the goals of the Clean Water Act. An effective Post-Construction Stormwater Management program has the ability to positively impact the chemical, biological, and overall health of the Commonwealth's streams, rivers, and lakes by reducing the rate and volume of, and improving the quality of, stormwater runoff from the MS4.

Post-Construction Stormwater Management refers to the activities that take place after construction is completed, and includes structural and non-structural stormwater controls that protect the environment from the harmful impacts of urban stormwater runoff. Stormwater BMPs incorporate planning practices and site improvements in a manner that promotes groundwater recharge, reduces the volume of, reduces peak discharge rates of, and removes pollutants from runoff.

All *Storm Water Management Plans* shall provide details related to all aspects of the construction. Developments are to be designed to ensure that controls are in place that would prevent or minimize water quality impacts. Designers are to develop and implement strategies, which include a combination of structural and/or non-structural Best Management Practices (BMPs) appropriate for the community. The plans must also ensure adequate long-term operation and maintenance of BMPs through notes or labels on construction drawings, Final Subdivision Plats, and Final Site Plans.

Supporting documentation is required to provide calculations justifying the use of the BMPs specified in the plans. These documents are to be submitted in conjunction with the Construction Plans for proposed developments. All proposed stormwater management plans are to be certified by the designer that the plans comply with the local city or county regulations (as applicable). Upon completion of the project, the designer shall certify that the infrastructure was built according to the design drawings and standards.

(b) Post-Construction Stormwater Management Site Performance Criteria

Unless judged by the City of Owensboro or Daviess County to be exempt or granted a waiver, the following performance criteria shall be addressed for stormwater quality management at all sites:

1. All site designs shall establish post-construction stormwater management practices to control the peak flow rates of stormwater discharge and reduce the generation of stormwater runoff. Where applicable, these practices should seek to utilize pervious areas for stormwater treatment and to infiltrate stormwater runoff from driveways, sidewalks, rooftops, parking lots, and landscaped areas to the maximum extent practical.
2. Post-construction stormwater management measures shall be required, in combination or alone, that are designed, built, and maintained to treat, filter, flocculate, infiltrate, screen, evapo-transpire, harvest and reuse the first **0.64** inches of a rain event (measured over the impervious area) in order to manage stormwater runoff quality.

Example: A commercial site 25,000 square feet of impervious surface is proposed. Measures (BMPs) must be designed to effectively treat the runoff volume generated from a 0.64 inch rainfall event falling on the impervious surface which equates to 0.03 ac-ft or 1333 cubic feet (see section (c) Stormwater Runoff Water Quality Treatment). If topography indicates that runoff will leave the site in more than one location the BMPs must be sized according to that portion of the runoff reaching them (i.e. if runoff is split so 30% goes to one exit point and 70% to another they must treat 400 cf and 933 cf of runoff, respectively).

3. Structural and non-structural controls may be used to obtain permanent stormwater management over the life of the property's use. Structural stormwater controls include, but are not limited to, grass swales, filter strips, infiltration basins, detention ponds, stormwater wetlands, natural filtration areas, sand filters, and rain gardens. Non-structural BMPs incorporate site planning and design techniques including, but not limited to, open spaces, vegetated conveyances and buffers, natural infiltration, and low impact development. Engineer shall check for tailwater conditions that may result from the water quality standard rainfall event and tailwater conditions shall be accounted for in outlet designs.
4. Areas of development and re-development that result in new or expanded discharge to high quality waters (HQWs) shall follow the "Standards for Protection of HQWs" in that follow in section (d) in order to protect existing in-stream water uses and the level of water quality necessary to protect existing uses.

High Quality Waters are defined as follows in 401 KAR 10:030 Section 1(3) (<http://www.lrc.ky.gov/kar/401/010/030.htm>):

1. A surface water shall be categorized as high quality water if the surface water is not listed as an outstanding national resource water or an exceptional water in Table 1 or 2 of this section and if the surface water does not meet the criteria for impaired water as provided for in subsection 4(a) of this section. (below)
 2. A surface water shall be categorized as a high quality water if the surface water is listed as an outstanding state resource water in 401 KAR 10:026 and is not listed as an outstanding national resource water in Table 1 or an exceptional water in Table 2 of this section.
- (4) Impaired water.
- (a) Categorization criteria. A surface water categorized as impaired for applicable designated uses shall be a water identified pursuant to 33 U.S.C. 1315(b).
 1. Surface water categorized as impaired shall be assessed by the cabinet as not fully supporting any applicable designated uses.
 2. A surface water shall not be categorized as impaired water if the surface water is listed as an outstanding state resource water in 401 KAR 10:026.
 3. A surface water shall not be categorized as impaired for the purposes of this administrative regulation if the surface water is listed only as mercury impaired for fish consumption.

Note: As of November 2013, there are no identified outstanding natural resource waters, exceptional waters, or outstanding state resource water in Daviess County.

5. A Stormwater Pollution Prevention Plan (SWPPP) shall be prepared and implemented and a Notice of Intent (NOI) filed under the provisions of the National Pollutant Discharge Elimination System (NPDES) general or individual permit. The SWPPP requirement applies to both existing and new development sites.
6. Stormwater discharges from land uses or activities with higher potential pollutant loadings, known as “hotspots”, may require the use of specific structural Stormwater Treatment Practices (STPs) and pollution prevention practices. Examples include business and industry producing or storing hazardous materials (petro-chemicals, toxic and persistent chemicals, metals, or biological substances). Wellhead Protection Zones shall also be considered hotspots due to the sensitivity of the area with regard to potential contamination of local aquifers.
7. Stormwater design calculations shall follow the current Subdivision Regulations and Public Improvement Specifications for Owensboro/Daviess County and incorporate the “Stormwater Runoff Quality Treatment Standard” accepted by the City of Owensboro and Daviess County that follows below.

(c) Stormwater Runoff Water Quality Treatment Standard

In urban areas the first flush of runoff pollutants carries a heavy load of pollutants from impervious areas such as streets and parking areas that can negatively impact receiving streams by altering the water chemistry and water quality. Capturing the “First Flush” of pollutants is one way to improve water quality leaving the MS4. The goal of this stormwater runoff quality treatment standard is to establish the water quality volume (WQ_v) metric and provide treatment for the WQ_v.

The term “water quality volume” is generally used to define the amount of storm water runoff from any given storm that should be captured and treated in order to remove a majority of storm water pollutants on an

average annual basis. Therefore, daily precipitation records were retrieved from the UK Ag Weather Station website (<http://www.agwx.ca.uky.edu/climdata.html>) between 1971 and 2010 for the Henderson and Evansville climatology stations. The data was sorted by depth with zero or trace amounts removed and the total number of rainfall events was multiplied by 0.8 to determine the event depth at which 80% of the total number of events were equal to or less than. The resulting average depth between the two stations was **0.64 inches**.

Completing the exercise for the two stations provided a better assessment of area climatology. The determined depths showed no difference in the 80% event depth. Therefore, the depth of 0.64 inches determined from either station is a representative event depth to use as the rainfall basis for the stormwater runoff quality treatment standard for Owensboro and Daviess County.

The water quality volume (WQ_v) can then be calculated using the formula below:

$$WQ_v = \left(\frac{A * d}{43560 \text{ ft}^2 / \text{ac} * 12 \text{ in} / \text{ft}} \right)$$

WQ_v = Ac•ft

A = Impervious area (ft²)

d = 0.64 (in)

The calculated WQ_v shall be treated in combination or alone, by management measures that are designed, built, and maintained to treat, filter, flocculate, infiltrate, screen, evapotranspire, harvest and reuse stormwater runoff, or otherwise manage the stormwater runoff quality.

If the proposed BMP has a flow-based performance standard, the water quality treatment flow rate can then be calculated using the Rational equation below:

$$WQ_Q = C * I * A$$

WQ_Q = cfs

C = runoff coefficient for impervious surfaces = 0.9

I = intensity factor for 0.64" rainfall (2 yr, 10 min) = 3.99

A = impervious area (ac)

(d) Standards for Protection of High Quality Waters (HQW)

Further justification of the requirements for a defined water quality standard are identified in KRS statutes as they pertain to High Quality Waters. KYR10 follows 401 KAR 10:030, Section 1(3) (Antidegradation Policy – High Quality Waters), which says a surface water shall be classified as a high quality water (HQW) if the surface water is not listed as an outstanding national resource, an exceptional water, or does not meet the criteria for impaired water. Currently, ~90% of the waters of the Commonwealth are categorized as HQWs and are subject to antidegradation implementation procedures, which requires maintaining and protecting existing in-stream water uses and the level of water quality necessary to protect the existing uses.

Waters of the Commonwealth and Waters of the US are defined as follows:

1. Waters of the Commonwealth (from KPDES No. KYG200000) means and includes any and all rivers, streams, creeks, lakes, ponds, impounding reservoirs, springs, wells, marshes, and all other bodies of surface or underground water, natural or artificial, situated wholly or partly within or bordering upon the Commonwealth or within its jurisdiction.
2. Waters of the United States, as defined by the Clean Water Act, applies only to surface waters, rivers, lakes, estuaries, coastal waters and wetlands. Not all surface waters are legally Waters of the United States. Generally those waters include the following:
 - a. All interstate waters
 - b. Intrastate waters used in interstate and/or foreign commerce
 - c. Tributaries of the above
 - d. Territorial seas at the cyclical high tide mark, and
 - e. Wetlands adjacent to all of the above.

Impaired Waterways in Daviess County are summarized in Exhibit 14.1

Areas of development and/or redevelopment inside a HQW watershed that result in new or expanded discharge from the MS4 shall:

1. Provide sufficient detention, storage, or infiltration BMPs to maintain or improve upon pre-construction flow in order to protect the existing in-stream designated water uses; and
2. Provide the necessary BMPs that focus on removal of pollutants most common to the type of development occurring in order to maintain the level of water quality that protects existing uses. BMPs selected for the site shall be approved by the City or County Engineer or their designee.
3. Areas of redevelopment will be required to meet the same water quantity criteria as new development, and will need to provide water quality treatment at a level equivalent to 20% of the requirement for new development. This shall be determined by calculating the required water quality volume and multiplying the result by 0.2. This reduction is allowed due to the inherent nature of redevelopment sites and the difficulty and limitations in retrofit options with redevelopment.
4. BMPs will be approved on a case-by-case basis by the local permitting authority to provide reasonable assurance that the BMPs selected are appropriate for the site and pollutants of concern.

(e) Exemptions for Providing Post-Construction Stormwater Management

Post-construction stormwater management measures must be implemented at construction sites meeting the criteria identified in the introduction of this chapter. The following activities may be exempt from the post-construction stormwater performance criteria:

- (1) Any logging and agricultural activity which is consistent with an approved soil conservation plan or a timber management plan approved by the City of Owensboro and Daviess County, as applicable;
- (2) Additions or modifications to existing single family structures;
- (3) Repairs to any stormwater treatment practice deemed necessary by the City of Owensboro and Daviess County;
- (4) Any emergency project that is immediately necessary for the protection of life, property or natural resource;
- (5) Linear construction projects, such as pipeline or utility line installation, that do not result in the installation of any additional impervious cover, as determined by the City of Owensboro or Daviess County;
- (6) Developments that result in less than ¼ acre of new impervious surface either through a single or multi-phase development plan.

(f) Waivers for Providing Post-Construction Stormwater Management

The minimum requirements for post-construction stormwater management may be waived in whole or in part upon written request of the applicant, provided that at least one of the following conditions applies:

- (1) It can be demonstrated that the proposed development is not likely to impair attainment of the objectives of this chapter;
- (2) The City Engineer of Owensboro or Daviess County Engineer finds that meeting the minimum on-site management requirements is not feasible due to the natural or existing physical characteristics of a site. Feasibility issues may involve one or more of the following:

- a. Cannot meet development requirements (setbacks, parking, sidewalks) for the zoned use while incorporating water quality BMPs
- b. Water table or rock preclude any effective infiltration BMP options
- c. Conventional BMPs cannot be implemented due to constraints with tying into existing infrastructure or waterways (depth, slope, adequate cover)
- d. Major Utility conflicts as determined by the City or County Engineer

Note: Project scheduling and/or budgets shall not be considered as rationale for waivers. Also, if the potential for impairment is likely, waivers or in-lieu compensation shall only be considered after all other options have been considered.

Where the City of Owensboro or Daviess County waives all or part of the minimum post-construction stormwater management requirements, or where the waiver is based on the provision of adequate stormwater facilities provided downstream of the proposed development, the applicant may be required to provide one of the following mitigation options as determined by the City of Owensboro or Daviess County:

- (1) A monetary contribution may be required in-lieu of the post-construction stormwater management practices as established by the City of Owensboro or Daviess County in the Public Improvement Specifications. All of the monetary contributions shall be credited to an appropriate stormwater quality capital improvements program project or maintenance of existing public BMPs, and shall be made by the developer prior to the issuance of any Cut and Fill permit for the development. In lieu fees shall be calculated according to the following equation:

$$ILF = (WQ) * (BR) * (1.5) + M \quad \text{where,}$$

ILF = in lieu fee (\$)

WQ = Water Quality Volume (cu. Ft) OR Flow Rate (cfs)

BR = BMP design and construction Bond Rate (\$/cu.ft or \$/cfs)

M = 5-year maintenance lump sum = \$5,000

Reference the Owensboro Public Improvements Surety Unit Costs for cu.ft. and cfs Bond Rate for impervious area.

- (2) In lieu of a monetary contribution, an applicant may obtain a waiver of the required post-construction stormwater management by entering into an agreement with the City of Owensboro or Daviess County to perform off-site mitigation in the same watershed as the original project. The off-site facility shall be designed and adequately sized to provide a level of stormwater control that is equal to or greater than that which would be afforded by on-site practices, and the developer or applicant shall enter into a long-term operation and maintenance agreement for the stormwater practice.

(g) Procedure for Exemptions and Waivers

Exemptions or waivers from post-construction stormwater management requirements shall not result in development or re-development that undermines the purpose of the Stormwater Ordinance and this Chapter. Written requests for exemptions or waivers shall be submitted to the City of Owensboro or Daviess County for approval.

For any waiver request, the applicant must demonstrate to the satisfaction of the City of Owensboro or Daviess County that the construction project will not result in the following impacts to downstream waterways:

- (1) Deterioration of existing culverts, bridges, dams, and other structures;
- (2) Degradation of biological functions or habitat;

- (3) Accelerated streambank or streambed erosion or siltation;
- (4) Increased threat of flood damage to public health, life, or property.

(h) Low Impact Development Practices

Introduction

Low Impact Development (LID) is a storm water management strategy concerned with maintaining or restoring the natural hydrologic functions of a site to achieve natural resource protection objectives and fulfill environmental regulatory requirements. LID employs a variety of natural and built features that reduce the rate of runoff, filter out its pollutants, and facilitate the infiltration of water into the ground. By reducing water pollution and increasing groundwater recharge, LID helps improve the quality of receiving surface waters and stabilize the flow rates of nearby streams.

Conventional storm water management systems rely on collection and conveyance systems to remove water safely from developed areas and protect life, property, and health. The systems are engineered and designed according to estimates of post development storm water flows and volumes from pervious and impervious areas. LID storm water management systems can reduce development costs through reduction or elimination of conventional storm water conveyance and collection systems. LID systems can reduce the need for paving, curb and gutter, piping, inlet structures, and storm water ponds by treating water at its source instead of at the end of the pipe. Municipalities also benefit in the long term through reduced maintenance costs.

There are numerous design practices and technologies developers can use through the LID approach. For instance, developers can work together with municipal officials and the general public during the initial planning stages of development to identify environmental protection opportunities. Examples may include saving trees on the site, avoiding designated sensitive areas, and orienting roads and lots to allow for passive solar orientation of homes. LID technologies can be structural or nonstructural. Sand filters and dry wells are examples of structural technologies used for water quality. Nonstructural technologies often use natural features or are land use strategies. Disconnecting rain gutters from storm water drains and redirection of rainwater toward rain gardens or grass swales are examples of nonstructural technologies.

While LID may benefit all types of development, it is best suited for new, suburban residential development. Moreover, the LID practices and technologies are best integrated into a developer's existing land development process and practices. With some planning, the technologies can be integrated into today's land development projects. Developers can decide which technology or combination of technologies will offer the best cost and environmental benefits taking into account the site and also local ordinances.

Benefits of LID

LID takes a second look at traditional development practices and technologies and focuses on identifying project-specific site solutions that benefit the municipality, the developer, the home buyer, and the environment. Besides the fact that LID makes good sense, LID development techniques can offer many benefits to a variety of stakeholders as shown in Exhibit 14.2.

LID Design Strategies

In general, site design strategies for any project will address the arrangement of buildings, roads, parking areas, and other features, and the conveyance of runoff across the site. LID site design strategies achieve all of the basic objectives of site design while also minimizing the generation of runoff. Optimal LID site design minimizes runoff volume and preserves existing flow paths. This minimizes infrastructural requirements. Typical LID site design strategies include the following:

- Grade to encourage sheet flow and lengthen flow paths.
- Maintain natural drainage divides to keep flow paths dispersed.
- Disconnect impervious area such as pavement and roofs from the storm drain network, allowing runoff to be conveyed over pervious areas instead.
- Preserve the naturally vegetated areas and soil types that slow runoff, filter out pollutants, and facilitate infiltration.
- Direct runoff into or across vegetated areas to help filter runoff and encourage recharge.
- Provide small-scale distributed features and devices that help meet regulatory and resource objectives.
- Treat pollutant loads where they are generated, or prevent their generation.

List of BMPs that Qualify as LID Technologies

There are numerous BMPs included in this chapter that are LID practices. The BMP types listed below are examples of LID practices that may be applicable for use in Owensboro and Daviess County.

- Infiltration Systems (biofiltration swales, rain gardens, dry wells)
 - BMPs function by capture and infiltration in a static location similar to detention but with the primary dewatering device being the soil itself. May also be used with underdrains.
- Green Roofs
 - Function similar to Infiltration systems with regard to capture, but dewatering is through underdrain systems, evaporation and evapotranspiration.
- Flow through Conveyance (filter strips, grassed swales)
 - Function by infiltration as runoff is conveyed down slope. Dependent on soils, height of vegetation, and flow depth.
- Infiltration structures (media filters, media inlets, ex Silva cells, filterra units)
 - Function similar to green roofs with capture and slow release through underdrain systems

Environmental Practices and Planning: Credits up to 30% (from individual or a combination of practices below) of the required WQ_v or WQ_Q may be provided for the following practices:

- Open-space Preservation – not applicable to WQ standard compliance but application can be made to reduce the required WQ volume or flow rate required. For every 25% above the required amount as identified in the subdivision regulations, a 10% reduction in WQ_v or WQ_Q is allowed
- Trees, Shrubs, and Vines – not applicable to WQ standard compliance but application can be made to reduce the required WQ volume or flow rate required. For every 25% above the required amount as identified in the subdivision regulations, a 10% reduction in WQ_v or WQ_Q is allowed.
- Preserving existing trees – For every tree greater than or equal to 18" caliper that is adequately preserved (no disturbance or fill inside the drip line), a 5% reduction in WQ_v or WQ_Q is allowed.

Developers are encouraged to use these practices individually or in combined systems to effectively manage storm water runoff on-site. Other practices may be allowed upon approval of the City/County Engineer. Developers shall determine the applicability and appropriateness of BMPs based on the site location, pollutant potential, and BMP performance potential.

(i) Requirements for Stormwater Management Plan Approval.

(a) Stormwater Management Plan Requirements

The Stormwater Management Plan must be submitted for approval and shall include all of the following required information:

1. Contact Information

The name, address, and telephone number of all persons having a legal interest in the property and parcel number of the property or properties affected.

2. Topographic Base Map

A topographic base map of the site which extends a minimum of 100 feet beyond the limits of the proposed development and indicates existing surface water drainage including streams, ponds, culverts, ditches, and wetlands; current land use including all existing structures; locations of utilities, roads, and easements; and significant natural and manmade features not otherwise shown.

3. Calculations

Hydrologic and hydraulic design calculations for the pre-development and post-development conditions shall follow the requirements for the design storms specified in these OMPC PI

Specifications for Owensboro/Daviess County. Such calculations shall include, as applicable, (i) description of the design storm frequency, intensity and duration, (ii) time of concentration, (iii) Soil Curve Numbers or runoff coefficients, (iv) peak runoff rates and total runoff volumes for the watershed associated with a stormwater control measure, (v) infiltration rates (as applicable), (vi) culvert capacities, (vii) flow velocities, (viii) data supporting the design of each stormwater control measure, (ix) documentation of sources for all computation methods and field test results, and (x) the Water Quality Volume calculation. Calculations shall be submitted and stamped by a PE licensed to practice in the State of Kentucky.

4. *Soils Information*

If a stormwater management control measure depends on the hydrologic properties of soils (e.g., infiltration basins), then a soils report shall be submitted. The soils report shall be based on on-site boring logs, soil pit profiles, or other methods approved in advance by the City of Owensboro or Daviess County. The number and location of required soil borings or soil pits shall be determined based on what is needed to determine the suitability and distribution of soil types present at the location of the control measure. Soils information obtained from soils maps are adequate for conceptual design and feasibility studies, but on-site testing is required for detailed and final design plans.

5. *Maintenance, Inspection, and Repair Plan*

The design and planning of all stormwater management facilities shall include detailed maintenance, inspection, and repair procedures to ensure their continued function. These plans will identify the parts or components of a stormwater management facility that need to be maintained and the equipment, skills, or training necessary. The Plan shall make provisions for the periodic review and evaluation of the effectiveness of the maintenance program and require the installer to document such activity and provide the information to the responsible party. Parties responsible for the operations, inspections, and maintenance shall retain all related records for at least three (3) years.

6. *Landscaping Plan*

The applicant must present a detailed plan for management of vegetation at the site after construction is finished, including who will be responsible for the maintenance of vegetation at the site and what practices will be employed to ensure that adequate vegetative cover is preserved.

7. *Maintenance Easements*

Prior to the issuance of any permit that has a stormwater management facility as one of the requirements of the permit, the applicant or owner of the site must execute a maintenance easement agreement that shall be binding on all subsequent owners of land served by the stormwater management facility. The agreement shall provide for access to the facility at reasonable times for periodic inspection (and repair if necessary due to non-compliance) by the City of Owensboro or Daviess County, or their contractor or agent to ensure that the facility is maintained in proper working condition to meet design standards and any other provisions established by this ordinance. The easement agreement shall be recorded by the City of Owensboro or Daviess County in the land records.

8. *Operations and Maintenance Agreement*

Maintenance of all stormwater management facilities shall be ensured through the creation of a formal operation and maintenance agreement that must be approved by the City of Owensboro or Daviess County and recorded into the land record prior to final plan approval. As part of the agreement, a schedule shall be developed for when and how often maintenance will occur to ensure proper function of the stormwater management facility. The agreement shall also include plans for annual inspections to ensure proper performance of the facility between scheduled cleanouts and submittal of annual reports to the City of Owensboro and Daviess County. An example maintenance covenant can be found at <http://www.wiompc.org>. Responsibility of BMP maintenance in Residential developments shall follow the accepted policies of the City or County, as applicable, which will be discussed at the time of plan submittal.

Until such time as the developer is granted release from any maintenance bond and has issued a Notice of Termination on the construction permit, the responsibility of maintenance shall fall upon the developer.

The owner of the property on which the stormwater management facility is located, shall, at the written request of the city or county engineer, employ a licensed professional engineer to certify that the private storm sewer system is being maintained at the level of service for which it was

originally designed. If a determination is made that the property owner is not maintaining the private system at or above the level of service indicated in the original design, a notice of deficiency shall be issued and the standard escalated process of enforcement initiated. It shall be unlawful for any person to refuse to maintain any part of a stormwater management facility that has been approved by the city engineer as part of the SWMP. The system shall be maintained at all times to the level of service it was designed for.

9. *Erosion and Sediment Control Plans for Construction of Stormwater Management Measures*
The applicant must prepare a SWPPP, as applicable to the project, per the City of Owensboro or Daviess County's Stormwater Ordinance, for all construction activities related to implementing any on-site stormwater management practices.

10. *Other Environmental Permits*

The applicant shall assure that all other applicable environmental permits have been acquired for the site prior to approval of the final Stormwater Design Plan

(j) Construction Inspection

The applicant must notify the City of Owensboro or Daviess County in advance before the construction of Post-Construction BMPs or Stormwater Management System. It shall be the responsibility of the contractor to conduct regular inspections of stormwater management system BMPs by qualified inspectors who are qualified through KEPSC qualification training or similar programs. All inspections shall be documented and written reports prepared that contain the following information:

- (1) The date and location of the inspection;
- (2) Whether construction is in compliance with the approved Stormwater Management Plan;
- (3) Variations from the approved construction specifications;
- (4) Installation date of all stormwater measures since the previous inspection; and
- (5) Any violations that exist.

If any violations are found, the property owner shall be notified in writing of the nature of the violation and the required corrective actions. No added work shall proceed until any violations are corrected and all work previously completed has received approval by the City of Owensboro or Daviess County

(k) Surety

The City of Owensboro or Daviess County will require the submittal of surety before OMPC issues a final plat in order to ensure that the stormwater practices are installed by the permit holder as required by the approved Stormwater Management Plan. The surety shall contain forfeiture provisions for failure to complete work specified in the Stormwater Management Plan.

The surety shall be released in full only upon submission of a written certification by a registered professional engineer that the stormwater practice has been installed in accordance with the approved plan and other applicable provisions of the OMPC Public Improvement Specifications. The City of Owensboro or Daviess County will make a final inspection of the stormwater practice to ensure that it is in compliance with the approved plan and the provisions herein prior to any release of surety.

(l) BMP Selection, Installation, and Maintenance

Identify Site Considerations

The objectives in stormwater quality management for each property can vary widely. Therefore, a specific understanding of the site characteristics and nature of the completed project is essential for selecting and implementing BMPs. This information should be carefully assembled and reviewed early in the design process. Once these dynamics are defined, then specific BMPs can be selected. The BMP site considerations should include the following:

Site characteristics and proposed contractor construction sequencing will affect the BMP selection, installation, and protection methods used on the construction site. It is important to plan the project to fit the topography and drainage patterns of the site, and to protect areas that are designated for infiltration practices (to avoid over compaction and/or sediment overloading). During the BMP evaluation and selection process, these factors should be carefully considered:

1. Site conditions that affect erosion, sedimentation, and infiltration which include:
 - a. Soil type, including underlying soil strata that are likely to be exposed
 - b. Natural terrain and slope
 - c. Depth to water table
 - d. Proximity to utilities, well fields, natural features
 - e. Location of concentrated flows, storm drains, and streams
 - f. Existing vegetation and ground cover
2. Other Site conditions related to the proposed design, which include:
 - a. Location of and amount of open space, including consideration of cluster-type development that allows for more open and contiguous open space.
 - b. Final slopes and grades
3. Land Use considerations
4. Construction schedules, construction sequencing, and phasing of construction.
5. Size of construction project and area to be graded.
6. Location of the construction activity relative to adjacent uses and public improvements.
7. Cost-effectiveness considerations.
8. Nature of the ultimate receiving water and any buffer requirements.

Select BMPs

Once the site considerations are evaluated, it is necessary to identify the BMPs that are best suited to the site and the project needs. To determine where to place BMPs, a map of the project site can be prepared with sufficient topographic detail to show existing and proposed drainage patterns and existing and proposed permanent storm water control structures. The project site map should identify the following:

- Locations where storm water enters and exits the site. Include both sheet and channel flow for the existing and final grading contours.
- Identify wetlands, springs, sinkholes, floodplains, floodways, sensitive areas, or buffers, which must not be disturbed, as well as other areas where site improvements will not be constructed. Establish clearing limits around these areas to prevent disturbance by the construction activity.
- Identify the boundaries of tributary areas for each outfall location. Then calculate the approximate area of each tributary area. Also determine the proposed impervious areas within each drainage tributary.

With this site map in hand, categories of BMPs can be selected and located. Detailed planning before construction begins and phasing construction activities provides the best opportunity for success and the most cost-effective solutions.

BMPs that can achieve multiple BMP objectives may be utilized to achieve cost-effective solutions. For instance, a detention facility, if designed with a water quality forebay structure (flow through structural unit or wetland) can provide both water quantity and quality compliance needs. Developers shall utilize the tables, matrices, and Minimum Standards that follow to guide them through the BMP selection process. The selection process should follow three basic steps:

- a. Identify the target pollutant(s), which are those most likely to be generated from the proposed land use

- b. Assess the site and soil conditions for appropriateness of potential BMPs
- c. Select BMPs based on target pollutant removal and site conditions

Target Pollutant(s): Identify the highest priority pollutants expected to be generated on the post-developed site based on land use from the table included as Exhibit 14.3. Exhibit 14.4 lists the event mean concentrations utilized to determine the pollutant generating potential rankings included in Exhibit 14.3.

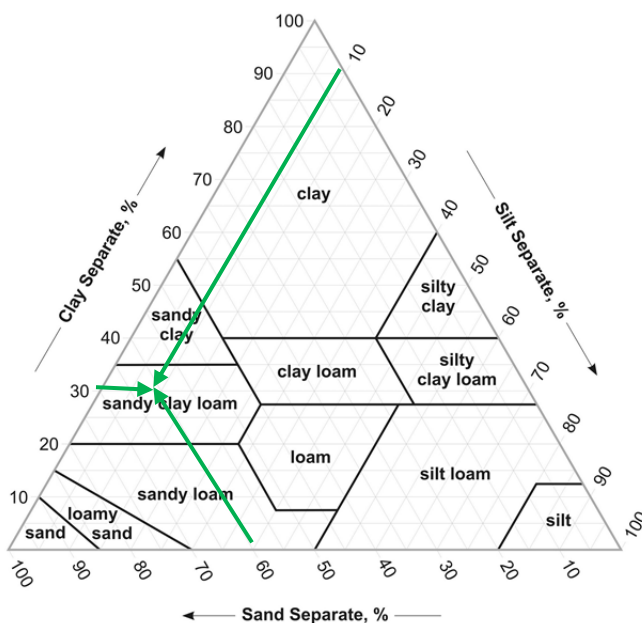
BMP Options: Identify BMPs from Exhibit 14.5 that are effective in treating the target pollutant(s) identified. High pollutant generation potential should be matched with full circle effectiveness BMPs for the specific pollutants. Medium pollution potential should be matched with half-circle effectiveness at a minimum. Low pollution potential may be matched with any effectiveness level.

Minimum Standards providing information on applicability, design, and maintenance for Low Impact Development BMPs are included at the end of this Chapter. For proprietary BMPs including, but not limited to, catch basin or manhole inserts, baffle boxes, oil/water separators, and media filters, the Developer shall provide manufacturer's specifications and supporting design calculations to demonstrate BMP treatment performance based on the required water quality treatment flow.

Soils Characterization: From review of the County Soil Survey and/or through field testing, determine the percent sand, silt, and clay of the soil at the depth at which infiltration will take place (ex, if using a 24 inch underground detention system the soils shall be characteristic of those found at a depth of 24 inches or more, not the topsoil layer). Enter the USDA Textural triangle from each side at the corresponding percent makeup of the three soil particle classes (sand, silt, clay) and follow the gridded line along the same plane as the text for each particle class (see example). The point where the three lines intersect is the soil type.

Soils may be amended to encourage faster infiltration into the media bed of BMPs such as bioinfiltration practices, bioswales, and media filters. This serves to reduce the period of standing water, but does not modify the overall infiltration rate into the subsoil layer, which typically is the limiting layer. For design of amended soil blends, adjust the percent composition of sand, silt, and clay according to the additional materials added. For example, if a more permeable soil is desired, add sand to the parent soil and adjust the percent by weight accordingly.

Soil Textural Triangle



Using the soil classification, go to the table of infiltration rates below and select the infiltration rate appropriate for the soil type for use in design calculations. Minimum and maximum rates correspond to the lowest and highest percent sand content within a soil type, respectively. Designers shall select a rate within a given range appropriate for the actual sand content of their soil type.

Soil Type	Infiltration Rate (in/hr) Minimum	Infiltration Rate (in/hr) Maximum
Sand	4.6	8.3
Loamy Sand	1.2	2.4
Sandy Loam	0.4	1.0
Loam	0.2	0.5
Silt Loam	0.2	0.3
Silt	0.13	0.25
Sandy Clay Loam	0.06	0.2
Clay Loam	0.04	0.1
Silty Clay Loam	0.04	0.06
Sandy Clay	0.025	0.05
Silty Clay	0.02	0.04
Clay	0.01	0.02

Exhibit 14.1 – 2010 Integrated Report: Impaired Streams in Daviess County

Panther Creek Watershed

Stream Name	County	River Miles	Pollutant
Burnett Fk. into N Fk. into Panther Cr.	Daviess	0.0 to 1.3	Nitrogen (Total)
Burnett Fk. into N Fk. into Panther Cr.	Daviess	0.0 to 1.3	Phosphorus (Total)
Cane Run into S. Fk. into Panther Cr.	Daviess	0.0 to 3.7	Nutrient/Eutrophication Biological Indicators
Cane Run into S. Fk. into Panther Cr.	Daviess	0.0 to 3.7	Phosphorus (Total)
Crooked Creek into Panther Creek	Daviess	0.0 to 3.0	Fecal Coliform
Deserter Cr. into S. Fk. Panther Cr.	Daviess	0.0 to 3.1	Fecal Coliform
Ford Ditch into Rhodes Creek	Daviess	0.0 to 3.3	Phosphorus (Total)
Ford Ditch into Rhodes Creek	Daviess	0.0 to 3.3	Total Dissolved Solids
Knoblick Cr. into Panther Cr.	Daviess	0.0 to 2.1	Fecal Coliform
N. Fk. Panther Cr. into Panther Cr.	Daviess	4.2 to 9.1	Fecal Coliform
N. Fk. Panther Cr. into Panther Cr.	Daviess	9.7 to 12.7	Phosphorus (Total)
Panther Creek into Green River	Daviess	0.1 to 3.0	Fecal Coliform
Panther Creek into Green River	Daviess	3.0 to 5.9	Fecal Coliform
Panther Creek into Green River	Daviess	17.9 to 20.4	Phosphorus (Total)
Rhodes Creek into Panther Cr.	Daviess	0.0 to 2.2	Phosphorus (Total)
Rhodes Creek into Panther Cr.	Daviess	2.2 to 7.5	Nutrient/Eutrophication Biological Indicators
Rhodes Creek into Panther Cr.	Daviess	2.2 to 7.5	Phosphorus (Total)
S. Fk. Panther Cr. into Panther Cr.	Daviess	0.0 to 2.4	Copper
S. Fk. Panther Cr. into Panther Cr.	Daviess	0.0 to 2.4	Fecal Coliform
S. Fk. Panther Cr. into Panther Cr.	Daviess	0.0 to 2.4	Nutrient/Eutrophication Biological Indicators
S. Fk. Panther Cr. into Panther Cr.	Daviess	0.0 to 2.4	Phosphorus (Total)
S. Fk. Panther Cr. into Panther Cr.	Daviess	9.55 to 14.0	Fecal Coliform
S. Fk. Panther Cr. into Panther Cr.	Daviess	9.55 to 14.0	Phosphorus (Total)
S. Fk. Panther Cr. into Panther Cr.	Daviess	14.0 to 18.3	Fecal Coliform
Sweepstakes Br. into S. Fk. Panther	Daviess	1.0 to 4.0	Nutrient/Eutrophication Biological Indicators
Wolf Br. Ditch into Rhodes Cr.	Daviess	0.0 to 4.1	Nutrient/Eutrophication Biological Indicators
Wolf Br. Ditch into Rhodes Cr.	Daviess	0.0 to 4.1	Phosphorus (Total)

Exhibit 14.2 – LID Benefits to Stakeholders

LID Benefits to Stakeholders	
Developers	
▪	Reduces land clearing and grading costs
▪	Reduces infrastructure costs (streets, curbs, gutters, sidewalks)
▪	Reduces storm water management costs
▪	Increases lot yields and reduces impact fees
▪	Increases lot and community marketability
Municipalities	
▪	Protects regional flora and fauna
▪	Balances growth needs with environmental protection
▪	Reduces municipal infrastructure and utility maintenance costs (streets, curbs, gutters, storm sewers)
▪	Fosters public/private partnerships
Home Buyers	
▪	Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to waterbodies
▪	Preserves and protects amenities that can translate into more salable homes and communities
▪	Provides shading for homes and properly orients homes to help decrease monthly utility bills
Environment	
▪	Preserves integrity of ecological and biological systems
▪	Protects site and regional water quality by reducing sediment, nutrient, and toxic loads to waterbodies
▪	Reduces impacts to local terrestrial and aquatic plants and animals
▪	Preserves trees and natural vegetation

Exhibit 14.3 – Pollutant Generating Potential by Land Use Categorization

Pollutant Generation Potential by Land Use (H = high, M = medium, L = low)								
Pollutant	<i>Low Density Residential</i>	<i>High Density Residential</i>	<i>Mixed</i>	<i>Industrial</i>	<i>Commercial</i>	<i>Roads</i>	<i>Open</i>	<i>Agric.</i>
Total Suspended Solids	L	L	M	L	H	H	L	H
Fecal Coliforms	M	M	L	L	L	L	M	H
Total Nitrogen	M	M	M	M	M	M	L	H
Total Phosphorus	M	M	M	L	M	L	M	H
Oil & Grease	M	M	M	H	H	H	L	L
Metals	M	M	M	M	H	H	L	L

Exhibit 14.4 – Pollutant Concentrations by Land Use Categorization

Event Mean Concentrations (EMC) of Pollutants for Different Land Uses

Pollutants	LOW DENSITY RES.	HIGH DENSITY RES.	MIXED	INDUS.	COMM.	ROADS	OPEN	AGRICUL
Total Suspended Solids (mg/L)	47	51	59	43	81	99	49.00	107
Fecal Coliforms (ppm)	7500	8000	5091	4500	2500	1700	7200	26000
Total Nitrogen (mg/L)	1.95	2.05	2	2.2	2.1	2.3	1.33	4.4
Total Phosphorus (mg/L)	0.29	0.31	0.27	0.22	0.3	0.25	0.31	1.3
Oil & Grease (mg/L)	3	3.2	3.5	4.7	4	8	0.00	0
Metals (mg/L)	0.097	0.103	0.11	0.12	0.3	0.28	0.05	0.02

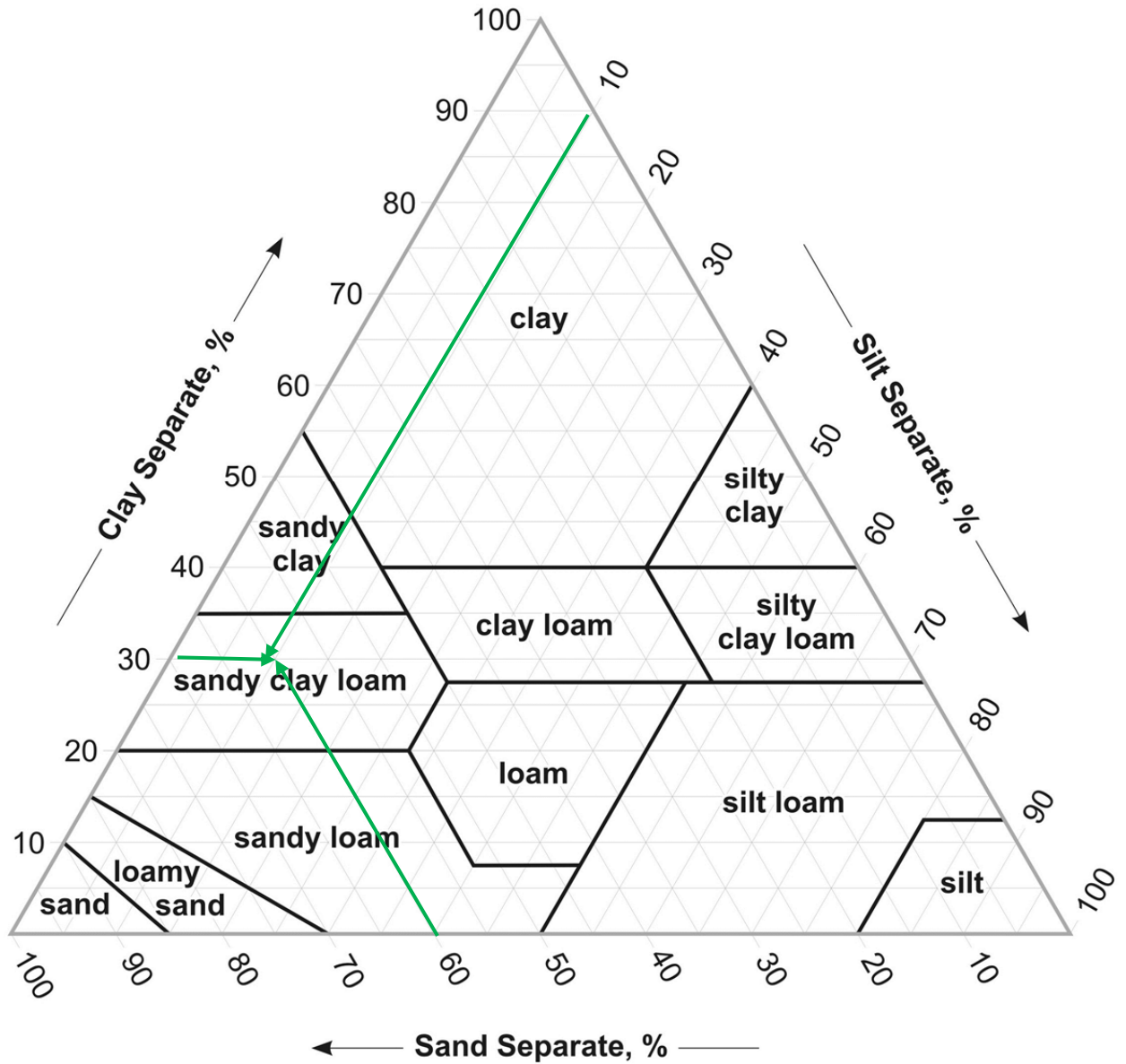
Exhibit 14.5 - BMP Effectiveness for Pollutant Removal

Significant Benefit ●, Partial Benefit ○, Low or Unknown Benefit ---

<u>Water Quality Treatment (WQ)</u>	#	Targeted Constituents								
		Sediment	Nutrients	Heavy Metals	Toxic Materials	Oil & Grease	Bacteria & Viruses	Organics/BOD	Floatable Materials	Construction Waste
Infiltration Basin *LID*	14.01	●	●	●	●	●	●	●	●	---
Infiltration Trench *LID*	14.02	●	●	●	●	●	●	●	●	---
Roof Downspout System (Dry Well) *LID*	14.03	(no targeted constituents)								
Permeable Pavement *LID*	14.04	---	●	●	○	●	○	○	---	---
Constructed Wetlands *LID*	14.05	●	○	●	●	●	●	●	●	---
Vegetated Filter Strip *LID*	14.06	●	—	●	○	●	—	○	---	---
Grass Swales *LID*	14.07	○	---	○	○	○	—	○	---	---
BioSwales *LID*	14.07	○	○	●	●	○	---	●	○	---
Bioretention & Rain Gardens *LID*	14.08	●	○	●	●	●	●	●	●	---
Bioretention Filters *LID*	14.09	●	○	●	●	●	●	●	●	---
Vegetated/Green Roofs *LID*	14.10	---	●	●	---	---	---	---	---	---
Manufactured Systems	14.11	●	○	●	---	○	---	---	●	○

Exhibit 14.6 – Soil Textural Triangle

Soil Textural Triangle

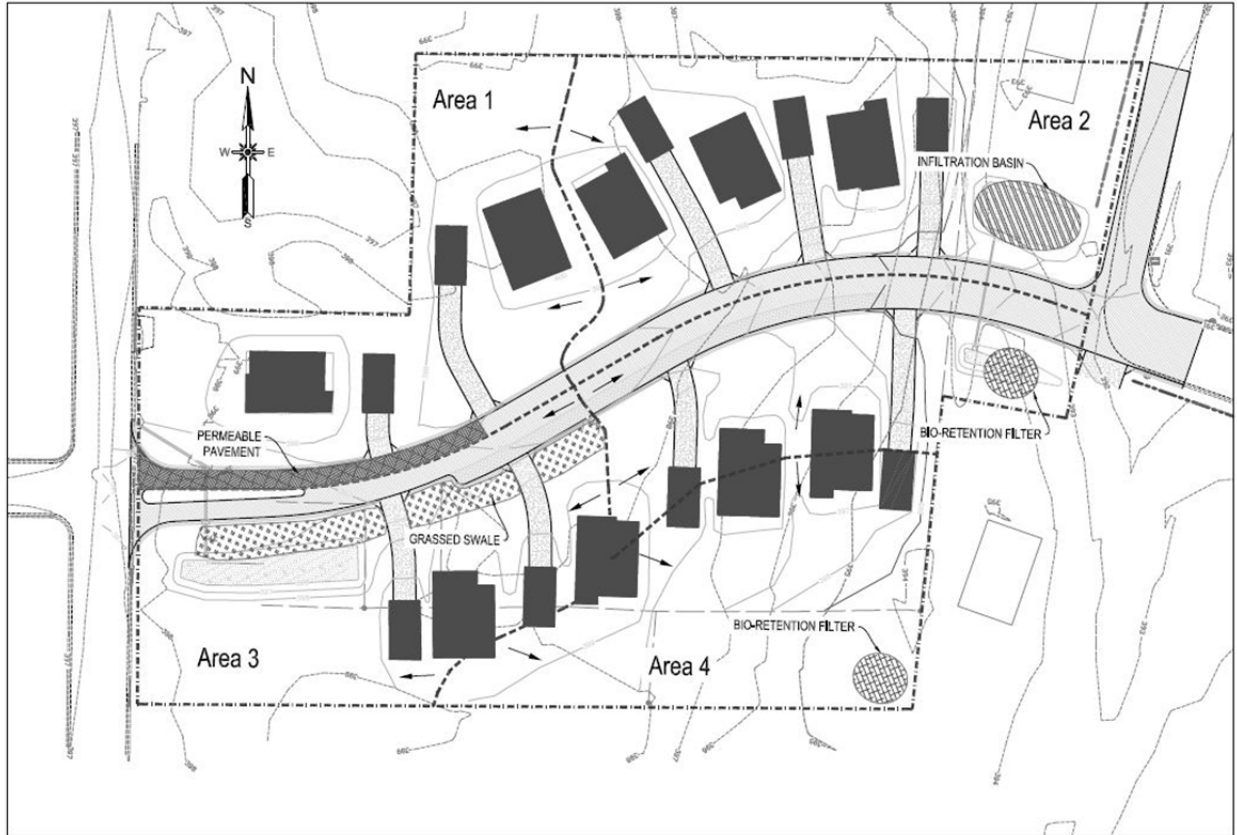


Appendix A: Design Examples

- Example 1 – Residential Development
- Example 2 – Commercial Development

Design Example No. 1: Residential Development

This is a BMP sizing example for a small residential subdivision on the west side of Owensboro. The layout of the subdivision is shown in Figure 1.



The following information was determined from field measurement and /or proposed design data:

- Total Site Area = 3.28 acres
- Four sub-watersheds
- Soil type is 100% Elk Silt Loam

Soil Symbol	Soil Name	Hydrologic Soil Group	Unified Soil Classification	CBR	% SAND	% SILT	% CLAY	Saturated hydraulic conductivity (in/hr)	Depth to Water Table (ft)
EkA	Elk Silt Loam	B	ML	3 to 5	7	63	30	0.75	> 6

Site soils were determined from the United States Department of Agriculture Natural Resources Conservation Service Web Soil Survey website:

<http://websoilsurvey.nrcs.usda.gov/app/>

California Bearing Ration (CBR) determined from the Kentucky Transportation Cabinet Pavement Design Guide (2007 Revision).

Primary pollutants for Roadways from Exhibit 14.3 are Total Suspended Solids (TSS), Oil/Grease, and Metals. It was assumed that offsite drainage areas were stabilized and runoff would follow overland flow over grassed surfaces, minimizing TSS and leaving oil/grease, and metals as the pollutants of concern. From Exhibit 14.5, Permeable Pavement (refer to Minimum Standard 14.04) is shown to provide significant benefit for removal of these pollutants of concern.

Area #1

Permeable Roadway – Level 1 Design with Underdrain (see Min. STD 14.04)

This example represents a roadway made of permeable pavement with a contributing impervious drainage area consisting of the following:

- 2,851 ft^2 of house roofs
- 1,028 ft^2 of garage roofs
- 1,554 ft^2 of driveways & sidewalks and 50% of permeable pavement area

The contributing pervious drainage area consists of the following:

- 1,352 ft^2 permeable roadway (actual area 2,704 ft^2 , but permeable pavements can only credit 50% as pervious)
- 22,952 ft^2 lawn area

This will be a Level 1 design since contributing drainage area consists of more than just the permeable pavement area.

The permeable pavement reservoir will be sized to store the water quality treatment volume and the 10 year 24 hour design storm event (4.74inches) to attenuate site peak discharge to help meet detention storage requirements (if desired – see note in step 2).

Step 1.

Calculate the water quality volume (WQ_v) using the formula below:

$$WQ_v = \left(\frac{A * d}{12in.} \right)$$

Where:

WQ_v = Design Storm Volume in (ft^3)

A = Impervious area (ft^2)

d = 0.64 (depth in inches)

Criteria:

- Size for the 80% rainfall event.
(80% rainfall event for Owensboro is 0.64 inches)

Total Area: $30,737.56 \text{ ft}^2$

$$WQ_v = \left(\frac{(6,433 \text{ ft}^2) * (0.64 \text{ in.})}{12 \text{ in.}} \right) = 343.09 \text{ ft}^3$$

Impervious Area: $6,433 \text{ ft}^2$

Step 2*.

Calculate the storage volume needed to attenuate design storm event using the formula below:

$$DS_v = \left(\frac{A * d}{12 \text{ in.}} \right)$$

Where:

DS_v = Design Storm Volume in (ft^3)

A = Impervious area (ft^2)

d = depth in inches

Impervious Area: $6,433 \text{ ft}^2$

$$DS_v = \left(\frac{(6,433 \text{ ft}^2) * (4.74 \text{ in.})}{12 \text{ in.}} \right) = 2,541 \text{ ft}^3$$

Since this is a Level 1 design due to the contributing drainage area consisting of more than just the permeable pavement area, underdrains need to be accounted for in the design.

*This step is not required for effective design for WQv; it is for providing an options for additional storage to help meet water quantity control requirements.

Step 3.

Use **Equation 14.04-3** to approximate the outflow rate from the underdrain.

$$q_u = k * m$$

Where:

q_u = outflow through the underdrain (per outlet pipe, assumed 6-inch diameter (ft./day))

k = hydraulic conductivity for the reservoir layer (ft./day – assume 100 ft./day)

m = underdrain pipe slope (ft./ft. – assume 1 ft./200 ft.)

$$q_u = (100 \text{ ft./day}) * (1 \text{ ft./200 ft.}) = 0.5 \text{ ft./day}$$

Step 4.

Use **Equation 14.04-4** to determine the depth of the reservoir layer needed to store the design storm accounting for the outflow rate through the underdrain.

$$d_p = \left(\frac{(d_c * R) + P - (i / 2 * t_f) - (q_u * t_f)}{V_r} \right)$$

Where:

d_p = depth of reservoir layer (ft.)

d_c = depth of runoff from contributing drainage area (not including the permeable paver surface) for the water quality volume (Level 1 = 0.64 in) or other design storm (ft.)

$R = A_c / A_p$ = ratio of the contributing drainage area (A_c , not including the permeable paving surface) to the permeable pavement surface area (A_p)
($R = 6,433 \text{ sf} / 1,352 \text{ sf} = 4.76$)

P = rainfall depth for water quality volume (Level 1 = 0.64 in (0.053 ft)) or other design storm (ft.)

i = field-verified infiltration rate for native soils (ft./day)

t_f = time to fill the reservoir layer (day) – typically 2 hours or 0.083 day

V_r = void ratio for the reservoir layer (0.4)

q_u = outflow through the underdrain (ft./day)

Water Quality Volume Reservoir Layer Depth with Underdrain

$$d_p = \left(\frac{(0.053 \text{ ft} * 4.76) + 0.053 \text{ ft} - (1.5 \text{ ft/day} / 2 * 0.083 \text{ day}) - (0.5 \text{ ft/day} * 0.083 \text{ day})}{0.4} \right)$$

$$d_p = 0.50 \text{ ft}$$

10 Year Storm Event Reservoir Layer Depth with Underdrain

$$d_p = \left(\frac{(0.4 \text{ ft} * 4.76) + 0.4 \text{ ft} - (1.5 \text{ ft/day} / 2 * 0.083 \text{ day}) - (0.5 \text{ ft/day} * 0.083 \text{ day})}{0.4} \right)$$

$$d_p = 5.5 \text{ ft}$$

Step 5.

Use **Equation 14.04-5** to calculate the maximum allowable depth of the reservoir layer which is constrained by the maximum allowable drain time:

$$d_{p-\max} = \left(\frac{(i / 2 * T_{\max}) + (q_u * T_{\max})}{V_r} \right)$$

Where:

$d_{p-\max}$ = maximum depth of the reservoir layer (ft.)

i = field-verified infiltration rate for native soils (ft./day)

V_r = void ratio for the reservoir layer (0.4)

T_{\max} = maximum allowable time to drain the reservoir layer, typically 2 days (days)

q_u = outflow through the underdrain (ft./day)

$$d_{p-\max} = \left(\frac{(1.5 \text{ ft./day} / 2 * 2 \text{ day}) + (0.5 \text{ ft./day} * 2 \text{ day})}{0.4} \right) = 6.25 \text{ ft.}$$

Since the reservoir layer depth for the 10 year storm event ($d_p = 5.5 \text{ ft.}$) is less than the allowable maximum reservoir layer depth ($d_{p-\max} = 6.25 \text{ ft.}$), the minimum depth of the reservoir is 5.5 ft. Of the 5.5 ft. reservoir depth 0.5 ft. is needed to store the water quality volume and the remaining 5 ft. is used for storing the 10 year storm event.

Note: If the reservoir layer necessary to temporarily store the design storm volume is less than the depth necessary to support structural loads then the Structural support requirements will dictate the depth of the underlying stone reservoir.

Step 6.

Calculate the area needed under the permeable pavement for the storage reservoir:

Required area = design storm volume/ required reservoir layer depth/ void ratio for the reservoir layer

$$2,541 \text{ ft}^3 / 5.5 / 0.4 = 1,155 \text{ ft}^2$$

Therefore, 1,155 ft^2 of the 2,704 ft^2 planned for permeable pavement will be required to have a minimum reservoir depth of 5.5 ft.

Area #2

Infiltration Basin (refer to Minimum Standard 14.01)

This example represents an infiltration basin with a contributing impervious drainage area consisting of the following:

- 4,199 ft^2 of house roofs
- 1,542 ft^2 of garage roofs
- 2,338 ft^2 of driveways & sidewalks
- 3,020 ft^2 of roadway

The contributing pervious drainage area consists of the following:

- 26,526 ft^2 lawn area

Step 1.

Calculate the water quality volume (WQ_v) using the formula below:

$$WQ_v = \left(\frac{A * d}{12in.} \right)$$

Where:

WQ_v = Design Storm Volume in (ft^3)

A = Impervious area (ft^2)

d = 0.64 (depth in inches)

Criteria:

- Size for the 80% rainfall event.
(80% rainfall event for Owensboro is 0.64 inches)

$$\text{Total Area: } 37,625 \text{ } ft^2 \quad WQ_v = \left(\frac{(11,099 \text{ } ft^2) * (0.64in.)}{12in.} \right) = 592 \text{ } ft^3$$

Step 2.

Calculate the design infiltration rate using the formula below:

$$f_d = 0.5 * f$$

f_d = design infiltration rate(ft/hr)

f = infiltration rate (ft/hr) determined from the soil analysis (Elk Silt Loam, 0.75 in/hr = 0.0625 ft/hr)

$$f_d = 0.5 * (0.0625 \text{ ft./hr}) = 0.031 \text{ ft./hr}$$

Step 3.

Calculate the maximum ponding time and depth using the formula below:

$$d_{\max} = f_d * T_{\max}$$

Where:

d_{\max} = maximum depth of the facility (ft.)

f_d = design infiltration rate of the basin area soils (ft./hr)

T_{\max} = maximum allowable drain time (48hrs)

$$d_{\max} = (0.031 \text{ ft./hr}) * 48 \text{ hrs} = 1.49 \text{ ft.}$$

Step 4.

Calculate the minimum surface area of the facility bottom using the formula below:

$$SA_{\min} = \left(\frac{WQ_v}{f * T_{\max}} \right)$$

Where:

SA_{\min} = minimum basin bottom surface area (ft²)

WQ_v = water quality volume requirements (ft³)

f_d = design infiltration rate of the basin area soils (ft./hr)

T_{\max} = maximum allowable drain time (48hrs)

$$SA_{\min} = \left(\frac{592 \text{ ft}^3}{(0.031 \text{ ft./hr}) * (48 \text{ hrs})} \right) = 398 \text{ ft}^2$$

From the calculations an infiltration basin designed to treat the water quality volume of 592ft³ needs to have a maximum depth of 1.49ft and a minimum bottom surface area of 398ft². This is the minimum infiltration basin design for water quality enhancement. Designers can incorporate a larger surface area if desired to reduce the drain time and ponding depth without sacrificing performance. The infiltration basin still must provide an overflow or spillway for the bypass of large storms. Chapter 8 provides the procedures for the design of the riser and barrel system and the emergency spillway design procedures.

Area #3

Grassed Swale (Refer to Minimum Standard 14.07)

This example represents an infiltration basin with a contributing impervious drainage area consisting of the following:

- 1,974 ft^2 of house roofs
- 975 ft^2 of garage roofs
- 1,456 ft^2 of driveways
- 4,512 ft^2 of roadway

The contributing pervious drainage area consists of the following:

- 19,840 ft^2 lawn area

Step 1.

Calculate the water quality volume (WQ_v) using the formula below:

$$WQ_v = \left(\frac{A * d}{12in} \right)$$

Where:

WQ_v = Water Quality Volume in (ft^3)

A = Impervious area (ft^2)

d = 0.64 (depth in inches)

Criteria:

- Size for the 80% rainfall event.
(80% rainfall event for Owensboro is 0.64 inches)

Total Area: 28,757 ft^2

$$WQ_v = \left(\frac{(8,917 \text{ } ft^2) * (0.64in.)}{12in.} \right) = 496 \text{ } ft^3$$

Impervious Area: 8,917 ft^2

Step 2.

Design a trapezoidal swale to have a bottom width, depth, length, and slope necessary to store the WQ_v with a maximum of 4 inches of ponding.

From the site plan there is 200ft available for the swale at 1% slope. For a trapezoidal section with a bottom width of 6ft, a WQ_v average depth of 4inches, 4:1 side slopes, compute a cross sectional area with the following equation:

$$A = bd + zd^2$$

Where:

A = area (ft^2)

b = bottom width ($ft.$)

d = depth ($ft.$)

z = channel side slope

$$A = (6 ft. * 0.33 ft.) + (4 ft. * (0.33 ft.)^2) = 2.42 ft^2$$

Check swale for WQ_v capacity.

$$2.42 ft^2 * 200 ft. = 484 ft^3 > WQ_v \text{ of } 476 ft^3 \{ok\}$$

Step 3.

Determine the number of check dams required to detain the WQ_v .

For the swale at 1% slope, and maximum depth of 4 inches place check dams at: $0.33 ft. / 0.01 = 33 ft.$ Six check dams spaced 33 $ft.$ apart are required.

Step 4.

Check the two-year velocity erosion potential. From hydrology information, the two-year flow is 1.11 cfs . From separate computer analysis using a Manning's n value of 0.15 for flow depths at or below 4 inches (See figure 14.07-4 for other Manning's values for depths above 4 inches) and a slope of 1%, the two-year velocity will be 0.44 ft/s at a depth of 0.35 $ft.$ Two year velocity of 0.44 ft/s is less than 4 ft/s allowed {ok}.

Step 5.

Check the ten-year velocity erosion potential. From hydrology information, the ten-year flow is 1.44 cfs . From separate computer analysis using a Manning's n value of 0.15 for flow depths below 12 inches and a slope of 1%, the ten-year velocity will be 0.47 ft/s at a depth of 0.40 $ft.$ Ten year velocity of 0.47 ft/s is less than 7 ft/s allowed {ok}. Total channel depth of one foot provides 0.6 $ft.$ of freeboard for the ten-year event which is greater than 0.5 $ft.$ of freeboard required.

Area #4

Bioretention Filter (Refer to Minimum Standard 14.08)

This example presents a Bioretention Filter with a contributing impervious drainage area consisting of the following:

- 3,521 ft^2 of house roofs
- 1,026 ft^2 of garage roofs
- 1,622 ft^2 of driveways & sidewalks
- 3,988 ft^2 of roadway

The contributing pervious drainage area consists of the following:

- 36,077 ft^2 lawn area

Step 1.

Calculate the water quality volume (WQ_v) using the formula below:

$$WQ_v = \left(\frac{A * d}{12in} \right)$$

Where:

WQ_v = Water Quality Volume in (ft^3)

A = Impervious area (ft^2)

d = 0.64 (depth in inches)

Criteria:

- Size for the 80% rainfall event.
(80% rainfall event for Owensboro is 0.64 inches)

Drainage area 4 is split in two with 47% of the area draining to the north west and 53% draining to the north east. The WQ_v for the two areas is determined as follows:

WQ_v draining to the northwest

$$\text{Total Area: } 21,730 \text{ } ft^2 \quad WQ_v = \left(\frac{(7,421 \text{ } ft^2) * (0.64in.)}{12in.} \right) = 386 \text{ } ft^3$$

Impervious Area: 7,241 ft^2

WQ_v draining to the northeast

$$\text{Total Area: } 24,504 \text{ } ft^2 \quad WQ_v = \left(\frac{(2,916 \text{ } ft^2) * (0.64in.)}{12in.} \right) = 156 \text{ } ft^3$$

Impervious Area: 2,916 ft^2

Step 2.

Determine the required floor area of the bioretention filter. The floor surface area is determined by dividing the volume of water to be treated by the maximum ponding depth (max 6"). Calculate the required floor area using the formula below:

$$FA = \left(\frac{WQ_v}{D} \right)$$

Where:

FA = required floor surface area (ft^2)

WQ_v = volume stored in bioretention filter (ft^3)

D = depth of water in bioretention filter (ft)

Required floor area for the northwest bioretention filter

$$FA = (386 \text{ ft}^3) / (0.5 \text{ ft}) = 772 \text{ ft}^2$$

Required floor area for the northeast bioretention filter

$$FA = (156 \text{ ft}^3) / (0.5 \text{ ft}) = 312 \text{ ft}^2$$

Step 3.

Determine the planting soil for the bioretention filter.

If native soils are to be used for the planting soil they must have a permeability of at least 0.25 in./hr, otherwise a prepared soil bed should be designed. A prepared soil bed shall contain a planting soil mixture of 50% sand, 30% leaf compost (fully composted, NOT partially rotten leaves), and 20% topsoil. Topsoil shall be sandy loam or loamy sand of uniform composition containing no more than 5% clay. Typical permeability for a mixture of this type ranges from 1 to 6 inches per hour.

Native soil for this site is Silt Loam with 30% clay which precludes its use in the planting soil bed. A prepared soil bed using suitable material must be used.

Step 4.

Determine the depth of the planting soil for the bioretention filter.

Provide a planting soil bed with a minimum depth of 3 feet (4 to 5 feet is preferable) over the entire floor area required for the bioretention filter. Place planting soil in lifts of 12 to 18 inches and loosely compact or tamp lightly with backhoe bucket.

Step 5.

Determine the rate of water flow through the bioretention filter planting bed.

The rate at which water moves through the planting bed can be estimated using Darcy's Law a well established equation used to determine the movement of groundwater.

Darcy's Law is calculated using the formula below:

$$q = \left(\frac{K * \Delta H}{L} \right)$$

Where:

q = flow per cross sectional area (ft/hr)

K = hydraulic conductivity for planting bed media ($0.083 ft/hr$)

ΔH = change in head (height of water) ($ft.$)

L = thickness of planting bed media ($3 ft.$)

$$q = \left(\frac{0.083 ft./hr * 3.5 ft.}{3 ft.} \right) = 0.097 ft./hr \text{ (per unit area)}$$

Multiply by the area of the bioretention filter determines the total flow through the planting bed media. Flow through the planting bed media is calculated using the formula below:

$$Q = q * FA * \left(\frac{1hr}{3600s} \right)$$

Where:

Q = flow through planting bed media (ft^3/s)

q = flow per cross sectional area (ft/hr)

FA = required floor surface area (ft^2)

Flow through planting bed media of the northwest bioretention filter

$$Q = (0.097 ft./hr) * (772 ft^2) * \left(\frac{1hr}{3600s} \right) = 0.02 ft^3 / s$$

Flow through planting bed media of the northeast bioretention filter

$$Q = (0.097 ft./hr) * (312 ft^2) * \left(\frac{1hr}{3600s} \right) = 0.008 ft^3 / s$$

Step 6.

Determine the size of the bioretention filter underdrain pipes. The pipes must be selected so that they drain water from underdrain area substantially faster than water enters from the soil fill layer above. As a factor of safety design for pipes to remove 5 to 10 times the amount of water that flows thru the soil planting bed.

Use the Manning Equation to determine the number of underdrain pipes and their associated diameter. The equation is given below:

$$D = 16 * \left(Q * \frac{n}{S^{0.5}} \right)^{3/8}$$

Where:

D = diameter of pipes (inches)

Q = flow to be carried (cfs)

n = Manning coefficient (0.014 for single wall corrugated pipe, 0.011 for smooth-walled pipe)

S = slope of pipe (0.5% minimum)

Apply a factor of safety and size the pipe system to carry at least 10 times the flow draining thru the planting bed media.

Flow through planting bed media of the northwest bioretention filter

$$Q = 0.02 \text{ ft}^3 / \text{s} * 10 = 0.2 \text{ ft}^3 / \text{s}$$

Flow through planting bed media of the northeast bioretention filter

$$Q = 0.008 \text{ ft}^3 / \text{s} * 10 = 0.08 \text{ ft}^3 / \text{s}$$

Determine the size of the underdrain pipes.

northwest bioretention filter

$$D = 16 * \left(0.2 \text{ ft}^3 / \text{s} * \frac{0.011}{0.005^{0.5}} \right)^{3/8} = 4.35 \text{ inches}$$

Therefore, at least two 4 inch smooth-walled pipes are needed or one 6 inch pipe.

northeast bioretention filter

$$D = 16 * \left(0.08 \text{ ft}^3 / \text{s} * \frac{0.011}{0.005^{0.5}} \right)^{3/8} = 3.08 \text{ inches}$$

Therefore, one 4 inch smooth-walled pipe is needed.

Step 7.

Determine the size of the overflow weir using the weir equation below:

$$Q = C_w * L * H^{3/2}$$

Q = peak flow from design storm (cfs)

C_w = weir coefficient (use 3)

H = height of water above weir (ft.) (typ. 0.17', max. 0.5')

L = weir length (ft.)

From a separate hydrological analysis for the site the following discharge rates were calculated:

10-year discharge rate

Northwest bioretention filter = $1.88 \text{ ft}^3/\text{s}$

Northeast bioretention filter = $2.15 \text{ ft}^3/\text{s}$

25-year discharge rate

Northwest bioretention filter = $2.08 \text{ ft}^3/\text{s}$

Northeast bioretention filter = $2.37 \text{ ft}^3/\text{s}$

Determine the weir lengths necessary to bypass both the 10-year and 25-year storm events. Rearranging the weir equation to solve for length:

$$L = \left(\frac{Q}{C_w * H^{3/2}} \right)$$

northwest bioretention filter

$$L_{10\text{yr}} = \left(\frac{1.88 \text{ cfs}}{3 * (0.17 \text{ ft})^{3/2}} \right) = 1.52 \text{ ft.}$$

$$L_{25\text{yr}} = \left(\frac{2.08 \text{ cfs}}{3 * (0.17 \text{ ft})^{3/2}} \right) = 1.69 \text{ ft.}$$

northeast bioretention filter

$$L_{10\text{yr}} = \left(\frac{2.15 \text{ cfs}}{3 * (0.17 \text{ ft})^{3/2}} \right) = 1.75 \text{ ft.}$$

$$L_{25\text{yr}} = \left(\frac{2.37 \text{ cfs}}{3 * (0.17 \text{ ft})^{3/2}} \right) = 1.92 \text{ ft.}$$

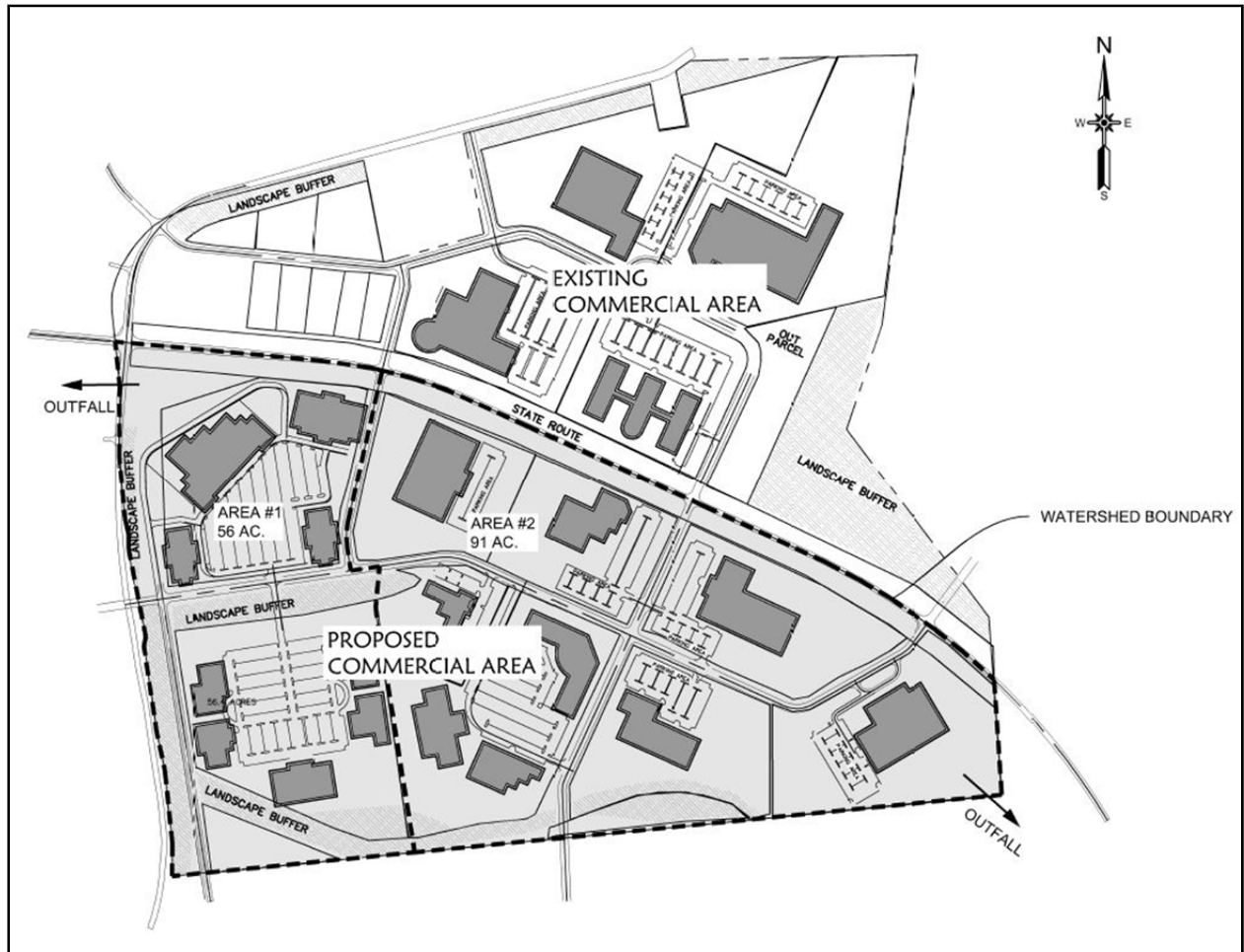
Determine an appropriately sized circular riser pipe to use as the overflow structure. Try an 8-inch circular riser pipe.

$$\begin{aligned} \text{Circumference} &= 3.14 * \text{diameter of catch basin} \\ &= 3.14 * (8''/12'') = 2.09 \text{ ft.} \end{aligned}$$

An 8-inch circular riser pipe has a circumference of 2.09' which is greater than the necessary weir lengths calculated. Use 8-inch riser pipe with a domed grate as the overflow weir elevated 0.17' (2inches) above the maximum ponding depth.

Design Example No. 2: Commercial Development

This is a BMP sizing example for a commercial development in Owensboro. The site is split into two distinct watersheds labeled Area 1 and Area 2 on the development layout plan of shown in Figure 1 below.



The developer intends to treat the water quality volume (WQ_v) from the site with two manufactured BMP systems, one installed in each watershed. Drainage from Area 1 flows to the northwest corner and discharges from a single outfall location. Drainage from Area 2 flows to the southeast corner and discharges from a single outfall location.

The following information was determined from field measurement and/or proposed design data:

Area #1

- Total Area = 56 acres ($0.088mi^2$)
- Impervious area = 35 acres
- Pervious area = 21 acres
- Time of Concentration = 18minutes ($0.3hr$)
- Effective CN = 87
- Water quality treatment depth = 0.64 inches

Area #2

- Total Area = 91 acres ($0.14 mi^2$)
- Impervious area = 35 acres
- Pervious area = 21 acres
- Time of Concentration = 24minutes ($0.4 hr$)
- Effective CN = 88
- Water quality treatment depth = 0.64 inches

The WQ_v discharge is used to select an appropriately sized manufactured BMP system. The WQ_v discharge is determined using the SCS TR-55 graphical peak discharge method for small watersheds (NRCS 1986). The peak discharge is calculated by the formula below:

$$q_p = q_u * A_m * Q * F_p$$

Where:

q_p = peak discharge (cfs)

q_u = unit peak discharge (csm/in)

A_m = drainage area (mi^2)

Q = WQ_v (in)

F_p = pond and swamp adjustment factor = 1 (no ponds or swamps in watershed)

Step 1.

In order to determine the unit peak discharge (q_u) the ratio of initial abstraction (I_a) to WQv rainfall depth (P) in inches is needed. This is defined as:

$$\left(\frac{I_a}{P}\right) = \left(\frac{0.2S}{P}\right)$$

Where:

S = potential maximum retention after runoff begins (*in*)

$$S = \left(\frac{1000}{CN}\right) - 10$$

Area #1

$$S = \left(\frac{1000}{87}\right) - 10 = 1.49 \text{ inches}$$

$$\left(\frac{I_a}{P}\right) = \left(\frac{0.2 * 1.49 \text{ inches}}{0.64 \text{ inches}}\right) = 0.47$$

Area #2

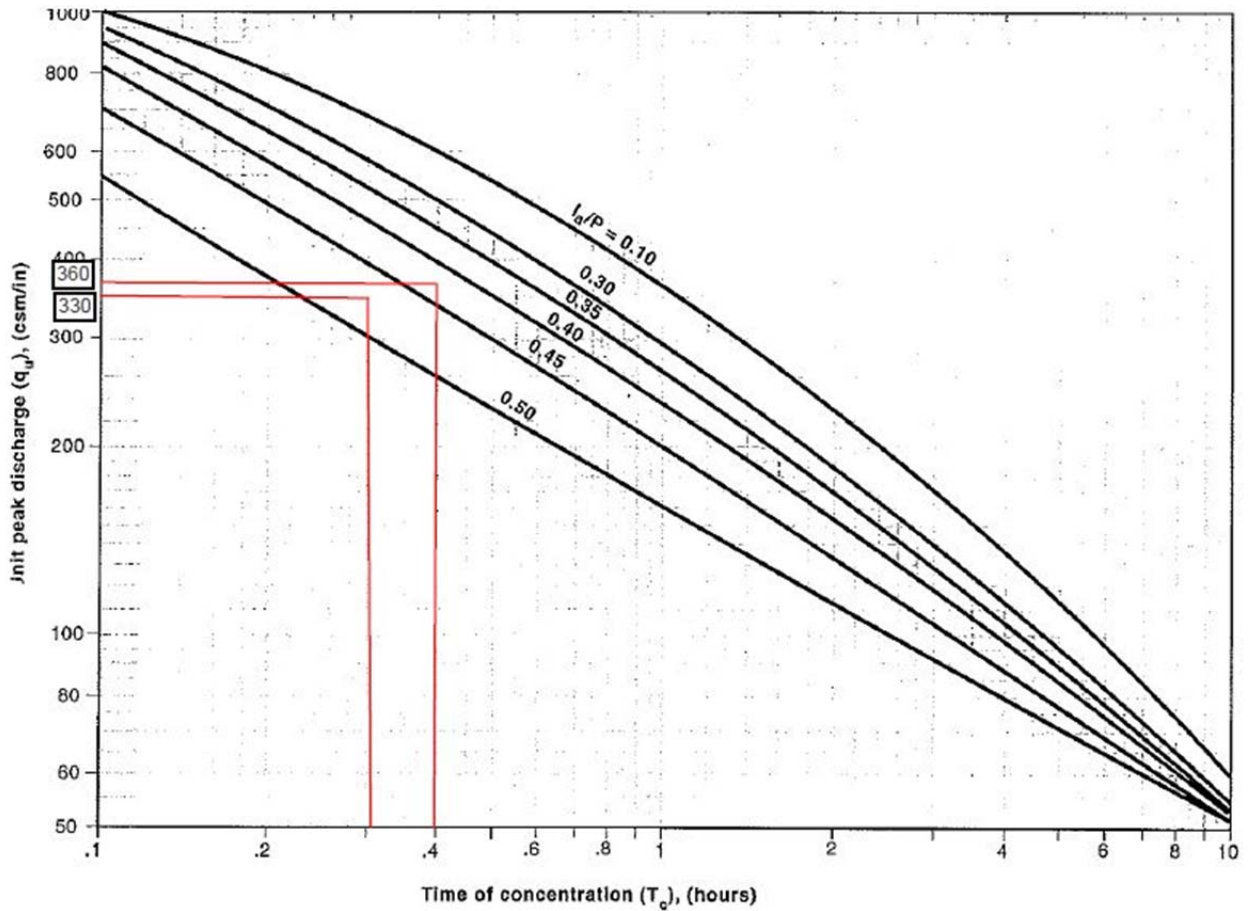
$$S = \left(\frac{1000}{88}\right) - 10 = 1.36 \text{ inches}$$

$$\left(\frac{I_a}{P}\right) = \left(\frac{0.2 * 1.36 \text{ inches}}{0.64 \text{ inches}}\right) = 0.43$$

Step 2.

Using the determined time of concentration and I_a / P ratio under SCS Type II storm conditions, the unit peak discharge (q_u) is determined graphically using Exhibit 4-II from NRCS 1986.

Exhibit 4-II Unit peak discharge (q_u) for NRCS (SCS) type II rainfall distribution



Area #1

$$q_u = 330 \text{ csm/in}$$

Area #2

$$q_u = 360 \text{ csm/in}$$

Step 3.

Determine the peak WQ_v design discharge to the manufactured BMP system:

Area #1

$$q_p = (330 \text{ csm} / \text{in}) * (0.088 \text{ mi}^2) * (0.64 \text{ in}) * 1 = 19 \text{ cfs}$$

Area #2

$$q_p = (360 \text{ csm} / \text{in}) * (0.14 \text{ mi}^2) * (0.64 \text{ in}) * 1 = 32 \text{ cfs}$$

Step 4.

Determine the appropriate size of manufactured BMP system to treat the peak WQ_v design discharge.

The City of Owensboro has pre-approved the use of the Nutrient Separating Baffle Box® as manufactured by Suntree Technologies Inc. for use as a manufactured BMP system. Below is a table of available Nutrient Separating Baffle Box® sizes for the peak treatment and peak design flow rates.

Model #	Pipe Size Range	Peak Treatment Flow	Peak Design Flow
3-6-84	up to 12"	2 cfs	5 cfs
4-8-84	up to 24"	8 cfs	12 cfs
6-12-84	up to 42"	24 cfs	46 cfs
8-16-96	up to 60"	45 cfs	75 cfs

Area #1

The peak WQ_v design discharge is 19 cfs so select Model # 6-12-84.

Area #2

The peak WQ_v design discharge is 32 cfs so select Model # 8-16-96.

If the peak WQ_v design discharge rate is greater than the peak treatment flow of available manufactured BMP systems then use two or more units as necessary to meet the required WQ_v discharge rate.

Appendix B: BMP Minimum Standards

- 1.Infiltration Basin**
- 2.Infiltration Trench**
- 3.Roof Downspout System**
- 4.Permeable Pavement**
- 5.Constructed Stormwater Wetland**
- 6.Vegetated Filter Strip**
- 7.Grassed Swale – Bioswale**
- 8.Bioretention Basin Practices**
- 9.Bioretention Filters**
- 10.Vegetated Roof**
- 11.Manufactured BMP Systems**

MINIMUM STANDARD 14.01

INFILTRATION BASIN



LIST OF ILLUSTRATIONS

<u>#</u>	<u>FIGURE</u>	<u>PAGE</u>
14.01-1	Infiltration Basin - Plan and Section	14.01-2

MINIMUM STANDARD 14.01

INFILTRATION BASIN

Definition

An infiltration basin is a vegetated, open impoundment where incoming stormwater runoff is stored until it gradually infiltrates into the soil strata.

Purpose

Infiltration basins are used primarily for water quality enhancement. However, flooding and channel erosion control may also be achieved within an infiltration basin by utilizing a multi-stage riser and barrel spillway to provide controlled release of the required design storms above the water quality (infiltration) volume (refer to Figure 14.01-1).

Conditions Where Practice Applies

Infiltration basins may be used where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and where the water table is low enough to prevent pollution of groundwater.

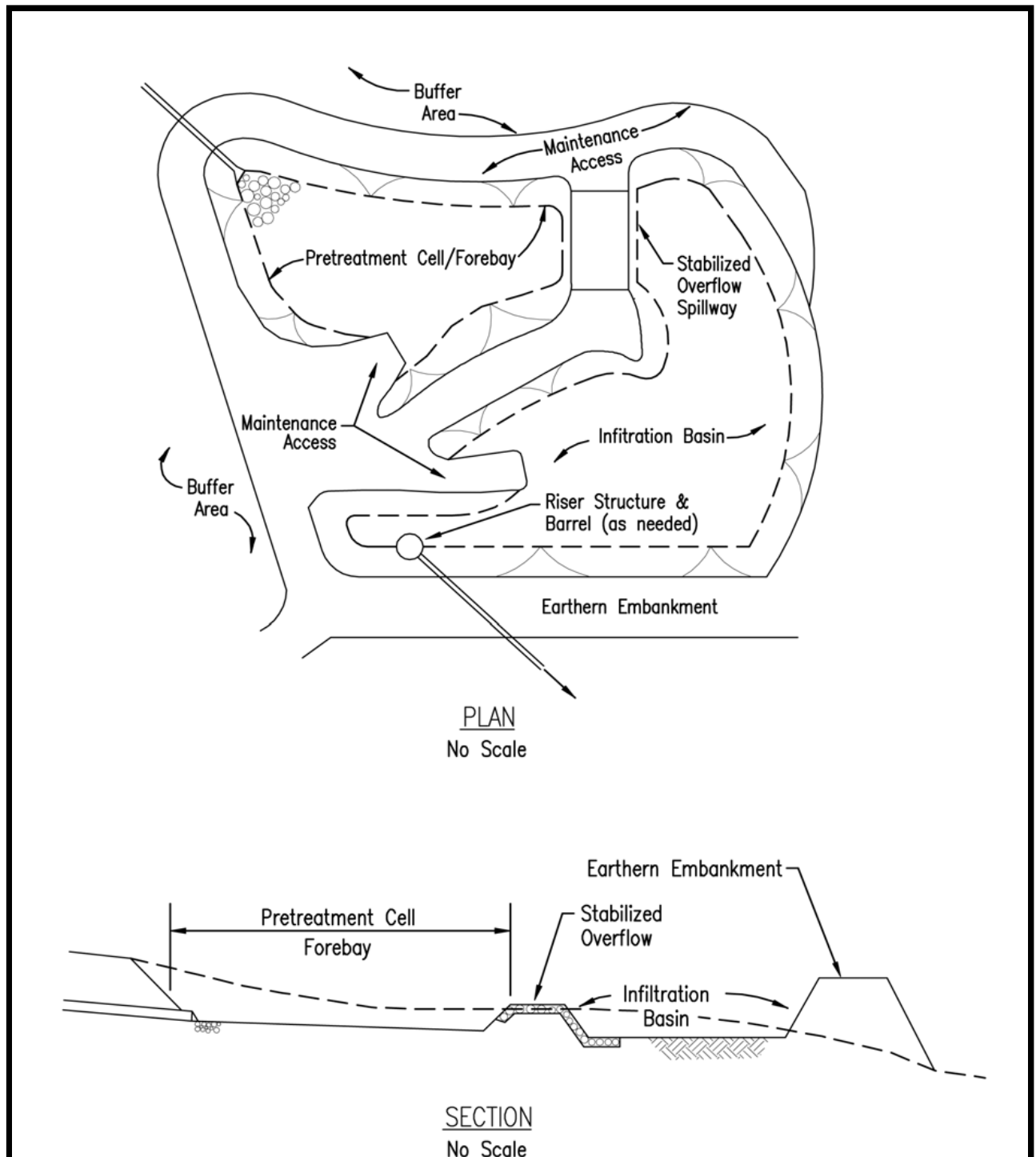
Drainage Area

Drainage areas served by infiltration basins should be limited to less than 50 acres. Drainage areas which are greater than 50 acres typically generate such large volumes of runoff that other detention or retention BMPs are more practical and cost-effective.

Development Conditions

Infiltration basins are generally suitable BMPs in low- to medium-density residential and commercial developments (38% to 66% impervious cover).

FIGURE 14.01-1
Infiltration Basin – Plan and Section



Hydrology and Hydraulics

Chapter 8, Surface Drainage should be used to develop the pre- and post-developed hydrology for a basin's contributing watershed. An infiltration basin designed for water quality enhancement still must provide an overflow or spillway for the bypass of large storms. Chapter 8 provides the procedures for the design of the riser and barrel system and the emergency spillway design procedures.

Soils Investigation

A minimum of one soil boring log should be required for each 5,000 square feet of infiltration basin area (plan view area) and under no circumstances should there be less than three soil boring logs per basin (Washington State DOE, 1992).

Topographic Conditions

Infiltration basins should be a minimum of 50 feet from any slope greater than 15%. If unavoidable, a geotechnical report should address the potential impact of infiltration on or near the steep slope. Developments on sloping sites often require extensive cut and fill operations. The use of infiltration basins on fill sites is not permitted. Also, infiltration basins should be a minimum of 100 feet up-slope and 20 feet down-slope from any buildings.

Design Infiltration Rate

The design infiltration rate, f_d , should be set to equal one-half the infiltration rate, f (in/hr), determined from the soil analysis. Therefore:

$$f_d = 0.5 f$$

Maximum Ponding Time and Depth

All infiltration basins should be designed to completely drain stored runoff within 2 days following the occurrence of a storm event. Thus, an allowable maximum ponding time, T_{\max} , of 48 hours should be used. The maximum ponding depth for an infiltration basin is:

$$d_{\max} = f_d T_{\max}$$

where: d_{\max} = maximum depth of the facility, in (ft).
 f_d = design infiltration rate of the basin area soils, in (ft/hr) ($f_d = \frac{1}{2} f$)
 T_{\max} = maximum allowable drain time = 48 hrs.

The ponding depth should not be so great as to contribute to the compaction of the soil surface. Depending on the specific soil characteristics, a maximum ponding depth of 2 feet is generally recommended (MWCOC, 1992).

The minimum surface area of the facility bottom is:

$$SA_{\min} = \frac{WQ_v}{f_d T_{\max}}$$

where: SA_{\min} = minimum basin bottom surface area, in (ft²);
 WQ_v = water quality volume requirements, in (ft³);
 f_d = design infiltration rate of the basin area soils, in (ft/hr);
 T_{\max} = maximum allowable drain time, in (hours)

Runoff Pretreatment

Infiltration basins should always be preceded by a pretreatment facility. Grease, oil, floatable organic materials, and settleable solids should be removed from the runoff before it enters the infiltration basin. Vegetated filters, sediment traps and/or forebays, water quality inlets (refer to Minimum Standard 14.11, Manufactured BMP Systems) are just a few of the available pretreatment strategies.

At a minimum, the layout and design of the basin should include a sediment forebay or pretreatment cell, as shown in Figure 14.01-1, to enhance and prolong the infiltration capacity. Any pretreatment facility should be included in the design of the basin and should include maintenance and inspection requirements. It is recommended that a grass strip or other vegetated buffer at least 20 feet wide be maintained around the basin to filter surface runoff.

Principal and Emergency Spillways

A diversion structure upstream of an off-line basin will regulate the rate of flow into the basin, but not the volume. Therefore, infiltration basins should have a spillway to convey flows from storm events which are larger than the design capacity. The primary outlet should be located above the required infiltration volume. Additionally, a riser and barrel system is advantageous for future conversion to an extended-detention or retention facility if the infiltration capacity of the soil becomes impaired. All design elements of a principal spillway should be per Chapter 8.

An emergency spillway is recommended for all impounding structures, including infiltration basins. If a vegetated spillway is to be used as the primary outlet above the water quality volume, care should be taken to design for the increased frequency of use. This is especially critical between maintenance operations when the infiltration capacity is decreased due to sediment loads. If a spillway is to be used for all storms which generate more runoff than the water quality volume, then a nonerodible surface should be provided.

Fencing

Fencing may be provided where deemed necessary by the developer, land owner, or locality for the purposes of public safety or protection of vegetation.

Construction Specifications

In general, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable. Further guidance can be found in the Soil Conservation Service's Engineering Field Manual. Specifications for the work should conform to the methods and procedures indicated for installing earthwork, concrete, reinforcing steel, pipe, water gates, metal work, woodwork and masonry as they apply to the site and the purpose of the structure. The specifications should also satisfy all requirements of the local government.

Sequence of Construction

The sequence of various phases of basin construction should be coordinated with the overall project construction schedule. Rough excavation of the basin may be scheduled with the rough grading phase of the project to permit use of the material as fill in earthwork areas. Otherwise, infiltration measures should not be constructed or placed into service until the entire contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas within the drainage area may load the newly formed basin with a large volume of fine sediment. This could seriously impair the natural infiltration ability of the basin floor.

The specifications for construction of a basin should state the following: 1) the earliest point at which storm drainage may be directed to the basin, and 2) the means by which this delay in basin use is to be accomplished. Due to the wide variety of conditions encountered among projects, each project should be evaluated separately to postpone basin use for as long as possible.

Excavation

Initially, the basin floor should be excavated to within one foot of its final elevation. Excavation to the finished grade should be delayed until all disturbed areas in the watershed have been stabilized or protected. The final phase of excavation should remove all accumulated sediment. Relatively light, tracked-equipment is recommended for this operation to avoid compaction of the basin floor.

After the final grading is completed, the basin floor should be deeply tilled by means of rotary tillers or disc harrows to provide a well-aerated, highly porous surface texture.

Lining Material

Establishing dense vegetation on the basin side slopes and floor is recommended. A dense vegetative cover will not only prevent erosion and sloughing, but will also provide a natural means to maintain relatively high infiltration rates. Inflow points to the basin should also be protected with erosion controls (e.g., riprap, flow spreaders, energy dissipators, etc.), as well as a sediment forebay.

Maintenance / Inspection Guidelines

The following maintenance and inspection guidelines are not intended to be all-inclusive. Specific facilities may require other measures not discussed here.

Inspection Schedule

When infiltration basins are first made functional they should be inspected monthly and after any large storm event. Thereafter, once the basin is functioning satisfactorily and without potential sediment problems, inspections may be made semi-annually and after any large storm events. All inspections should include investigation for potential sources of contamination.

Sediment Control

The basin should be designed to allow for maintenance. Access should be provided for vehicles to easily maintain the forebay (pre-settling basin) without disturbing vegetation or sediment any more than what is absolutely necessary.

Grass bottoms in infiltration basins seldom need replacement since grass serves as a good filter material. If silty water is allowed to trickle through the turf, most of the suspended material is strained out within a few yards of surface travel. Well-established turf on a basin floor will grow up through sediment deposits forming a porous turf and preventing the formation of an impenetrable layer. Grass planted on basin side slopes should also prevent erosion.

Vegetation Maintenance

Maintenance of the vegetation on the basin floor and side slopes is necessary to promote a dense turf with extensive root growth, which subsequently enhances infiltration, prevents erosion and sedimentation, and deters invasive weed growth. Bare spots should be immediately stabilized and revegetated.

The use of low-growing, stoloniferous grasses will permit long intervals between mowings. Mowing twice a year is generally satisfactory. Fertilizers should be applied only as necessary and in limited amounts to avoid contributing to pollution problems, including groundwater pollution, for which the infiltration basin helps mitigate.

Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of an infiltration basin.

1. Determine if the anticipated development conditions and drainage area are appropriate for an infiltration basin application.
2. Determine if the soils (permeability, bedrock, water table, embankment foundation, etc.) and topographic conditions (slopes, building foundations, etc.) are appropriate for an infiltration basin application.
3. Locate the infiltration basin on the site within topographic constraints.
4. Determine the drainage area to the infiltration basin and calculate the required water quality volume.
5. Evaluate the hydrology of the contributing drainage area to determine peak rates of runoff.
6. Design the infiltration basin:
 - Design infiltration rate, $f_d = 0.5 f$.
 - Max. Storage time $T_{\max} = 48$ hours
 - Max. Storage depth, d_{\max}
 - Runoff pretreatment - concentrated input, sheet flow input, sediment forebay
 - Vegetated buffer around basin to filter surface runoff
 - Vegetated emergency spillway and/or riser and barrel design
 - Earthen Embankment design
7. Provide material specifications.
8. Provide sequence of construction.
9. Provide maintenance and inspection requirements

MINIMUM STANDARD 14.02

INFILTRATION TRENCH

LIST OF ILLUSTRATIONS

<u>#</u>	<u>FIGURE</u>	<u>PAGE</u>
14.02-1	Infiltration Trench - Section	14.02-2
14.02-2	Observation Well	14.02-5
14.02-3	Filter Fabric Placement	14.02-6

MINIMUM STANDARD 14.02

INFILTRATION TRENCH

Definition

An infiltration trench is a shallow, excavated trench backfilled with a coarse stone aggregate to create an underground reservoir. Stormwater runoff diverted into the trench gradually infiltrates into the surrounding soils from the bottom and sides of the trench. The trench can be either an open surface trench or an underground facility.

Purpose

Infiltration trenches are used primarily as water quality BMPs. Trenches are generally 2 to 10 feet deep and are backfilled with a coarse stone aggregate, allowing for temporary storage of storm runoff in the voids between the aggregate material. Stored runoff gradually infiltrates into the surrounding soil. The surface of the trench can be covered with grating and/or consist of stone, gabion, sand, or a grassed area with a surface inlet. Utilizing underground pipes within the trench can increase the temporary storage capacity of the trench and can sometimes provide enough storage for flooding and/or stream channel erosion control (see Figure 14.02-1).

Conditions Where Practice Applies

An infiltration trench may be used where the subsoil is sufficiently permeable to provide a reasonable infiltration rate and where the water table is low enough to prevent pollution of groundwater.

Drainage Area

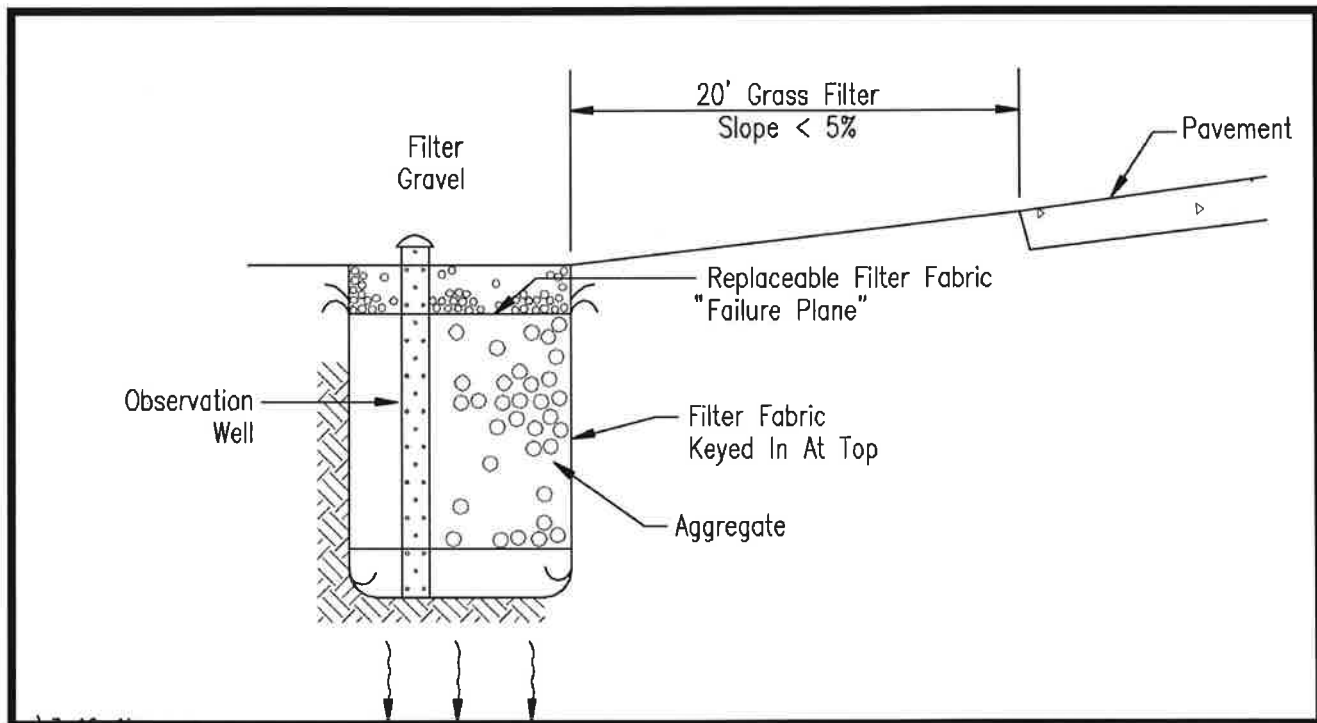
Infiltration trenches are not practical for large drainage areas. Generally, the drainage area for infiltration trenches should be limited to 5 acres. Multiple trenches may be considered to control the runoff from a large site, but this also increases the associated maintenance responsibilities.

Development Conditions

Infiltration trenches are generally suited for low- to medium-density residential and commercial developments. They can be installed in multi-use areas, such as along parking lot perimeters, or in small areas that cannot readily support retention basins or similar structures. Infiltration trenches can be used in residential areas, commercial areas, parking lots and open space areas. Unlike most

BMPs, trenches can easily fit into the margin, perimeter, or other unused areas of developed sites, making them particularly suitable for retrofitting in existing developments or in conjunction with other BMPs. A trench may also be installed under a swale to increase the storage of the related infiltration system. In all cases, pretreatment of the stormwater runoff to remove coarse sediment and particulate pollutants prior to entering the infiltration trench should be provided.

FIGURE 14.02-1
Infiltration Trench - Section



Planning Considerations

Appropriate soil conditions and protection of groundwater are two important considerations when planning for an infiltration trench.

Design Criteria

The purpose of this section is to provide recommendations and minimum criteria for the design of infiltration trenches intended to comply with the runoff quality requirements of the Owensboro / Daviess County Stormwater Management program.

General

Infiltration trenches are assumed to have rectangular cross-sections. Thus, the infiltration surface area (trench bottom) can be readily calculated from the trench geometry. The storage volume of the trench must be calculated using the void ratio of the backfill material that will be placed in it.

The same general criteria presented for the design of infiltration basins apply to trenches; the following information is provided for additional guidance.

Soils Investigation

A minimum of one soil boring log should be required for every 50 feet of trench length. A minimum of two soil boring logs should be required for each proposed trench location (Washington State DOE, 1992).

Topographic Conditions

Infiltration trenches should be located 20 feet down-slope and 100 feet up-slope from building foundations. An analysis should be completed to identify any possible adverse effects of seepage zones if there are nearby building foundations, basements, roads, parking lots or sloping sites. Developments on sloping sites often require the use of extensive cut and fill operations. The use of infiltration trenches on fill sites is not permitted.

Design Infiltration Rate

The design infiltration rate, f_d , should be set to equal one-half the infiltration rate obtained from the soil analysis. Therefore,

$$f_d = 0.5 f$$

Maximum Storage Time and Trench Depth

All infiltration trenches should be designed to empty within 2 days following the occurrence of a storm event. Thus, a maximum allowable storage time, T_{\max} , of 48 hours should be used.

The maximum depth for an infiltration trench may be defined as:

$$d_{\max} = \frac{f_d T_{\max}}{V_r}$$

where:

- d_{\max} = maximum allowable depth of the facility, in ft;
- f_d = design infiltration rate of the trench area soils, in ft/hr ($f_d = 0.5f$);
- T_{\max} = maximum allowable drain time = 48 hrs.;
- V_r = void ratio of the stone reservoir expressed in terms of the percentage of porosity divided by 100 (0.4 typ.).

Refer to the KYTC's Road and Bridge Specifications, latest edition, for information and specifications for coarse aggregates. A void ratio of 0.40 is assumed for stone reservoirs using 1.5 to 3.5 inch stone - KYTC No. 1 Coarse-graded Aggregate.

The minimum surface area of the facility bottom may be defined as:

$$SA_{\min} = \frac{Vol_{wq}}{f_d T_{\max}}$$

where: SA_{\min} = minimum trench bottom surface area, in ft^2 ;
 Vol_{wq} = water quality volume requirements, in ft^3 ;
 f_d = design infiltration rate of the trench
 area soils, in ft/hr ($f_d = 0.5f$);
 T_{\max} = maximum allowable drain time = 48 hrs.

Runoff Pretreatment

Infiltration trenches should always be preceded by a pretreatment facility. Grease, oil, floatable organic materials, and settleable solids should be removed from the runoff before it enters the trench. Vegetated filters, sediment traps or forbays, water quality inlets (refer to Minimum Standard 14.11, Manufactured BMP Systems) are just a few of the available pretreatment strategies. To reduce both the frequency of turbulent flow-through and the associated scour and/or resuspension of residual material, infiltration trenches and associated pretreatment facilities should be installed off-line (MWCOG, 1992). Additional pretreatment arrangements are illustrated in Figure 3.10-3.

A grass strip or other type of vegetated buffer at least 20 feet wide should be maintained around trenches that accept surface runoff as sheet flow. The slope of the filter strip should be approximately 1% along its entire length and 0% across its width. A recent study by MWCOG (Galli, 1992) concluded that for areas receiving high suspended solid loads, a minimum filter length of 50 feet is desirable.

All trenches with surface inlets should be engineered to capture sediment from the runoff before it enters the stone reservoir. Any pretreatment facility design should be included in the design of the trench, complete with maintenance and inspection requirements.

Backfill Material

Backfill material for the infiltration trench should be clean aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches (i.e., KYTC No. 1 Open-graded Coarse Aggregate or equivalent). The aggregate should contain few aggregates smaller than the selected size. Void spaces for KYTC No. 1 aggregate is assumed to be 40 percent.

An 8 inch deep bottom sand layer (KYTC Fine Aggregate, Grading A or B) is required for all trenches to promote better drainage and reduce the risk of soil compaction when the trench is

backfilled with stone (MWCOG, 1992).

Filter Fabric

The aggregate fill material should be surrounded with an engineering filter fabric as shown in Figure 14.02-3. For an aggregate surface trench, filter fabric should surround all of the aggregate fill material except the top one foot. A separate piece of fabric should be used for the top layer to act as a failure plane. This top piece can then be removed and replaced upon clogging. Note, however, that filter fabric should not be placed on the trench bottom.

Overflow Channel

Usually, because of the small drainage areas controlled by an infiltration trench, an emergency spillway is not necessary. However, the overland flow path taken by the surface runoff, when the capacity of the trench is exceeded, should always be evaluated. A nonerosive overflow channel leading to a stabilized watercourse should be provided, as necessary, to insure that uncontrolled, erosive, concentrated flow does not develop.

Observation Well

An observation well should be installed for every 50 feet of infiltration trench length. The observation well will show how quickly the trench dewateres following a storm, as well as providing a means of determining when the filter fabric is clogged and maintenance is needed (refer to Figure 14.02-2).

The observation well should consist of perforated PVC pipe, 4 to 6 inches in diameter. It should be installed in the center of the structure, flush with the ground elevation of the trench. Putting the observation well in a non-parking or traffic area to simplify inspections is best. The top of the well should be capped to discourage vandalism and tampering.

FIGURE 14.02-2
Observation Well

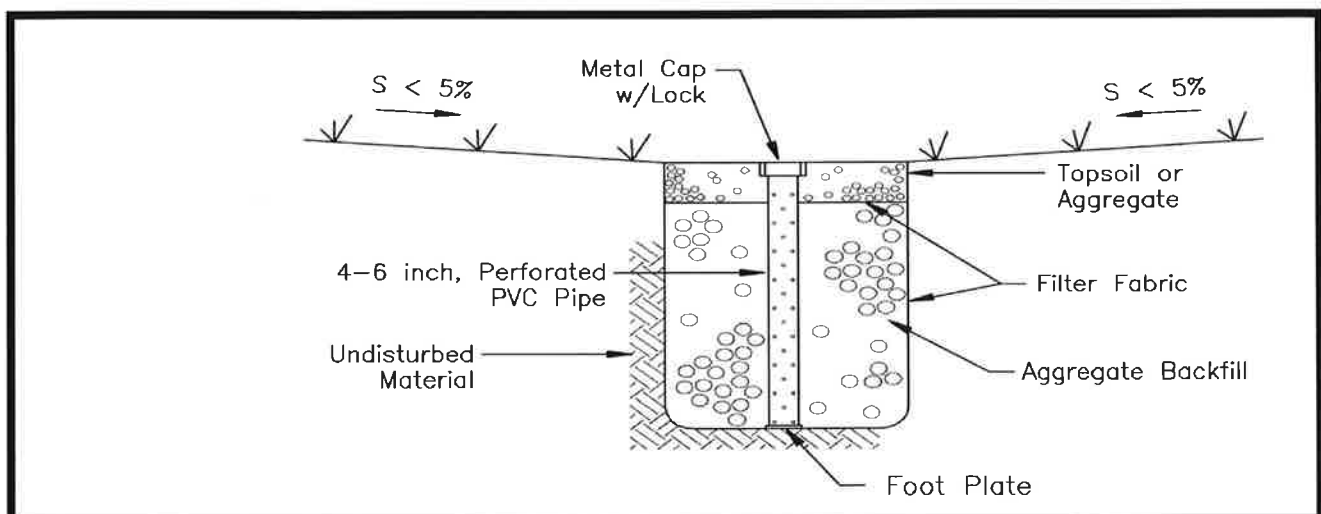
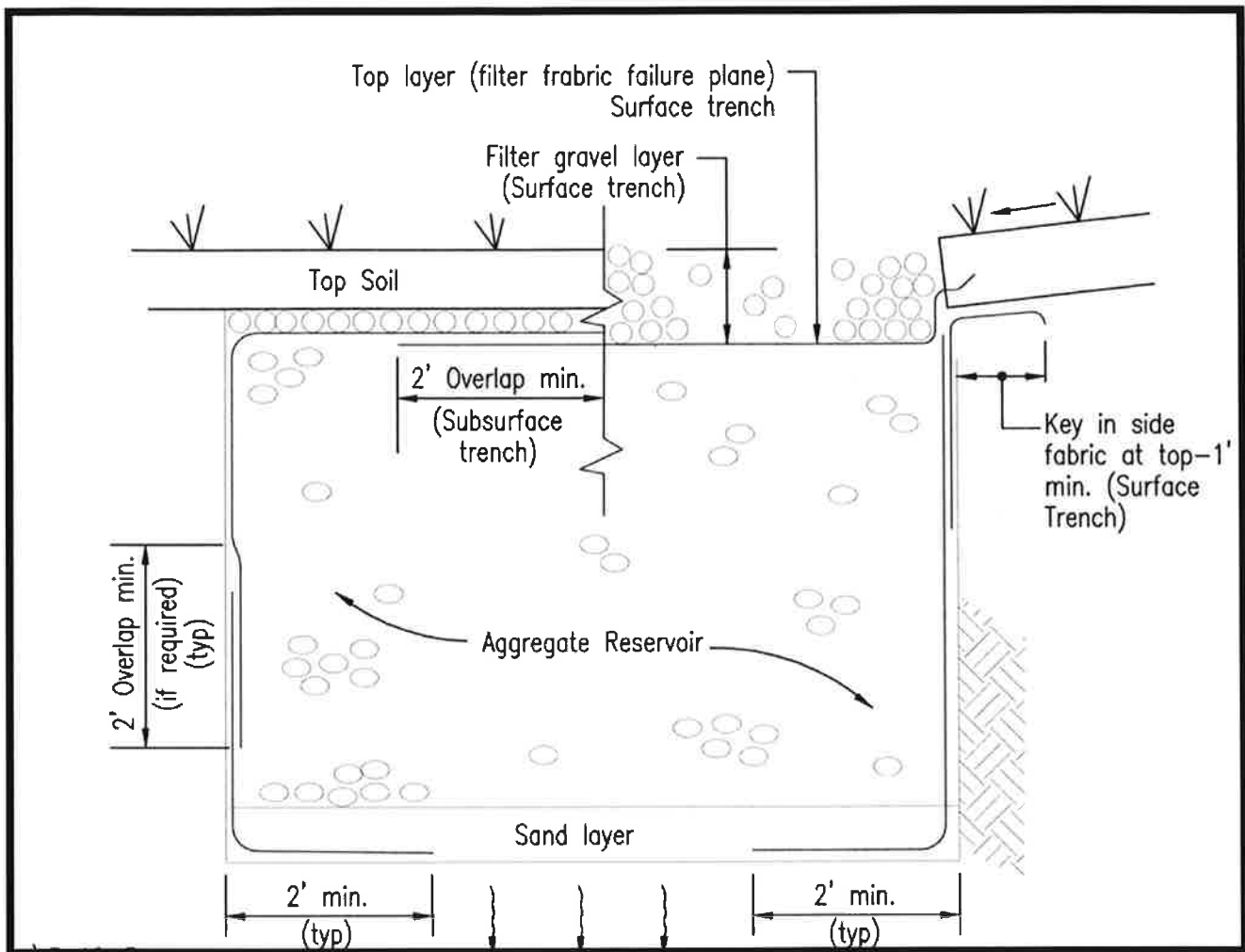


FIGURE 14.02-3
Filter Fabric Placement



Construction Specifications

Overall, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable. Further guidance can be found in the Soil Conservation Service's Engineering Field Manual. Specifications for the work should conform to the methods and procedures indicated for installing earthwork, concrete, reinforcing steel, pipe, water gates, metal work, woodwork and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government.

Construction of an infiltration trench should also be in conformance with the following:

Sequence of Construction

An infiltration trench should not be constructed or placed into service until all of the contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas within the drainage area may load the newly formed trench and/or pretreatment facility

with a large volume of fine sediment.

The specifications for the construction of an infiltration trench should state the following: 1) the earliest point at which storm drainage may be directed to the trench, and 2) the means by which this delay in use is to be accomplished. Due to the wide variety of conditions encountered among development projects, each project should be evaluated separately to postpone trench use for as long as possible.

Trench Preparation

Trench excavation should be limited to the specific trench dimensions. Excavated materials should be placed away from the trench sides to avoid impacting the trench wall stability.

The trench should be excavated with a backhoe or similar device that allows the equipment to stand away from the trench bottom. This bottom surface should be scarified with the excavator bucket teeth on the final pass to eliminate any smearing or shearing of the soil surface. Similarly, the sand filter material should be placed on the trench bottom so that it does not compact or smear the soil surface. The sand must be deposited ahead of the loader so the equipment is always supported by a minimum of 8 inches of sand.

Large tree roots must be trimmed flush with the trench sides to prevent the fabric from puncturing or tearing during subsequent installation procedures. No voids between the filter fabric and the excavation walls should be present. If boulders or similar obstacles are removed from the excavated walls, natural soils should be placed in these voids before the filter fabric is installed. The side walls of the trench should be roughened where sheared and sealed by heavy equipment.

Vertically excavated walls may be difficult to maintain in areas where the soil moisture is high or where soft cohesive or cohesionless soils predominate. These conditions may require that the side slopes be laid back to maintain stability; trapezoidal rather than rectangular cross sections may result.

Fabric Laydown

The roll of filter fabric should be cut to the proper width before installation. The width should allow for perimeter irregularities plus a minimum 12-inch overlap at the top. When a fabric overlap is required elsewhere, the upstream section should overlap the downstream section by a minimum of 2 feet to ensure that the fabric conforms to the excavation surface during aggregate placement. Note that filter fabric should not be placed on the trench bottom.

Stone Aggregate Placement Compaction

The crushed stone aggregate should be placed in the trench in loose lifts of about 12 inches using a backhoe or front-end loader with a drop height near the bottom of the trench, and should be lightly compacted with plate compactors. Aggregate should not be dumped into the trench by a truck.

Backfill material for the infiltration trench should be clean, washed aggregate 1.5 to 3.5 inches in diameter (KYTC No. 1 Open-graded Coarse Aggregate or equivalent). The aggregate should contain few aggregates smaller than the selected size.

The 8 inch deep bottom sand layer should consist of KYTC Fine Aggregate, Grading A or B.

Overlapping and Covering

Following the stone aggregate placement, the filter fabric should be folded over the stone aggregate to form a 12-inch minimum longitudinal overlap. The desired fill soil or stone aggregate should be placed over the lap at sufficient intervals to maintain the lap during subsequent backfilling.

Potential Contamination

Clean aggregate should not be mixed with natural or fill soils. All contaminated aggregate should be removed and replaced with clean aggregate.

Traffic Control

To prevent or reduce compaction of the soil, heavy equipment and traffic should not travel over the infiltration trench.

Observation Well

Observation wells should be provided as specified in the design criteria. The depth of the well at the time of installation should be clearly marked on the well cap.

Maintenance / Inspection Guidelines

The following maintenance and inspection guidelines are not intended to be all-inclusive. Specific facilities may require other measures not discussed here.

Inspection Schedule

The observation well and pretreatment facility should be monitored quarterly and after every large storm event. It is recommended that a log book be maintained showing the depth of water in the well at each observation in order to determine the rate at which the facility dewateres after runoff producing storm events. Once the performance characteristics of the structure have been verified, the monitoring schedule can be reduced to an annual basis, unless the performance data suggest that a more frequent schedule is required.

Sediment Control

Sediment buildup in the top foot of stone aggregate or the surface inlet should be monitored on the same schedule as the observation well. A monitoring well in the top foot of stone aggregate should be provided when the trench has a stone surface. Sediment deposited should not be allowed to build up to the point where it will reduce the infiltration rate into the trench.

It is recognized that infiltration facilities are subject to clogging. Once a trench facility has clogged, very little can be done to correct it, short of excavating the facility. Maintenance efforts, therefore, should focus on the measures used for pretreatment of runoff, in addition to the facility itself.

Vegetation Maintenance

Any vegetated buffers associated with an infiltration trench should be inspected regularly and maintained as needed. Regular maintenance of the buffer is necessary to promote dense turf with extensive root growth, which subsequently enhances runoff filtering, prevents erosion and sedimentation, and deters invasive weed growth. Bare spots should be immediately stabilized and revegetated. Fertilizers should be applied only as necessary and in limited amounts to avoid contributing to pollution problems which the infiltration basin helps to mitigate.

Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of an infiltration trench.

1. Determine if the anticipated development conditions and drainage area are appropriate for an infiltration trench application.
2. Determine if the soils (permeability, bedrock, water table, etc.) and topographic conditions (slopes, building foundations, etc.) are appropriate for an infiltration trench application.
3. Locate the infiltration trench on the site within topographic constraints.
4. Determine the drainage area for each infiltration trench and calculate the required water quality volume.
5. Evaluate the hydrology of the contributing drainage area to determine peak rates of runoff.
6. Design the infiltration trench:
 - design infiltration rate, $f_d = 0.5 f$
 - max. storage time $T_{\max} = 48$ hours
 - max. storage depth, d_{\max}
 - stone backfill of clean aggregate (1.5" to 3.5") KYTC Open-Graded Course Aggregate
 - sand layer on trench bottom (8 inches)
 - runoff pretreatment - concentrated input, sheet flow input
 - vegetated buffer around trench to filter surface runoff
 - filter fabric on trench sides and top (not on trench bottom) keyed into trench
 - overflow channel or large storm bypass
 - observation well
7. Provide material specifications.
8. Provide sequence of construction.
9. Provide maintenance and inspection requirements.



MINIMUM STANDARD 14.03

ROOF DOWNSPOUT SYSTEM



LIST OF ILLUSTRATIONS

<u>#</u>	<u>FIGURE</u>	<u>PAGE</u>
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MINIMUM STANDARD 14.03

ROOF DOWNSPOUT SYSTEM

Definition

A roof downspout system is an infiltration trench practice intended only for infiltrating rooftop runoff transported to the trench via roof downspout drains.

Purpose

The purpose of a roof downspout system is to provide water quality enhancement of rooftop runoff via infiltration of the water quality volume into the surrounding soils. This facility is not designed to infiltrate other surface water that could transport sediment or pollutants, such as from paved areas.

Conditions Where Practice Applies

Roof downspout systems may be used in any situation where disposing of rooftop runoff without direct connections to existing drainage systems or BMPs is acceptable and advantageous. Because of their small size, they are well suited for retrofitting in areas where runoff control of existing or new rooftop areas associated with building additions becomes necessary. As part of a low impact development strategy, roof downspout systems effectively disconnect the rooftop imperviousness from the drainage system which helps reduce the stormwater impact of the development. Use of roof downspout systems (or infiltration trenches in general) in residential areas should be used with caution due to concern for the potential lack of inspections and maintenance, and ultimate failure and abandonment of the facility.

Planning Considerations

The planning considerations for roof downspout systems are the same as those for infiltration trenches (Minimum Standard 14.02). The drainage area is limited to the rooftop areas of residential and/or commercial structures.

Design Criteria

This section provides recommendations and minimum criteria for the design of roof downspout systems intended to comply with the runoff quality requirements of the Owensboro/Daviess County Stormwater Management program.

The design criteria for roof downspout systems are the same as those for infiltration trenches with the following exceptions and/or additions:

Distance from Structures

Roof downspout systems should be a minimum of 10 feet down-slope from any structure or property line, and 30 feet from any septic tank or drain field.

Runoff Pre-Treatment

Gutters should be fitted with mesh screens to prevent leaf litter and other debris from entering the system in areas where there is tree cover. The expected growth of newly planted trees should be considered.

A pretreatment settling basin as shown in Figure 14.03-1 should be provided on all roof downspout systems.

Overflow

An overflow outlet should be provided on the downspout at the surface elevation to allow flow to bypass the infiltration facility when it is full or clogged. (See Figure 14.03-1.)

Adequate surface drainage away from the structure should be provided according to appropriate building codes.

Construction Specifications

The construction specifications for roof downspout systems are the same as those for infiltration trenches.

Maintenance and Inspection Guidelines

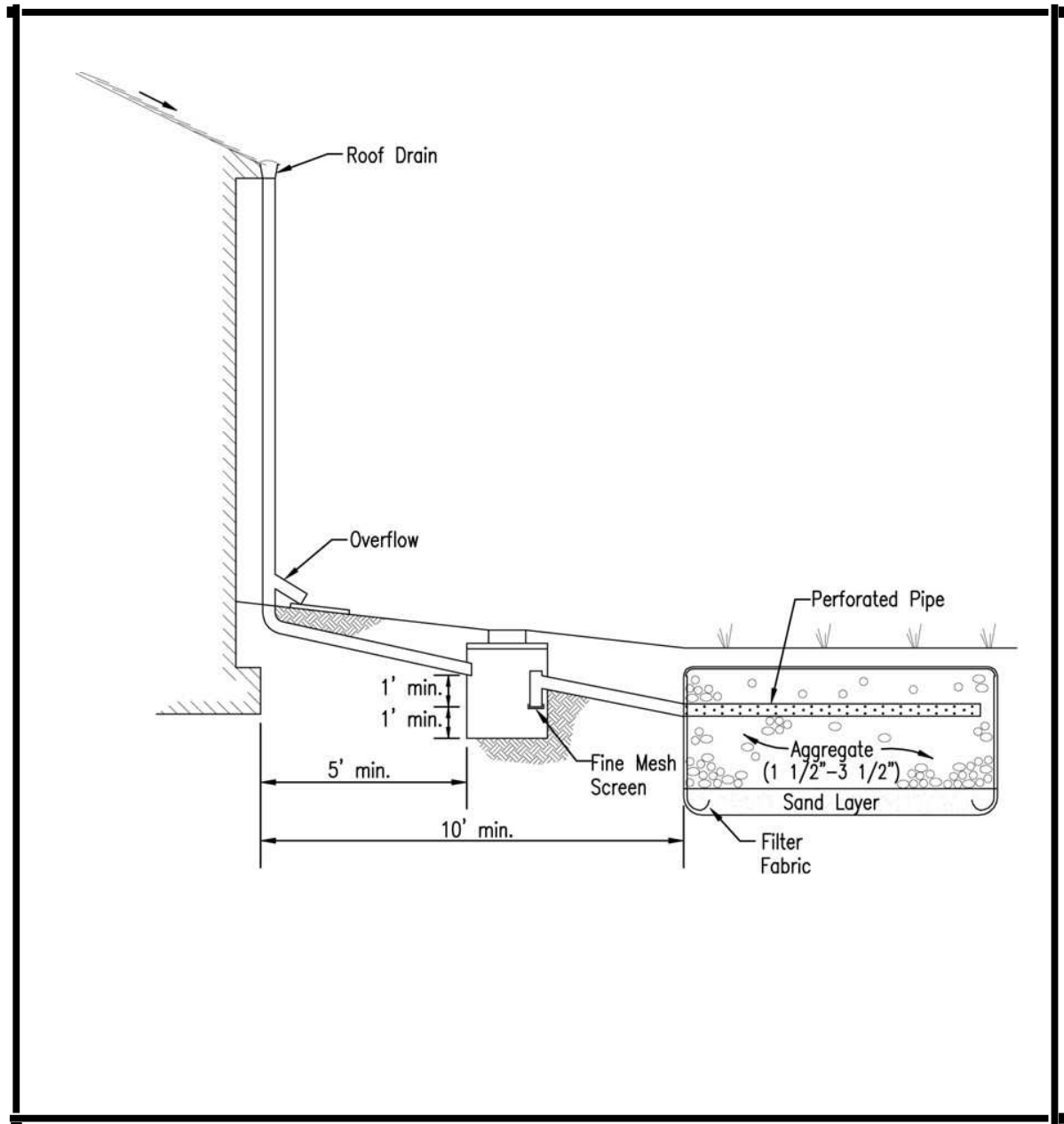
Maintenance procedures are identical for those of an infiltration trench. Since these facilities are installed on individual buildings and other structures, provisions need to be made for their maintenance, especially when they are installed on single family dwellings. When flow is observed to be bypassing the facility, the system has clogged and should be evaluated for rehabilitation.

Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of a roof downspout system.

1. Determine if the anticipated development conditions and rooftop areas are appropriate for a roof downspout system.
2. Determine if the soils (permeability, bedrock, water table, etc.) and topographic conditions (slopes, building foundations, etc.) are appropriate for a roof downspout system.
3. Locate the roof downspout system on the site within site topographic constraints.
4. Determine the roof area for each roof downspout system and calculate the required water quality volume.
5. Design the roof downspout system:
 - design infiltration rate, $f_d = 0.5 f$
 - max. Storage time $T_{\max} = 48$ hours
 - max. Storage depth, d_{\max}
 - stone backfill of clean aggregate (1.5" to 3.5" diameter) - KYTC No. 1 Open-graded Course Aggregate
 - sand layer on trench bottom (8 inches
 - runoff pretreatment - concentrated input: gutter screens, settling basin
 - filter fabric on trench sides and top (not on trench bottom) keyed into trench
 - overflow channel or large storm bypass
 - observation well
6. Provide material specifications.
7. Provide sequence of construction.
8. Provide maintenance and inspection requirements.

FIGURE 14.03-1
Roof Downspout System with a Pretreatment Sump Basin



MINIMUM STANDARD 14.04

PERMEABLE PAVEMENT



LIST OF ILLUSTRATIONS

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14.04-2	Comparative Properties of the Three Major Permeable Pavement Types	14.04-3
14.04-3	Permeable Pavement Design Criteria	14.04-4
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MINIMUM STANDARD 14.04

PERMEABLE PAVEMENT

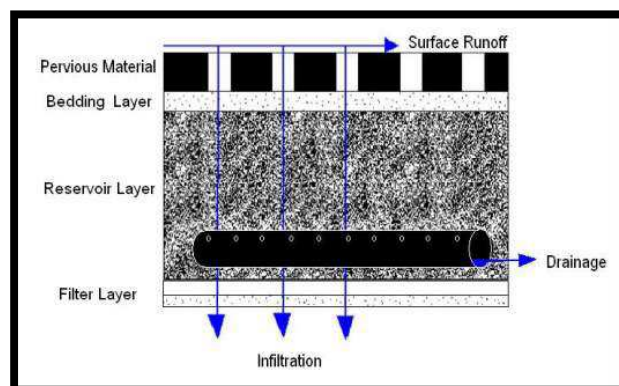
DESCRIPTION

Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated. A variety of permeable pavement surfaces are available, including **pervious concrete**, **porous asphalt** and permeable **interlocking concrete pavers**. While the specific design may vary, all permeable pavements have a similar structure, consisting of a surface pavement layer, an underlying stone aggregate reservoir layer and a filter layer or fabric installed on the bottom (See **Figure 14.04-1** below).

The thickness of the reservoir layer is determined by both a structural and hydrologic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. In low-infiltration soils, some or all of the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in the native soils permit, permeable pavement can be designed without an underdrain, to enable full infiltration of runoff. A combination of these methods can be used to infiltrate a portion of the filtered runoff.

Figure 14.04-1.

Cross Section of Typical Permeable Pavement (Source: Hunt & Collins, 2008)



Permeable pavement is typically designed to treat stormwater that falls on the actual pavement surface area, but it may also be used to accept run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops. However, careful sediment control is needed for any run-on areas to avoid clogging of the down-gradient permeable pavement. Permeable pavement has been used at commercial, institutional, and residential sites in spaces that are traditionally impervious. Permeable pavement promotes a high degree of runoff volume reduction and nutrient removal, and it can also reduce the effective impervious cover of a development site.

PERFORMANCE

The overall stormwater functions of permeable pavement are shown in **Table 14.04-1**.

Table 14.04-1.
Summary of Stormwater Functions Provided by Permeable Pavement

Stormwater Function	Level 1 Design	Level 2 Design
Est. Annual Runoff Volume Reduction (RR)	45%	75%
Channel Protection	<ul style="list-style-type: none">Design extra storage (optional, as needed) in the stone underdrain layer to accommodate larger storm volumes, and use NRCS TR-55 Runoff Equations ¹ to compute a CN adjustment.	
Flood Mitigation	Partial. May be able to design additional storage into the reservoir layer by adding perforated storage pipe or chambers.	
¹ NRCS TR-55 Runoff Equations 2-1 thru 2-5 and Figure 2-1 can be used to compute a curve number adjustment for larger storm events based on the retention storage provided by the practice(s).		

Sources: CWP and CSN (2008) and CWP (2007)

The choice of what kind of permeable pavement to use is influenced by site-specific design factors and the intended future use of the permeable surface. A general comparison of the engineering properties of the three major permeable pavement types is provided in **Table 14.04-2**, although designers should check with product vendors and their local review authority to determine their specific requirements and capabilities. Designers should also note that there are other paver options, such as concrete grid pavers and reinforced turf pavers, that function in the same general manner as permeable pavement.

Table 14.04-2.
Comparative Properties of the Three Major Permeable Pavement Types

Design Factor	Porous Concrete (PC)	Porous Asphalt (PA)	Interlocking Pavers (IP)
Scale of Application	Small and large scale paving applications	Small and large scale paving applications	Micro, small and large scale paving applications
Pavement Thickness ¹	5 to 8 inches	3 to 4 inches	3 inches ^{1,8}
Bedding Layer ^{1,8}	None	2 inches No. 57 stone	2 inches of No. 8 stone
Reservoir Layer ^{2,8}	No. 57 stone	No. 2 stone	No. 2 stone 3-4 inches of No.57 stone
Construction Properties ³	Cast in place, seven day cure, must be covered	Cast in place, 24 hour cure	No cure period; manual or mechanical installation of pre-manufactured units, over 5000 sf/day per machine
Design Permeability ⁴	10 feet/day	6 feet/day	2 feet/day
Construction Cost ⁵	\$ 2.00 to \$6.50/sq. ft.	\$ 0.50 to \$1.00/ sq. ft.	\$ 5.00 to \$ 10.00/ sq. ft.
Min. Batch Size	500 sq. ft.		NA
Longevity ⁶	20 to 30 years	15 to 20 years	20 to 30 years
Overflow	Drop inlet or overflow edge	Drop inlet or overflow edge	Surface, drop inlet or overflow edge
Temperature Reduction	Cooling in the reservoir layer	Cooling in the reservoir layer	Cooling at the pavement surface & reservoir layer
Colors/Texture	Limited range of colors and textures	Black or dark grey color	Wide range of colors, textures, and patterns
Traffic Bearing Capacity ⁷	Can handle all traffic loads, with appropriate bedding layer design.		
Surface Clogging	Replace paved areas or install drop inlet	Replace paved areas or install drop inlet	Replace permeable stone jointing materials
Other Issues		Avoid seal coating	Snowplow damage
Design Reference	American Concrete Institute # 522.1.08	Jackson (2007) NAPA	Smith (2006) ICPI
¹ Individual designs may depart from these typical cross-sections, due to site, traffic and design conditions. ² Reservoir storage may be augmented by corrugated metal pipes, plastic arch pipe, or plastic lattice blocks. ³ ICPI (2008) ⁴ NVRA (2008) ⁵ WERF 2005 as updated by NVRA (2008) ⁶ Based on pavement being maintained properly, Resurfacing or rehabilitation may be needed after the indicated period. ⁷ Depends primarily on on-site geotechnical considerations and structural design computations. ⁸ Stone sizes correspond to ASTM D 448: <i>Standard Classification for Sizes of Aggregate for Road and Bridge Construction</i> .			

DESIGN TABLE

The major design goal of Permeable Pavement is to maximize nutrient removal and runoff reduction. To this end, designers may choose to use a baseline permeable pavement design (Level 1) or an enhanced design (Level 2) that maximizes nutrient and runoff reduction. To qualify for Level 2, the design must meet all design criteria shown in the right hand column of **Table 14.04-3**.

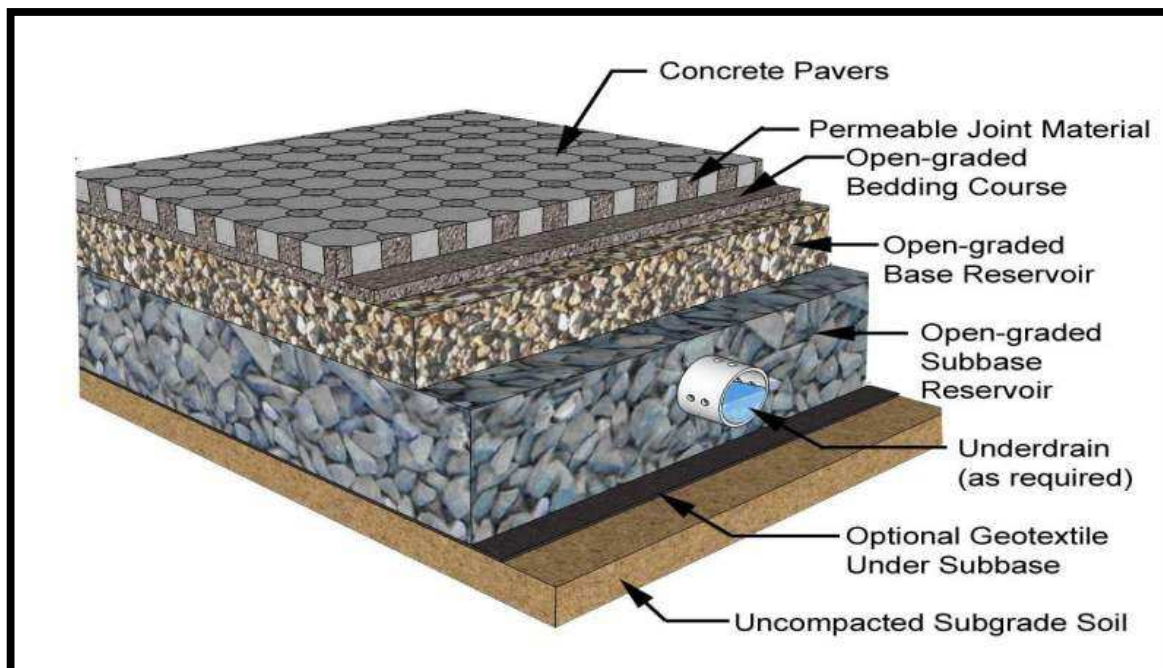
Table 14.04-3.
Permeable Pavement Design Criteria

Level 1 Design	Level 2 Design
$WQ_v = (0.64)(A) / 12$ – any volume reduced by an upstream BMP ¹	$WQ_v = (0.77)(A) / 12$
Soil infiltration is less than 0.5 in./hr.	Soil infiltration rate exceeds 0.5 in./hr.
Underdrain required	Underdrain not required; OR If an underdrain is used, a 12-inch stone sump must be provided below the underdrain invert; OR The WQ_v has at least a 48-hour drain time, as regulated by a control structure.
CDA = The permeable pavement area plus upgradient parking, as long as the ratio of external contributing area to permeable pavement does not exceed 2:1.	CDA = The permeable pavement area

¹ The contributing drainage area to the permeable pavements should be limited to paved surfaces, to avoid sediment wash-on, and sediment source controls and/or a pre-treatment strip or sump should be used. When pervious areas are conveyed to permeable pavement, pre-treatment must be provided, and the pre-treatment may qualify for a runoff reduction credit.

TYPICAL DETAILS

Figure 14.04-2.
Typical Detail (Source: Smith, 2009)



**PHYSICAL FEASIBILITY &
DESIGN APPLICATIONS**

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

Available Space. A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Soils. Soil conditions do not constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Groups (HSG) C or D usually require an underdrain, whereas HSG A and B soils often do not. In addition, permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain.

If the proposed permeable pavement area is designed to infiltrate runoff without underdrains, it must have a minimum infiltration rate of 0.5 inches per hour. Initially, projected soil infiltration rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site infiltration measurement. As a rule of thumb, native soils should have silt/clay content less than 40% and clay content less than 20% to be considered suitable. More detailed analysis should be completed to confirm infiltration potential.

Designers should also evaluate existing soil properties during initial site layout, and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of HSG A or B soils shown on NRCS soil surveys should be considered as primary locations for all types of infiltration.

External Drainage Area. Any external drainage area contributing runoff to permeable pavement should generally not exceed twice the surface area of the permeable pavement, and it should be as close to 100% impervious as possible. Some field experience has shown that an upgradient drainage area (even if it is impervious) can contribute particulates to the permeable pavement and lead to clogging (Hirschman, et al., 2009). Therefore, careful sediment source control and/or a pre-treatment strip or sump (e.g., stone or gravel) should be used to control sediment run-on to the permeable pavement section.

Pavement Slope. Steep slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. Designers should consider using a terraced design for permeable pavement in sloped areas, especially when the local slope is several percent or greater.

The bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal slope) to enable even distribution and infiltration of stormwater. However, a maximum longitudinal slope of 1% is permissible if an underdrain is employed. Lateral slopes should be 0%.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal, although 2 to 4 feet of head may be needed to drive flows through underdrains. Flat terrain may affect proper drainage of Level 1 permeable pavement designs, so underdrains should have a minimum 0.5% slope.

Minimum Depth to Water Table. A high groundwater table may cause runoff to pond at the bottom of the permeable pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Setbacks. Permeable pavement should not be hydraulically connected to structure foundations, in order to avoid harmful seepage. Setbacks to structures and roads vary, based on the scale of the permeable pavement installation (see **Table 14.04-3** above). At a minimum, small- and large-scale pavement applications should be located a minimum horizontal distance of 100 feet from any water supply well, 50 feet from septic systems, and at least 5 feet down-gradient from dry or wet utility lines. Setbacks can be reduced at the discretion of the local program authority for designs that use underdrains and/or liners.

Informed Owner. The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuum sweeping) to maintain the pavement's hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them.

High Loading Situations. Permeable pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail.

Groundwater Protection: The Community and Environmental Concerns Section of this specification presents a list of potential stormwater hotspots that pose a risk of groundwater contamination. Infiltration of runoff from designated hotspots is highly restricted or prohibited.

Limitations. Permeable pavement can be used as an alternative to most types of conventional pavement at residential, commercial and institutional developments, with two exceptions:

- Permeable pavement should not been used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes and roadway shoulders; and
- Permeable pavement should not be used to treat runoff from stormwater hotspots, as noted above.

Design Scales. Permeable pavement can be installed at the following three scales:

1. The smallest scale is termed **Micro-Scale Pavements**, which applies to converting impervious surfaces to permeable ones on small lots and redevelopment projects, where the installations may range from 250 to 1000 square feet in total area. Where redevelopment or retrofitting of existing impervious areas results in a larger foot-print of permeable pavers (small-scale or large-scale, as described below), the designer should implement the Load Bearing, Observation Well, Underdrain, Soil Test, and Building Setback criteria associated with the applicable scale.
2. **Small-scale pavement** applications treat portions of a site between 1000 and 10,000 square feet in area, and include areas that only occasionally receive heavy vehicular traffic.
3. **Large scale pavement** applications exceed 10,000 square feet in area and typically are installed within portions of a parking lot.

Table 14.04-4 outlines the different design requirements for each of the three scales of permeable pavement installation.

Table 14.04-4.
The Three Design Scales for Permeable Pavement

Design Factor	Micro-Scale Pavement	Small-Scale Pavement	Large-Scale Pavement
Impervious Area Treated	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	More than 10,000 sq. ft.
Typical Applications	Driveways Walkways Court Yards Plazas Individual Sidewalks	Sidewalk Network Fire Lanes Road Shoulders Spill-Over Parking Plazas	Parking Lots with more than 40 spaces Low Speed Residential Streets
Most Suitable Pavement	IP	PA, PC, and IP	PA, PC and IP
Load Bearing Capacity	Foot traffic Light vehicles	Light vehicles	Heavy vehicles (moving & parked)
Reservoir Size	Infiltrate or detain some or all of the WQv	Infiltrate or detain the full WQv and as much of the CPv and design storms as possible	
External Drainage Area?	No	Yes, impervious cover up to twice the permeable pavement area may be accepted as long as sediment source controls and/or pretreatment is used	
Observation Well	No	No	Yes
Underdrain?	Rare	Depends on the soils	Back-up underdrain
Required Soil Tests	One per practice	Two per practice	One per 5000 sq. ft of proposed practice
Building Setbacks	5 feet down-gradient 25 feet up-gradient	10 feet down-gradient 50 feet up-gradient	25 feet down-gradient 100 feet up-gradient

Regardless of the design scale of the permeable pavement installation, the designer should carefully consider the expected traffic load at the proposed site and the consequent structural requirements of the pavement system. Sites with heavy traffic loads will require a thick aggregate base and, in the case of porous asphalt and pervious concrete, may require the addition of an admixture for strength or a specific bedding design. In contrast, most micro-scale applications should have little or no traffic flow to contend with.

DESIGN CRITERIA**Sizing of Permeable Pavement**

Structural Design. If permeable pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations should be consulted. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Bedding and Reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the underlying soils have a low California Bearing Ratio (CBR) (less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally rules out their use for infiltration.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- OMPC Pavement Design for Subdivision and Secondary Roads;
- AASHTO Guide for Design of Pavement Structures (1993); and,
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998).

Hydraulic Design. Permeable pavement is typically sized to store the Water Quality Volume (WQv) or another design storm volume in the reservoir layer. The infiltration rate typically will be less than the flow rate through the pavement, so that some underground reservoir storage will usually be required. Designers should initially assume that there is no outflow through underdrains, using **Equation 14.04-1** to determine the depth of the reservoir layer, assuming runoff fully infiltrates into the underlying soil:

Equation 14.04-1

$$d_p = \frac{\{(d_c \times R) + P - (i/2 \times t_f)\}}{V_r}$$

Where:

- d_p = The depth of the reservoir layer (ft.)
- d_c = The depth of runoff from the contributing drainage area (not including the permeable paving surface) for the Water Quality Volume (WQv/ A_c), or other design storm (ft.)
- R = A_c/A_p = The ratio of the contributing drainage area (A_c , not including the permeable paving surface) to the permeable pavement surface area (A_p)
 [NOTE: With reference to **Table 14.04-3**, the maximum value for the Level 1 design is $R = 2$, (the external drainage area A_c is twice that of the permeable pavement area A_p ; and for Level 2 design $R = 0$ (the drainage area is made up solely of permeable pavement A_p).
- P = The rainfall depth for the Water Quality Volume (Level 1= 0.64 in; Level 2= 0.77 inch), or other design storm (ft.)
- i = The field-verified infiltration rate for native soils (ft./day)
- t_f = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
- V_r = The void ratio for the reservoir layer (0.4)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 14.04-2**.

Note: If the reservoir layer necessary to temporarily store the design storm volume is less than the depth necessary to support structural loads then the Structural support requirements will dictate the depth of the underlying stone reservoir.

Equation 14.04-2

$$d_{p-\square \max} = \frac{(i/2 \times t_{\max})}{V_r}$$

Where:

- d_{p-max} = The maximum depth of the reservoir layer (ft.)
 i = The field-verified infiltration rate for the native soils (ft./day)
 V_r = The void ratio for reservoir layer (0.4 – see assumptions, below)
 t_{max} = The maximum allowable time to drain the reservoir layer, typically 1 to 2 days (days)

The following design assumptions apply to **Equations 14.04-1 and 14.04-2**:

- The contributing drainage area (A_c) should not contain pervious areas.
- For design purposes, the native soil infiltration rate (i) should be the field-tested soil infiltration rate divided by a factor of safety of 2. The minimum acceptable native soil infiltration rate is 0.5"/hr.
- The void ratio (V_r) for No. 57 stone = 0.4.
- Max. drain time for the reservoir layer should be not less than 24 nor more than 48 hours.

If the depth of the reservoir layer is too great (i.e. d_p exceeds d_{p-max}), or the verified soil infiltration rate is less than 0.5 inches per hour, then the design method typically changes to account for underdrains. The storage volume in the pavements must account for the underlying infiltration rate and outflow through the underdrain. In this case, the design storm should be routed through the pavement to accurately determine the required reservoir depth. Alternatively, the designer may use **Equations 14.04-3 through 14.04-5** to approximate the depth of the reservoir layer for designs using underdrains.

Equation 14.04-3 can be used to approximate the outflow rate from the underdrain. The hydraulic conductivity, k , of gravel media is very high (~17,000 ft./day). However, the permeable pavement reservoir layer will drain increasingly slower as the storage volume decreases (i.e. the hydraulic head decreases). To account for this change, a conservative permeability coefficient of

100 ft./day can be used to approximate the average underdrain outflow rate.

Equation 14.04-3

$$q_u = k \times m$$

Where:

- q_u = Outflow through the underdrain (per outlet pipe, assumed 6-inch diameter) (ft./day)
 k = Hydraulic conductivity for the reservoir layer (ft./day – assume 100 ft./day)
 m = Underdrain pipe slope (ft./ft.)

Once the outflow rate through the underdrain has been approximated, **Equation 14.04-4** is used to determine the depth of the reservoir layer needed to store the design storm.

Equation 14.04-4

$$d_p = \frac{\{d_c \times R\} + P - (i/2 \times t_f) - (q \times t_f)}{V_r}$$

Where:

- d_p = Depth of the reservoir layer (ft.)
- d_c = Depth of runoff from the contributing drainage area (not including the permeable pavement surface) for the Water Quality Volume (WQv/ A_c), or other design storm (ft.)
- R = A_c/A_p = The ratio of the contributing drainage area (A_c) (not including the permeable pavement surface) to the permeable pavement surface area (A_p)
- P = The rainfall depth for the Water Quality Volume (Level 1 = 0.64 inch; Level 2 = 0.77 inch), or other design storm (ft.)
- i = The field-verified infiltration rate for the native soils (ft./day)
- t_f = The time to fill the reservoir layer (day) – typically 2 hours or 0.083 day
- V_r = The void ratio for the reservoir layer (0.4)
- q_u = Outflow through Underdrain (ft./day)

The maximum allowable depth of the reservoir layer is constrained by the maximum allowable drain time, which is calculated using **Equation 14.04-5**.

Note: If the reservoir layer necessary to temporarily store the design storm volume is less than the depth necessary to support structural loads then the Structural support requirements will dictate the depth of the underlying stone reservoir.

Equation 14.04-5

$$d_{p-max} = \frac{(i/2 \times t_{max}) + (q_u \times t_{max})}{V_r}$$

Where:

- d_{p-max} = The maximum depth of the reservoir layer (ft.)
- i = The field-verified infiltration rate for the native soils (ft./day)
- V_r = The void ratio for the reservoir layer (0.4)
- t_{max} = The time to drain the reservoir layer (day – typically 1 to 2 days)
- q_u = The outflow through the underdrain (ft./day)

If the depth of the reservoir layer is still too great (i.e. d_p exceeds d_{p-max}), the number of underdrains can be increased, which will increase the underdrain outflow rate.

Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage within the stone aggregate layer, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet.

Soil Infiltration Rate Testing

To design a permeable pavement system *without* an underdrain, the measured infiltration rate of subsoils must be 0.5 inch per hour or greater. A minimum of one test must be taken per 1,000 sq. ft. of planned permeable pavement surface area. In most cases, a single soil test is sufficient for micro-scale and small-scale applications. At least one soil boring must be taken to confirm the underlying soil properties *at the depth where infiltration is designed to occur* (i.e., to ensure that the depth to water table, or depth to bedrock is defined). Soil infiltration testing should be conducted within any confining layers that are found within 4 feet of the bottom of a proposed permeable pavement system.

Type of Surface Pavement

The type of pavement should be selected based on a review of the factors in **Table 14.04-2** above, and designed according to the product manufacturer's recommendations.

Internal Geometry and Drawdowns

- ***Elevated Underdrain.*** To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain should be installed with a stone jacket that creates a
- 12 to 18 inch deep storage layer *below* the underdrain invert. The void storage in this layer can help qualify a site to achieve Level 2 design.
- ***Rapid Drawdown.*** When possible, permeable pavement should be designed so that the target runoff reduction volume stays in the reservoir layer for at least 36 hours before being discharged through an underdrain.
- ***Conservative Infiltration Rates.*** Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

Pretreatment

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. Additional pretreatment may be appropriate if the pavement receives run-on from an adjacent pervious or impervious area. For example, a gravel filter strip can be used to trap coarse sediment particles before they reach the permeable pavement surface, in order to prevent premature clogging.

Conveyance and Overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system. The following is a list of methods that can be used to accomplish this:

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The placement and/or design should be such that the incoming runoff is not captured (e.g., placing the perforations on the

- underside only).
- Increase the thickness of the top of the reservoir layer by as much as 6 inches (i.e., create freeboard). The design computations used to size the reservoir layer often assume that no freeboard is present.
- Create underground detention within the reservoir layer of the permeable pavement system.
- Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for the management of extreme event flows.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system (typically in remote areas). The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

Reservoir layer

The thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of in situ soils, structural requirements of the pavement sub-base, depth to water table and bedrock, and frost depth conditions (see **Regional and Special Case Design Adaptations**). A professional should be consulted regarding the suitability of the soil subgrade.

- The reservoir below the permeable pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The storage layer may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional storage and structural stability.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface.

Underdrains

The use of underdrains is recommended when there is a reasonable potential for infiltration rates to decrease over time, when underlying soils have an infiltration rate of less than 1/2-inch per hour, or when soils must be compacted to achieve a desired Proctor density. Underdrains can also be used to manage extreme storm events to keep detained stormwater from backing up into the permeable pavement.

- An underdrain(s) should be placed within the reservoir and encased in 8 to 12 inches of clean, washed stone.
- The underdrain outlet can be fitted with a flow-reduction orifice as a means of regulating the stormwater detention time. The minimum diameter of any orifice should be 0.5 inch.
- An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

Maintenance Reduction Features

Maintenance is a crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment, which can be reduced by the following measures:

- ***Periodic Vacuum Sweeping.*** The pavement surface is the first line of defense in trapping and eliminating sediment that may otherwise enter the stone base and soil subgrade. The rate of sediment deposition should be monitored and vacuum sweeping done once or twice a year. This frequency should be adjusted according to the intensity of use and deposition rate on the permeable pavement surface. At least one sweeping pass should occur at the end of winter.
- ***Protecting the Bottom of the Reservoir Layer.*** There are two options to protect the bottom of the reservoir layer from intrusion by underlying soils. The first method involves covering the bottom with nonwoven, polypropylene geotextile that is permeable, although some practitioners recommend avoiding the use of filter fabric since it may become a future plane of clogging within the system. Permeable filter fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. The second method is to form a barrier of choker stone and sand. In this case, underlying native soils should be separated from the reservoir base/subgrade layer by a thin 2 to 4 inch layer of clean, washed, choker stone (ASTM D 448 No. 8 stone) covered by a layer of 6 to 8 inches of course sand.
- ***Observation Well.*** An observation well, consisting of a well-anchored, perforated 4 to 6 inch (diameter) PVC pipe that extends vertically to the bottom of the reservoir layer, should be installed at the downstream end of all large-scale permeable pavement systems. The observation well should be fitted with a lockable cap installed flush with the ground surface (or under the pavers) to facilitate periodic inspection and maintenance. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event.
- ***Overhead Landscaping.*** Most local communities now require from 5% to 10% (or more) of the area of parking lots to be in landscaping. Large-scale permeable pavement applications should be carefully planned to integrate this landscaping in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface.

Material Specifications

Permeable pavement material specifications vary according to the specific pavement product selected. **Table 14.04-5** describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending whether the system is PC, PA or IP (see **Table 14.04-2** above). A general comparison of different permeable pavements is provided in **Table 14.04-6** below, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 14.04-5.
Material Specifications for Underneath the Pavement Surface

	Specification	Notes
Bedding Layer	PC: None PA: 2 in. depth of No. 8 stone IP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57	ASTM D448 size No. 8 stone (e.g. 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines.
Reservoir Layer	PC: No. 57 stone PA: No. 2 stone IP: No. 57 stone	ASTM D448 size No. 57 stone (e.g. 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines.
Underdrain	Use 4 to 6 inch diameter perforated PVC (AASHTO M 252) pipe, with 3/8-inch perforations at 6 inches on center; each underdrain installed at a minimum 0.5% slope located 20 feet or less from the next pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications). Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T's and Y's installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Filter Layer	The underlying native soils should be separated from the stone reservoir by a thin, 2 to 4 inch layer of choker stone (e.g. No. 8) covered by a 6 to 8 inch layer of coarse sand (e.g. ASTM C 33, 0.02-0.04 inch).	The sand should be placed between the stone reservoir and the choker stone, which should be placed on top of the underlying native soils.
Filter Fabric (optional)	Use a needled, non-woven, polypropylene geotextile with Grab Tensile Strength equal to or greater than 120 lbs (ASTM D4632), with a Mullen Burst Strength equal to or greater than 225 lbs./sq. in. (ASTM D3786), with a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in "A" Soil subgrade, using FHWA or AASHTO selection criteria.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface.	

Table 14.04-6.
Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C 1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.
Pervious Concrete	Void content: 15% to 25 %. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 Mpa. Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

**REGIONAL & SPECIAL CASE
DESIGN ADAPTATIONS**

The design adaptations described below permit permeable pavement to be used on a wider range of sites. However, it is important not to force this practice onto marginal sites. Other runoff reduction practices are often preferred alternatives for difficult sites.

Clay Soils

In areas where the underlying soils are not suitable for complete infiltration, permeable pavement systems with underdrains can still function effectively to reduce runoff volume and nutrient loads.

- If the underlying soils have an infiltration rate of less than 0.5 in./hr., an underdrain must be installed to ensure proper drainage from the system.
- Permeable pavement should not be installed over underlying soils with a high shrink/swell potential.
- To promote greater runoff reduction for permeable pavement located on marginal soils, an elevated underdrain configuration may be used.

Cold Climate and Winter Performance

In cold climates and winter conditions, freeze-thaw cycles may affect the structural durability of the permeable pavement system. In these situations, the following design adaptations may be helpful:

- To avoid damage caused by freezing, designs should not allow water to pond in or above the permeable pavement. Ensure complete drainage of the permeable pavement system within 24 hours following a rainfall event.
- Extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size, to reduce the freezing potential.
- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the permeable pavement.
- Sand should never be applied for winter traction over permeable pavement or areas of standard (impervious) pavement that drain toward permeable pavement, since it will quickly clog the system.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous asphalt (PA), pervious concrete (PC) and interlocking pavers (IP) can be plowed similar to traditional pavements, using similar equipment and settings.
- Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater.

CONSTRUCTION

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

Necessary Erosion & Sediment Controls

- All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing, particularly if they are intended to infiltrate runoff.
- Permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should be clearly
- marked on all construction documents and grading plans. To prevent soil compaction, heavy vehicular and foot traffic should be kept out of permeable pavement areas during and immediately after construction.
- During construction, care should be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.
- Any area of the site intended ultimately to be a permeable pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an
- area intended for permeable pavement is unavoidable, the invert of the sediment basin must
- be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the subbase, base and surface materials.

Permeable Pavement Construction Sequence

The following is a typical construction sequence to properly install permeable pavement, which may need to be modified to depending on whether Porous Asphalt (PA), Pervious Concrete (PC) or Interlocking Paver (IP) designs are employed.

Step 1. Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen bedding materials.

Step 2. As noted above, temporary erosion and sediment (E&S) controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials that are contaminated by sediments must be removed and replaced with clean materials.

Step 3. Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For micro-scale and small-scale pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so that cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4. The native soils along the bottom and sides of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of the filter layer or filter fabric. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (NOTE: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design.)

Step 5. Filter fabric should be installed on the bottom and the sides of the reservoir layer. In some cases, an alternative filter layer may be warranted. Filter fabric strips should overlap down-slope by a minimum of 2 feet, and be secured a minimum of 4 feet beyond the edge of the excavation. Where the filter layer extends beyond the edge of the pavement (to convey runoff to the reservoir layer), install an additional layer of filter fabric 1 foot below the surface to prevent sediments from entering into the reservoir layer. Excess filter fabric should not be trimmed until the site is fully stabilized.

Step 6. Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down towards the outlet at a grade of 0.5% or steeper. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure that there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7. Moisten and spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8. Install the desired depth of the bedding layer, depending on the type of pavement, as follows:

- **Pervious Concrete:** No bedding layer is used.
- **Porous Asphalt:** The bedding layer for porous asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D 448 No.57 stone. The filter course must be leveled and pressed (choked) into the reservoir base with at least four (4) passes of a 10-ton steel drum static roller.
- **Interlocking Pavers:** The bedding layer for open-jointed pavement blocks should consist of 1-1/2 to 2 inches of washed ASTM D 448 No.8 stone. The thickness of the bedding layer is to be based on the block manufacturer's recommendation or that of a qualified professional.

Step 9. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

- **Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007).
 - o Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230°F and 260°F, with a minimum air temperature of 50°F, to ensure that the surface does not stiffen before compaction.
 - o Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
 - o The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.
 - o Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
 - o Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
 - o Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine that the facility is draining properly.
- **Installation of Pervious Concrete.** The basic installation sequence for pervious concrete is outlined by the American Concrete Institute (2008). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:
 - o Drive the concrete truck as close to the project site as possible.
 - o Water the underlying aggregate (reservoir layer) before the concrete is placed, so that the aggregate does not draw moisture from the freshly laid pervious concrete.
 - o After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
 - o Compact the pavement with a steel pipe roller. Care should be taken so that over-compaction does not occur.
 - o Cut joints for the concrete to a depth of 1/4 inch.
 - o The curing process is very important for pervious concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least seven (7) days. Do not allow traffic on the pavement during this time period.

- **Installation of Interlocking Pavers.** The basic installation process is described in greater detail by Smith (2006).
 - o Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement (IP) systems require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard KYTC curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.
 - o Place the No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four (4) passes of a 10-ton steel drum static roller until there is no visible movement. The first two (2) passes are in vibratory mode, with the final two (2) passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
 - o Place and screed the bedding course material (typically No. 8 stone).
 - o Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third (1/3) of the full unit size.
 - o Pavers may be placed by hand or with mechanical installers. Fill the joints and openings with stone. Joint openings must be filled with KYTC No. 8 stone, although KYTC No. 8P or No. 9 stone may be used where needed to fill narrower joints. Remove excess stones from the paver surface.
 - o Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
 - o Do not compact within 6 feet of the unrestrained edges of the pavers.
 - o The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
 - o Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
 - o Inspect the facility 18 to 30 hours after a significant rainfall (1/2 inch or greater) or artificial flooding to determine whether the facility is draining properly.

Construction Inspection

Inspections before, during and after construction are needed to ensure that permeable pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intent.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.

- The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- Check the aggregate material to confirm that it is clean and washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the permeable pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- Ensure that caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles that are often produced shortly after conventional asphalt is laid down.

MAINTENANCE

Maintenance Agreements

Section 26.352 of the Stormwater Ordinance specifies the circumstances under which a maintenance agreement must be executed between the owner and the local program. This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

In addition, the maintenance agreements should also note which conventional parking lot maintenance tasks must be *avoided* (e.g., sanding, re-sealing, re-surfacing, power-washing). Signs should be posted on larger parking lots to indicate their stormwater function and special maintenance requirements.

When micro-scale or small-scale permeable pavement are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a deed restriction, drainage easement or other mechanism enforceable by the qualifying local program to help ensure that the permeable pavement system is maintained and functioning. The mechanism should, if possible, grant authority for local agencies to access the property for inspection or corrective action.

Maintenance Tasks

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of permeable pavement systems over time. Most installations work reasonably well year after year with little or no maintenance, whereas some have problems right from the start.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging. Vacuum settings for large-scale interlocking paver applications should be calibrated so they *do not* pick up the stones between pavement blocks.

Maintenance Inspections

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications.

Maintenance of permeable pavement is driven by annual inspections that evaluate the condition and performance of the practice. The following are suggested annual maintenance inspection points for permeable pavements:

- The drawdown rate should be measured at the observation well for three (3) days following a storm event in excess of 1/2 inch in depth. If standing water is still observed in the well after three days, this is a clear sign that clogging is a problem.
- Inspect the surface of the permeable pavement for evidence of sediment deposition, organic debris, staining or ponding that may indicate surface clogging. If any signs of clogging are
- noted, schedule a vacuum sweeper (no brooms or water spray) to remove deposited material. Then, test sections by pouring water from a five gallon bucket to ensure they work.
- Inspect the structural integrity of the pavement surface, looking for signs of surface deterioration, such as slumping, cracking, spalling or broken pavers. Replace or repair affected areas, as necessary.
- Check inlets, pretreatment cells and any flow diversion structures for sediment buildup and structural damage. Note if any sediment needs to be removed.
- Inspect the condition of the observation well and make sure it is still capped.
- Generally inspect any contributing drainage area for any controllable sources of sediment or erosion.

Based on inspection results, specific maintenance tasks will be triggered and scheduled to keep the facility in operating condition.

**COMMUNITY &
ENVIRONMENTAL CONCERNS**

Compliance with the Americans with Disabilities Act (ADA). Porous concrete and porous asphalt are generally considered to be ADA compliant. Most localities also consider interlocking concrete pavers to be complaint, if designers ensure that surface openings between pavers do not exceed 1/2 inch. However, some forms of interlocking pavers may not be suitable for handicapped parking spaces. Interlocking concrete pavers interspersed with other hardscape features (e.g., concrete walkways) *can* be used in creative designs to address ADA issues.

Groundwater Protection. While well-drained soils enhance the ability of permeable pavement to reduce stormwater runoff volumes, they may also increase the risk that stormwater pollutants might migrate into groundwater aquifers. Designers should avoid the use of infiltration-based permeable pavement in areas known to provide groundwater recharge to aquifers used for water supply. In these source water protection areas, designers should include liners and underdrains in large-scale permeable pavement applications (i.e., when the proposed surface area exceeds 10,000 square feet).

Stormwater Hotspots. Designers should also certify that the proposed permeable pavement area will not accept any runoff from a severe stormwater hotspot. Stormwater hotspots are operations or activities that are known to produce higher concentrations of stormwater pollutants and/or have a greater risk of spills, leaks or illicit discharges. Examples include certain industrial activities, gas stations, public works areas, petroleum storage areas. For potential hotspots, restricted infiltration means that a minimum of 50% of the total WQv must be treated by a filtering or bioretention practice prior to the permeable pavement system. For known severe hotspots, the risk of groundwater contamination from spills, leaks or discharges is so great that infiltration of stormwater or snowmelt through permeable pavement is *prohibited*.

Underground Injection Control Permits. The Safe Drinking Water Act regulates the infiltration of stormwater in certain situations pursuant to the Underground Injection Control (UIC) Program, which is administered either by the EPA or a delegated state groundwater protection agency. In general, the EPA (2008) has determined that permeable pavement installations are not classified as Class V injection wells, since they are always wider than they are deep.

Cold Climate or Winter Time Operation. Experience has shown that permeable pavement can operate properly in snow and ice conditions, and there is evidence that a permeable surface increases meltwater rates compared to conventional pavement (thereby reducing the need for deicing chemicals). However, in larger parking lot applications certain snow management practices need to be modified to maintain the hydrologic function of the permeable pavement. These include not applying sand for traction and educating snowplow operators to keep blades from damaging the pavement surface. The jointing material for interlocking concrete paver systems (typically No. 8 stone) can be spread over surface ice to increase tire traction.

Air and Runoff Temperature. Permeable pavement appears to have some value in reducing summer runoff temperatures, which can be important in watersheds with sensitive cold-water fish populations. The temperature reduction effect is greatest when runoff is infiltrated into the sub-base, but some cooling may also occur in the reservoir layer, when underdrains are used. ICPI (2008) notes that the use of certain reflective colors for interlocking concrete pavers can also help moderate surface parking lot temperatures.

Vehicle Safety. Permeable pavement is generally considered to be a safer surface than conventional pavement, according to research reported by Smith (2006), Jackson (2007) and ACI (2008). Permeable pavement has less risk of hydroplaning, more rapid ice melt and better traction than conventional pavement.

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MINIMUM STANDARD 14.05

CONSTRUCTED STORMWATER WETLAND



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MINIMUM STANDARD 14.05

CONSTRUCTED STORMWATER WETLAND

Definition

Constructed stormwater wetlands are manmade shallow pools that create growing conditions suitable for both emergent and aquatic vegetation.

Purpose

Constructed wetlands are intentionally installed on non-wetland sites to enhance the quality of stormwater runoff.

In contrast, created wetlands are also intentionally installed on non-wetland sites, but are designed to produce or replace natural functional wetlands and wetland habitats (e.g., for compensatory mitigation projects).

This handbook deals primarily with constructed wetlands. Sometimes, a constructed wetland may provide some of the benefits of a created wetland. However, understanding the differences in these two manmade systems is important. For a natural or created wetland, pre-treatment BMPs, such as erosion controls, presettling basins, biofilters, etc., are used to reduce pollutants entering the wetland to prevent its degradation and clogging. The primary function of a constructed wetland, on the other hand, is to provide those same types of pre-treatment functions within the wetland itself. The constructed wetland, therefore, will require maintenance to assure long-term pollutant removal. It should be noted that the pre-treatment BMPs mentioned above will often simplify or reduce maintenance requirements, as well as enhance and prolong the useful life of a constructed stormwater wetland.

Water Quality Enhancement

A constructed stormwater wetland can achieve high removal rates of particulate and soluble pollutants (nutrients) through gravitational settling, wetland plant uptake, absorption, physical filtration, and biological decomposition. The pollutant removal efficiency of a constructed wetland is dependent on various design criteria relating to the size and design of the pool area. Other site-specific design features and variations in environmental conditions such as soils, climate, hydrology, etc. make it difficult to predict the actual pollutant removal efficiency. Monitoring of many stormwater wetland facilities has confirmed the wide range of pollutant removal efficiencies associated with such systems.

Constructed stormwater wetlands operate similar to retention basins, yet their overall performance

is expected to be more variable. This may be due to any of the following:

1. The decrease in biological activity associated with seasonal cold weather.
2. The conversion of plant species and densities as the wetland matures and becomes acclimated to various environmental factors such as soils, hydrology, climate, and sediment and pollutant load.
3. The uncertainty of the biological cycling processes of phosphorous in the wetland environment.

Flood Control & Channel Erosion Control

Constructed stormwater wetlands should generally not be used for flood control or stream channel erosion control. This is due to the anticipated water level fluctuations associated with quantity controls. The clearing of vegetation and the addition of impervious surfaces may cause large and sudden surges of runoff during rain events, and may cause less than normal base flows due to lack of groundwater during dry periods. Large, sudden fluctuations in water levels can stress emergent wetland and upland edge vegetation. Most edge vegetation cannot survive drought or saturation extremes, leaving wetland banks exposed to potential erosion. It should be noted that the large surface area requirement for constructed stormwater wetlands will help to minimize the “extreme” water level fluctuations during all but the larger storm events. Also, certain plants can be specified for the upland banks which may be more tolerant to the wet and dry extremes. Therefore, preventing surges whenever possible and designing for gradual increases and decreases in water level is important for successful constructed wetland design. See Design Criteria for further discussion.

Conditions Where Practice Applies

Drainage Area

The drainage area criteria for a constructed stormwater wetland is similar to that of a retention basin. However, because of their shallow depth, constructed stormwater wetlands may consume two to three times the site area compared with other stormwater quality BMPs (MWCOG, 1992). Vertical (depth) storage is usually not possible in constructed wetlands due to the needs of aquatic plants. Therefore, the maximum watershed size depends on the available area on the site that is suitable for a constructed wetland system.

The minimum watershed drainage area for constructed stormwater wetlands should be 10 acres. However, this minimum should be confirmed based on the watershed’s hydrology and the presence of an adequate base flow to support the selected vegetation. Similar to retention basins, a drainage area of 15 to 20 acres or the presence of a dependable base flow is most desirable to maintain a healthy wetland. A clay liner may be necessary to prevent infiltration if losses are expected to be high.

Development Conditions

Constructed stormwater wetlands are suited for both low- and high-visibility sites. However, the aesthetic problems associated with having a natural and free growing landscape feature in an otherwise manicured development setting should be avoided for high-visibility sites. Additional concerns regarding stagnation or excessive infiltration during the dry summer months may also influence the choice of location. Proper planning, design, and maintenance are critical to ensure the pollutant removal capabilities of a constructed wetland and to insure its acceptance by adjacent landowners.

Like retention basins, constructed wetlands are also suited for low- and medium-density residential or commercial developments. However, the land area required for this BMP may limit its use.

Planning Considerations

Constructed stormwater wetlands should be designed to duplicate the functions of natural wetlands, while allowing for ongoing maintenance. The designer faces the difficult task of replicating natural wetland hydrology in a constructed setting, while ensuring easy access for maintenance.

Hydrology

The hydrology of a constructed stormwater wetland is largely influenced by surface runoff. The hydrology, in turn, affects several key characteristics of a stormwater wetland, such as:

1. Water level fluctuations. A constructed stormwater wetland will experience rapid inundation and drawdown periods with each runoff-producing event.
2. Permanent pool. A natural wetland may experience seasonal standing water and/or periodic drawdowns. However, a constructed stormwater wetland is engineered to permanently hold a specific volume of water, or at a minimum, maintain pools of water of varying depths. This stored water supports the aquatic and emergent plant regime and maintains the pollutant removal efficiency of the BMP.
3. Vegetation. The vegetation diversity in a constructed wetland is established by the landscape plan or volunteer vegetation. The selection of vegetation should be limited to native plant species suitable for the pool depths expected within the different depth zones. Care should be taken to avoid the introduction of exotic or invasive species. The use of appropriate donor soil and wetland mulch will help prevent this problem.

In contrast, a natural wetland vegetates itself through natural selection based on the growing conditions within it. The existing source of seeds, which is usually enhanced by wildlife, allows for the constant renewal of plant life.

4. Sediment and pollutant load. A stormwater wetland is subject to sediment loads, especially from upland pervious areas during the first growing season. During this period, permanent vegetation in the developing watershed is still growing. Without a well-established ground cover, surface sediments can be easily transported by rainfall and resulting runoff. Accumulation of this sediment in the constructed stormwater wetland during the first growing season alone can dramatically alter the topography of the facility, affecting water levels and flow paths. Furthermore, the pollutant load (nutrients and organics) associated with urban runoff and sediments entering a constructed wetland is usually higher than that which enters a natural or undisturbed wetland in undeveloped watershed. Therefore, if the constructed wetland is used to remove pollutants, the water quality within the wetland itself will be decreased. During the planning stage of a facility, the designer should have a good understanding of site-specific runoff constituents and an understanding of their possible effects on the selected vegetation.

Site Conditions

Site conditions, such as property lines, easements, utilities, structures, etc., that may impose constraints on development should be considered when designing a constructed wetland. Local government land use and zoning ordinances may also specify certain requirements.

All facilities should be a minimum of 20 feet from any structure, property line, or vegetative buffer, and 100 feet from any septic tank/drainfield. Local landuse setbacks and other restrictions may apply.

All facilities should be a minimum of 50 feet from any steep slope (greater than 10%). Alternatively, a site-specific geotechnical report must address the potential impact of a constructed stormwater wetland that is to be installed on, or near, such a slope.

Additional considerations are as follows:

1. Soils—

Permeable soils are not suited for constructed stormwater wetlands. A thorough analysis of the soil strata should be conducted to verify its suitability for holding water. In the past, many BMP designs were accepted based upon soils information compiled from available data, such as SCS soil surveys. While such a source may be appropriate for a pre-engineering feasibility study, final design and acceptance should be based on an actual subsurface analysis and permeability tests, accompanied by appropriate engineering recommendations.

The goal of a subsurface analysis is to determine if the soils are suitable for a constructed stormwater wetland. The textural character of the soil horizons and/or strata units within the subsoil profile should be identified to at least 3 feet below the bottom of the facility. This information is used to verify the infiltration rate or permeability of the soil. For constructed stormwater wetlands, water inflow (base flow and groundwater) must be greater than water losses (infiltration and evaporation). If the infiltration rate of the soil is too great, then a constructed wetland may not be an appropriate BMP, or a liner may be required. The soil

permeability may be such that the shallow depths of a constructed wetland can be maintained. However, as the depth of the permanent pool increases, the increased head or pressure on the soil may increase the infiltration rate.

For discussions regarding the appropriate soils for landscaping, see the Landscape section in this standard.

2. Rock—

The subsurface investigation should also identify the presence of any rock or bedrock layers. The excavation of rock to achieve the proper wetland dimensions and hydrology may be too expensive or difficult with conventional earth moving equipment. However, blasting may open seams or create cracks in the underlying rock that may result in unwanted drawdown of the permanent pool. Blasting of rock is not recommended unless a liner is used.

3. Existing Utilities—

Most utility companies will not allow their underground lines and right-of-ways to be submerged under a permanent pool. If such a site must be used, the designer should obtain permission before designing the BMP. Note that if the utilities ever require maintenance or repair, the characteristics of the constructed wetland may be irreparably changed or damaged. The cost to move any existing utilities during initial wetland construction should be determined and included in the project's overall construction costs.

Environmental Impacts

Constructed stormwater wetlands are generally located in areas with favorable hydrology. These locations are prone to being environmentally sensitive (low-lying) as well, and may contain existing wetlands, shallow marshes, perennial streams, wildlife habitat, etc., which may be protected by state or federal laws. The owner or designer should review local wetland maps and contact local, state, and federal permitting agencies to verify the presence of wetlands, their protected status, and the suitability of the location for a constructed wetland.

With careful planning, it may be possible to incorporate wetland mitigation into a constructed stormwater wetland. This assumes that the functional value of the existing or impacted wetland can be identified and included, reconstructed, or mitigated for, in the stormwater wetland. The Kentucky Division of Water should be contacted for more information regarding wetland mitigation.

Sediment Control

A constructed stormwater wetland should not be used as a sediment control facility during site construction. A presettling basin, or forebay, may be constructed above the proposed constructed wetland facility, however, any planting or preparation of the constructed wetland site should occur after the site construction has been completed. This will eliminate any foreseeable impact from sediment loads that overwhelm temporary erosion and sediment control measures during storm events.

Maintenance

Constructed stormwater wetlands require periodic maintenance, as does any stormwater BMP. In addition, a constructed wetland will require active management of the hydrology and vegetation during the first few years or growing seasons in order for it to achieve the performance and functions for which it was designed.

Vehicular access and maneuvering room in the vicinity of a constructed wetland (and sediment forebay) is necessary to allow for long-term maintenance. In addition, the establishment of an on-site sediment disposal area, properly located and contained, will significantly reduce the cost of routine maintenance and sediment removal. Care must be taken in the disposal of sediment that may contain an accumulation of heavy metals. Sediment testing is recommended prior to sediment removal to assure proper disposal.

Design Criteria

This section provides minimum criteria and recommendations for the design of a constructed stormwater wetland intended to comply with the runoff quality requirements of OPMC Public Improvement Specifications. It is the designer's responsibility to decide which aspects of the program apply to the particular facility being designed and if any additional design elements are required to ensure the long-term functioning of the wetland.

Hydrology and Hydraulics

Chapter 8, Surface Drainage should be used to develop the post-developed hydrology of the wetland's contributing watershed, to analyze the hydraulics of the riser and barrel system (if used) and to design the emergency spillway.

The contributing watershed's area should be a minimum of 10 acres and/or there should be an adequate base flow to support the hydrology.

Embankment

The design of the earthen embankment for any impoundment BMP should comply with Chapter 8 requirements. Specific requirements for geotechnical analysis, seepage control, maximum slopes, and freeboard are particularly appropriate.

Principal Spillway

The design of the principal spillway and barrel system, or weir overflow system, anti-vortex device, and trash racks should comply with Chapter 8. Weir spillways have a large cross-sectional area that can pass a considerable flow rate at low head conditions. Since reducing the depth of ponding in a constructed wetland helps to avoid stressing plant communities, an armored, weir-type spillway may be the most desirable overflow device for a constructed stormwater wetland. Further, the use of an adjustable weir will help maintain the proper water surface elevation during seasonal extremes.

Emergency Spillway

An emergency spillway that complies with detention basin requirements should be provided when possible.

Permanent Pool

Sizing a constructed stormwater wetland is based on maximizing its pollutant removal efficiency. The physical and hydraulic factors that influence the wetland's pollutant removal efficiency are the permanent pool volume, depth, surface area, geometry, and hydraulic residence time. Minimum design criteria are presented below for each of these factors:

1. Volume –

The required permanent pool volume of a constructed stormwater wetland is 2 times the water quality volume ($2 \times WQ_V$).

2. Depth –

Four depth zones are needed within the permanent pool of a constructed stormwater wetland: a) deep pool, b) low marsh, c) high marsh, and d) semi-wet (see Figure 14.05-2).

- a. The deep pool areas of a constructed wetland should be 18 inches to 6 feet in depth and may consist of 1) sediment forebays, 2) micro-pools, and/or 3) deep-water channels.
 1. Sediment forebays are highly recommended in constructed stormwater wetlands. They should be installed at stormwater inflow points to reduce the velocity of incoming runoff and trap coarse sediments, and to spread the runoff evenly over the wetland area. The forebay should be constructed as a separate cell from the rest of the wetland and provide easy access for maintenance with heavy equipment.
 2. Micro-pools offer open water areas to attract plant and wildlife diversity. If a low-flow discharge pipe is used, it should be constructed on a reverse slope and extended into the wetland below the pool surface elevation but above the bottom elevation. This helps to prevent clogging, since a typical wetland environment consists of floating plant debris and possible sediment and organic accumulation at the bottom. (Refer to the Overflow discussion later in this section.)
 3. Deep-water channels provide an opportunity to lengthen the flow path to avoid seasonal short-circuiting (see pool geometry).
- b. The low-marsh zone ranges in depth from 6 to 18 inches.
- c. The high-marsh zone ranges in depth from 0 to 6 inches. Usually, this zone will support the greatest density and diversity of emergent plant species.

- d. The semi-wet zone refers to the area that, during normal, non-rainfall periods, is above the pool, but is inundated during storm events for a period of time, depending on the amount of rainfall, and the hydraulics of the overflow device.

Note: The low-marsh, high-marsh, and semi-wet zones are useful as a perimeter shelf 10 to 15 feet wide. This shelf, or aquatic bench, can serve as a safety feature to keep children away from the open water deep pool areas. Also, as a secondary benefit, a heavily vegetated perimeter will help to discourage geese from using the facility as a permanent habitat.

The recommended surface area allocation for these depth zones is presented in Table 14.05-2.

3. Surface Area—

At a minimum, the pool surface area of a constructed stormwater wetland should equal 2% of the size of the contributing watershed. Recommended surface area allocations for different depth zones are shown in Table 14.05-1 (MWCOG, 1992). Note that if the surface area criteria conflict with the volume allocations, the surface area allocations are more critical to an effective design.

4. Geometry—

The geometry of the constructed stormwater wetland must be designed to avoid short-circuiting. Maximum pollutant removal efficiency is achieved with the longest possible flow path, since this increases the contact time over the wetland area. The minimum length-to-width ratio of the pool should be 1:1 in wet weather and 2:1 during dry weather (see Figure 14.05-3).

TABLE 14.05-1
Recommended Allocation of Surface Area and Treatment Volume for Various Depth Zones

Depth Zone	% of Surface Area	% of Treatment Volume
Deep Water 1.5 to 6 feet deep	10	20
Low Marsh 0.5 to 1.5 feet deep	40	*
High Marsh 0 to 0.5 feet deep	50	*
		* combined marsh area = 80% of treatment volume

Adapted from MWCOG, 1992

The wet weather length-to-width ratio is calculated by dividing the straight line distance from the inlet to the outlet by the wetland's average width. The dry weather length-to-width ratio is calculated by dividing the dry weather flow path length by the wetland's average width. Note that the dry weather flow path is created by constructing high marsh areas perpendicular to the straight line flow path described above. These marsh areas act as submerged berms and lengthen the

effective flow path.

5. Hydraulic Residence Time—

The hydraulic residence time is the permanent pool volume, divided by the average outflow discharge rate. The longer the residence time, the higher the pollutant removal efficiency (Driscoll, 1983, Kulzer, 1989).

Using $2 \times \text{WQV}$ to size the permanent pool means that smaller storms ($1 \times \text{WQV}$ or 0.64-in.) will displace only half of the pool volume of the wetland, thus providing for extended residence times. Larger treatment volumes with respect to the watershed size ($3 \times \text{WQV}$) will provide longer residence times and, therefore, greater efficiencies. In certain situations, using these larger volumes and efficiencies may be acceptable, but the decision should be made carefully. The associated challenge is to provide the recommended surface area allocations for the different depth zones as previously discussed.

Overflow

Providing flood control and/or channel erosion control within a constructed stormwater wetland creates a hydrologic regime that is very difficult to adapt to in the landscaping plan, due to extreme water depth fluctuations. If a constructed wetland is to serve as a quantity control BMP, it should be designed to provide adequate overflow or bypass for the full range of design storms with as little vertical ponding depth as possible. The hydraulic head needed to pass a design storm is a function of the relationship between the constructed wetland surface area, the geometry of the overflow

structure, and the allowable discharge (refer to Chapter 8, Surface Drainage). Outlet structures should be sized to pass the design storms (up to the 10-year storm) with a maximum of 2 feet of water ponded above the wetland pool.

In a stormwater wetland designed for water quality enhancement only, a bypass or diversion structure may be used to prevent sudden surges of runoff from flushing through the wetland (see Figure 14.05-4). This establishes the constructed wetland as an off-line facility. If site constraints prevent the use of an off-line facility, then the overflow should be designed to pass the full range of design storms with as little head as possible. An oversized riser and barrel system or a weir structure installed along the berm at the outlet may be used. Refer to Chapter 8 for outlet structure design criteria.

Sediment Forebay

Sediment forebays should be installed and designed to be constructed at the outfall of incoming storm drain pipes or channels and should be made accessible for maintenance equipment. To lower maintenance costs, an on-site disposal area should be included in the design. Sediment forebays enhance the pollutant removal efficiency of BMPs by containing incoming sediment in one area, which also simplifies monitoring and removal. Therefore, the target pollutant removal effectiveness of a constructed stormwater wetland is predicated on the use of sediment forebays at all inflow points.

Liner to Prevent Infiltration

Constructed stormwater wetlands should have negligible infiltration rates through their bottom. Infiltration impairs the proper functioning of any retention facility by lowering its pool elevation. If infiltration is expected, then a retention BMP must not be used, or a liner should be installed to prevent infiltration. If a clay liner is used, the specifications provided in Table 14.05-2 apply and the following are recommended:

1. A clay liner should have a minimum thickness of 12 inches.
2. A layer of compacted topsoil (6 to 12 inches thick, minimum) should be placed over the liner.
3. Other liners may be used if adequate documentation exists to show that the material will provide the required performance.

Safety

The side slopes of a constructed stormwater wetland should be no steeper than 3H:1V. Also, local ordinances may require fencing of deep pool areas next to the shoreline as an additional safety measure. Dense plantings of shoreline fringe vegetation can serve as a safety feature by discouraging access to the pool areas.

TABLE 14.05 - 2
Clay Liner Specifications

Property	Test Method (or equal)	Unit	Specification
Permeability	ASTM D-2434	cm/sec	1×10^{-6}
Clay Plasticity Index	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of Standard Proctor Density

Source: City of Austin, 1988

Access

A 10 to 12-foot wide access road with a maximum grade of 12% should be provided to allow vehicular access to the outlet structure area, at least one side of the basin, and the sediment forebay(s). The road's surface should be selected to support the anticipated frequency of use and vehicular load without excessive erosion or damage.

Landscaping

A qualified individual should prepare the landscape plan for a constructed stormwater wetland. Appropriate aquatic, emergent, shoreline fringe, transitional, and floodplain terrace vegetation must be selected to correspond with the expected frequency, duration, and depth of inundation.

The landscaping plan for a constructed wetland is based on the projected depth zones and onsite soil analysis, and should contain the following:

1. The location, quantity, and propagation methods of plant species and grasses for the stormwater wetland and its buffer.

The location of plants is based on the depth zones in the wetland and the inundation tolerance of the plant species. Planting zones of uniform depth should be identified for each species selected.

Only one-half of the low- and-high marsh depth zones need to be planted. If the appropriate planting depths are achieved, the entire wetland should be colonized within three years. At least 5 to 7 emergent wetland species, including a minimum of two species for each of the marsh depth zones (high and low), should be used. Selections should be based on wildlife food value, depth tolerance, price, commercial availability and/or shade limitations. Certain species, such as cattails, should be selected with caution. Although they may provide excellent pollutant removal characteristics, they can be invasive and may eventually crowd out other species.

A constructed stormwater wetland does not contain a seed bank, nor does it have an existing natural seed transport cycle as found in native wetlands. While the use of donor soil from disturbed or dredged sites may provide a seed bank, these opportunities may not be readily available. Therefore, the most common and convenient technique for establishing wetland vegetation in a constructed system is to transplant nursery-grown stock. Other propagation techniques (which are outside the scope of this manual) may also prove successful, but special growing conditions must exist.

2. Instructions for site preparation.

The soil in which the vegetation is planted should be appropriate for the wetland plants selected. Soil tests showing the adequacy of the soil, or a soil enhancement plan should be submitted with the wetland design.

The soil substrate must be soft enough to permit easy insertion of the plants. If the basin soil is compacted or vegetation has formed a dense root mat, the upper 6 inches of soil should be disked before planting. If soil is imported, it should be laid at least 4 inches deep to provide sufficient depth for plant rooting.

3. A schedule for transplanting emergent wetland stock.

The window for transplanting emergent stock extends from early April to mid-June. Dormant rhizomes can be planted in fall or winter. To insure availability, ordering stock 3 to 6 months in advance may be necessary.

4. Planting procedures.

A landscape plan should describe any special procedures for planting nursery stock. Most emergent plants may be planted in flooded or dry conditions. If planting is done in dry conditions, then instructions should be included for flooding the wetland immediately following installation.

Proper handling of nursery stock is crucial. The roots must be kept moist to prevent damage. Plants received from the nursery will be in peat pots or bare-rooted. Bare-rooted plants will have some form of protection to keep the roots moist and may be kept for several days, but out of direct sunlight. For the maximum chance of success, all nursery stock should be planted as soon as possible. A minimum acceptable success rate of the plantings should be specified in the plan.

5. A maintenance and vegetation reinforcement schedule for the first three years after construction.

Sometimes additional stabilization of the basin area may be necessary to ensure that the vegetation becomes established and mature prior to the erosion of the planting soil. Annual grasses may be used for this purpose. However, the specified application rates in the KYTC Standard Specifications.: Temporary Seeding should be reduced to help prevent these grasses from competing with other plants, particularly those emerging from bulbs and rhizomes. Overall, permanent seeding should be prohibited in zones 1 through 4, as the grasses will indefinitely compete with the wetland plants. Refer to the Maintenance and Inspection section in this standard for more information.

Buffer Zones

A minimum 20-foot wide vegetated buffer, measured from the maximum water surface elevation, should be maintained beside the wetland.

Construction Specifications

Overall, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers for embankment ponds and reservoirs, should be followed to build the impoundment.

Further guidance can be found in Chapter 17 of the Soil Conservation Service's Engineering Field Manual. Specifications for the work should conform to methods and procedures specified for earthwork, concrete, reinforcing steel, pipe water gates, metal work, woodwork and masonry and any other items that apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government.

Maintenance and Inspections

A constructed stormwater wetland may be maintained without a permit from the U. S. Army Corps of Engineers or the Kentucky Division of Water (KDOW).

Any pre-treatment facility or diversion structure should be inspected and maintained regularly to remove floatables and any large debris. Sediment should be removed from the forebay every 3 to 5 years, or when 6 to 12 inches have accumulated, whichever comes first. To clean the forebay, draining or pumping and a possible temporary partial drawdown of the pool area may be required. Refer to the VESCH, 1992 edition for proper dewatering methods. A predesignated spoil area, away from the wetlands, should be used.

The constructed stormwater wetland should be inspected at least twice a year in the first three years after construction, during both the growing and non-growing seasons, for vegetative establishment. Inspectors should document plant species distribution and fatality rates and verify compliance with the landscaping specifications. Also, sediment accumulation, water elevations, and the condition of the outlet should be documented. Records should be kept to track the wetland's health over time.

Management of Wetland Vegetation

The constructed wetland and its buffer may need a reinforcement planting at the onset of the second growing season after construction. The size and species of plants to be used should be based on the growth and survival rate of the existing plants at the end of their first growing season. Controlling the growth of certain invasive species, such as cattail and phragmites, may also be necessary. These plants can be very hard to contain if they are allowed to spread unchecked. The best strategy may be to design for a wide range of distinct depth zones.

Research shows that for most aquatic plants the bulk of the pollutants is stored in the roots, not the stems and leaves (Lepp 1981). Therefore, harvesting before winter dieback is unnecessary. Many unanswered questions remain concerning the long-term pollutant storage capacity of plants. Additional plant maintenance recommendations may be presented in the future, as such information becomes available.

The embankment and BMP access road should be mowed biannually, at a maximum, to prevent the growth of trees. Otherwise, the buffer and upland areas should be allowed to grow in meadow conditions.

FIGURE 14.05 - 1
Constructed Stormwater Wetlands - Plan

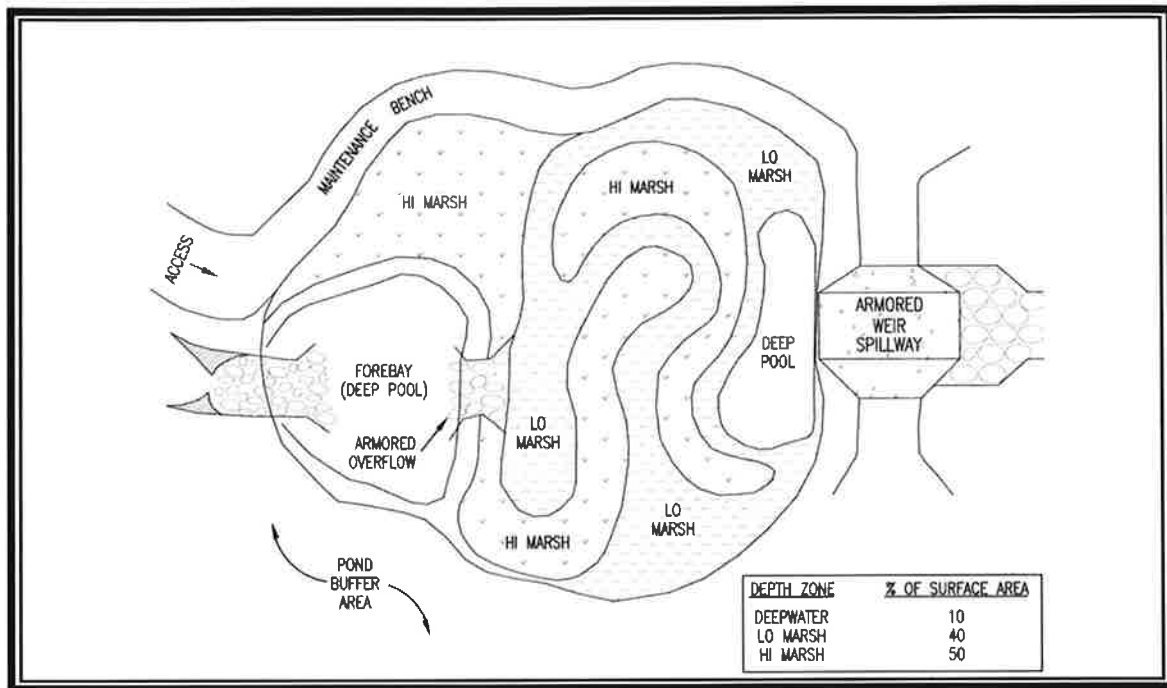


FIGURE 14.05 - 2
Constructed Stormwater Wetlands - Depth Zones

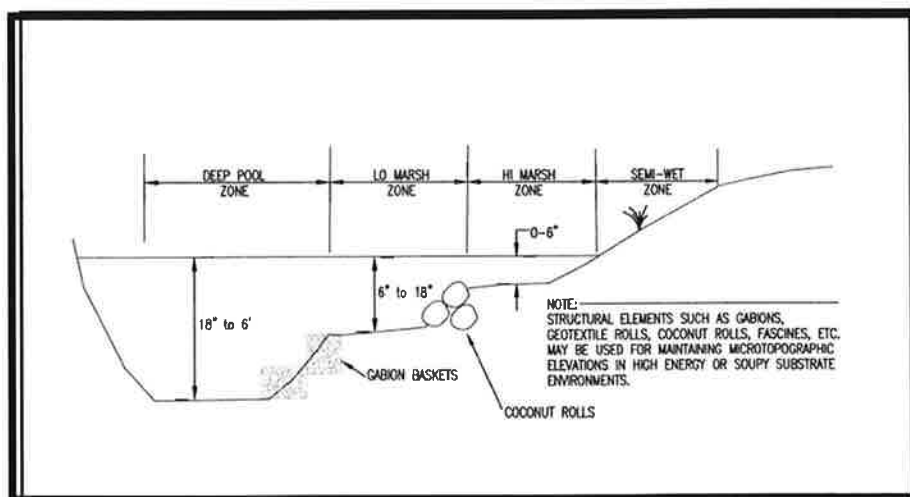


FIGURE 14.05- 3
Dry Weather and Wet Weather Flow Paths

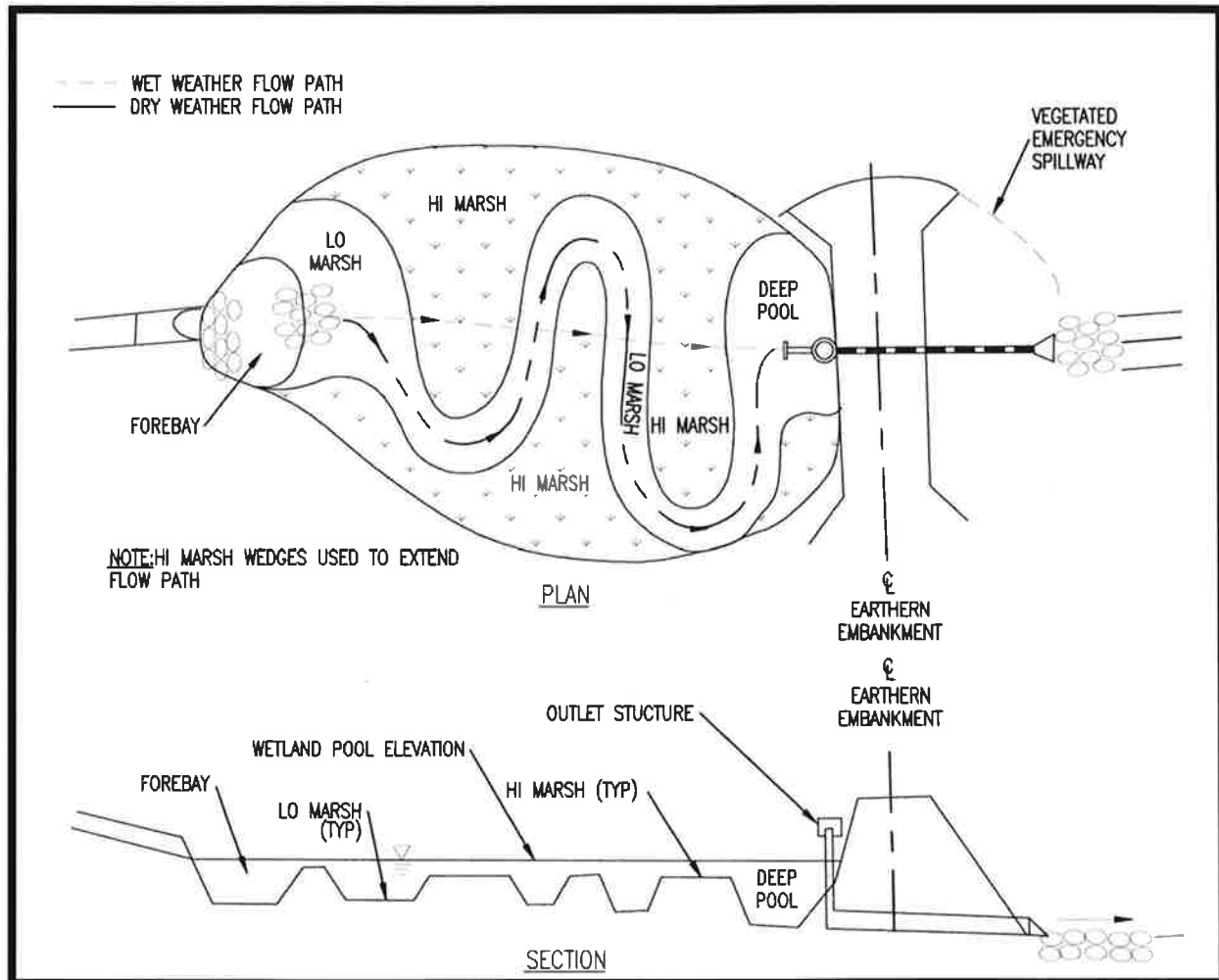
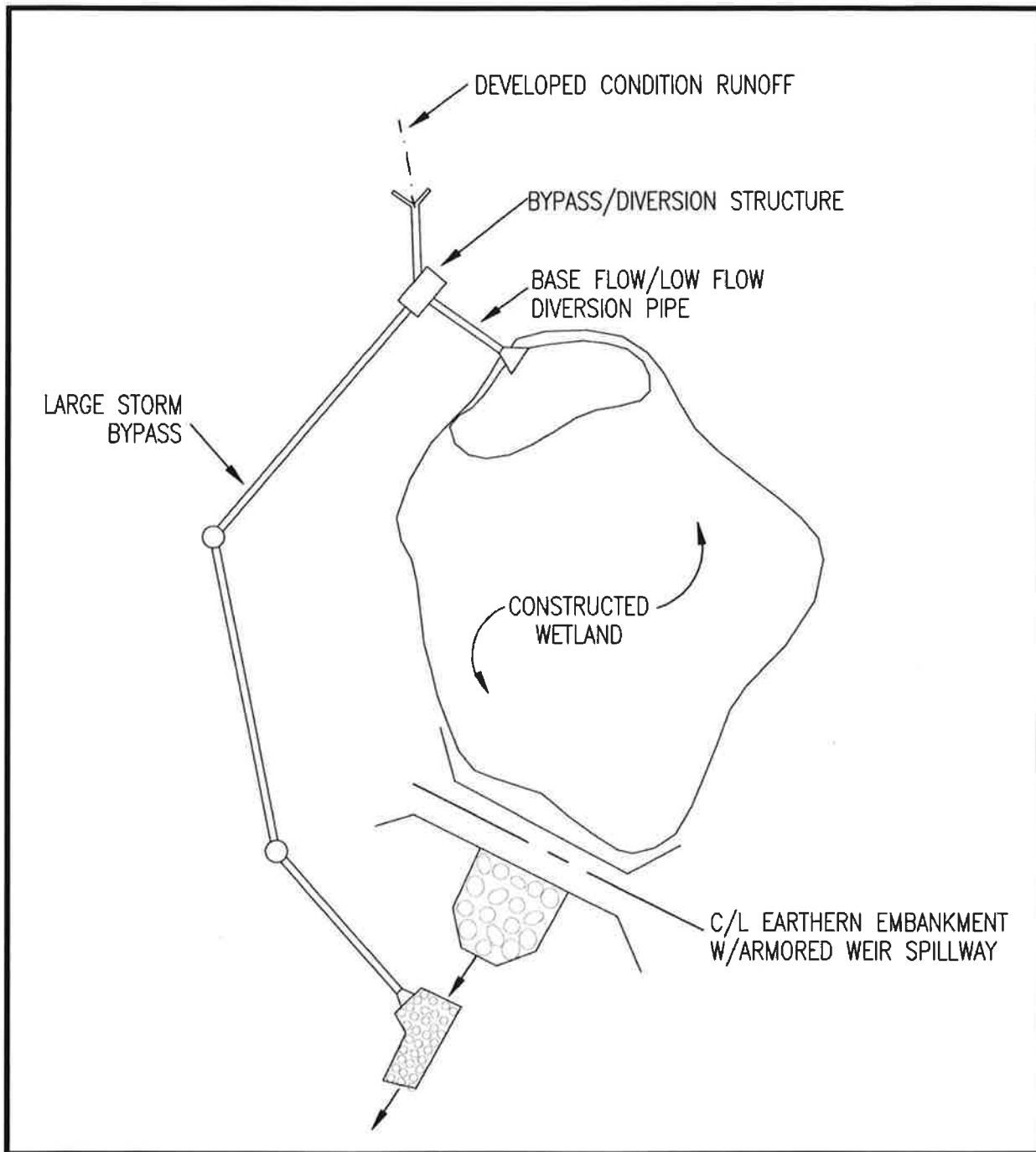


FIGURE 14.05- 4
Off-line Bypass Structure



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Constructed Stormwater Wetland – recently completed.



Constructed Stormwater Wetland – becoming stabilized, emergent vegetation barely visible.

Constructed Stormwater Wetland



Constructed Stormwater Wetland. Note vegetation protected from waterfowl by netting system.



Forebay and Constructed Stormwater Wetland incorporated into regional retention basin design.

Constructed Stormwater Wetland

MINIMUM STANDARD 14.06

VEGETATED FILTER STRIP



LIST OF ILLUSTRATIONS

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14.06-3	USDA Plant Hardiness Zones	14.06-9

MINIMUM STANDARD 14.06

VEGETATED FILTER STRIP

Definition

A vegetated filter strip is a densely vegetated strip of land engineered to accept runoff from upstream development as overland sheet flow. It may adopt any naturally vegetated form, from grassy meadow to small forest.

Purpose

The purpose of a vegetated filter strip is to enhance the quality of stormwater runoff through filtration, sediment deposition, infiltration and absorption.

A vegetated filter strip may be used as a pretreatment BMP in conjunction with a primary BMP. This reduces the sediment and particulate pollutant load that could reaching the primary BMP, which, in turn, reduces the BMP's maintenance costs and enhances its pollutant removal capabilities.

Vegetated filter strips rely on their flat cross-slope and dense vegetation to enhance water quality. Their flat cross-slope assures that runoff remains as sheet flow while filtering through the vegetation. There is limited ponding or storage associated with these BMPs, so they are ineffective for reducing peak discharges. Vegetated filter strips may lower runoff velocities and, sometimes, runoff volume. Typically, however, the volume reduction is not adequate for controlling stream channel erosion or flooding.

Conditions Where Practice Applies

Drainage Area

A vegetated filter strip should not receive large volumes of runoff since such flows tend to concentrate and form channels. Channels within a filter strip allow runoff to short-circuit the BMP, rendering it ineffective. Therefore, the contributing drainage area for a vegetated filter strip is based on the linear distance behind it that is maintained as sheet flow. Runoff is assumed to change from sheet flow to shallow concentrated flow after traveling 150 feet over pervious surfaces and 75 feet over impervious surfaces (Center for Watershed Protection, 1996). A level spreader may be used to convert shallow concentrated flow from larger areas back to sheet flow before it enters the filter strip. In any event, the contributing drainage area should never exceed five acres.

Development Conditions

Vegetated filter strips have historically been used and proven successful on agricultural lands, primarily due to their low runoff volumes. In urban settings, filter strips are most effective in treating runoff from isolated impervious areas such as rooftops, small parking areas, and other small impervious areas. Filter strips should not be used to control large impervious areas.

Since vegetated filter strips should not be used to treat concentrated flows, they are suitable only for low- to medium-density development (16-21% impervious), or as a pretreatment component for structural BMPs in higher density developments.

Planning Considerations

Site Conditions

The following site conditions should be considered when selecting a vegetated filter strip as a water quality BMP:

1. Soils – Vegetated filter strips should be used with soils having an infiltration rate of 0.52 inches/hour; (sandy loam, loamy sand). Soils should be capable of sustaining adequate stands of vegetation with minimal fertilization.
2. Topography – Topography should be relatively flat to maintain sheet flow conditions. Filter strips function best on 5 percent or less (NVPDC).
3. Depth of Water Table – A shallow or seasonally high groundwater table will inhibit the opportunity for infiltration. Therefore, the lowest elevation in the filter strip should be at least 2 feet above the water table.

If the soil's permeability and/or depth to water table are unsuitable for infiltration, the filter strip's primary function becomes the filtering and settling of pollutants. A modified design may be provided to allow ponding of the water quality volume at the filter's downstream end. The ponding area may be created by constructing a small permeable berm using a select soil mixture. (For berm details, see the Pervious Berm section in this standard.) The maximum ponding depth behind the berm should be 1 foot.

Water Quality Enhancement

Vegetated filter strips are occasionally installed as a standard feature in residential developments. To be used as a water quality BMP, however, filter strips must comply with certain design criteria. Vegetated filter strip designs should include specific construction, stabilization, and maintenance specifications. The most significant requirement is for runoff to be received as sheet flow. Certain

enhancements may be necessary, such as added vegetation and grading specifications, or the use of level spreaders, to ensure that runoff enters the filter strip as sheet flow.

Sediment Control

A natural area that is designed to serve as a vegetated filter strip should not be used for temporary sediment control. Sediment deposition may have significant impacts on the existing vegetation. If a vegetated filter strip is proposed in a natural area marginally acceptable for use, due to topography or existing vegetation, then it may be appropriate to use the filter strip for temporary sediment control. However, when the project is completed, the sediment accumulation should be removed, the area should be regraded to create the proper design conditions (sheet flow), and the strip should be re-stabilized per the landscaping plan.

Design Criteria

This section provides recommendations and minimum design criteria for vegetated filter strips intended to enhance water quality. It is the designer's responsibility to decide which criteria are applicable to the each facility and to decide if any additional design elements are required. The designer must also provide for the long-term functioning of the BMP

Hydrology

The hydrology of a filter strip's contributing drainage area should be developed per Chapter 8, Surface Drainage.

Filter Strip Geometry

Compliance with the following parameters will result in optimal filter strip performance (NVPDC):

1. Length – The minimum length of a filter strip should be 25 feet, at a maximum slope of 2 percent. The length should increase by 4 feet for any 1 percent increase in slope. The optimum filter strip length is 80 to 100 feet.
2. Width – The width of the filter strip (perpendicular to the slope) should be equal to the width of the contributing drainage area. When this is not practical, a level spreader should be used to reduce the flow width to that of the filter strip. The level spreader's width will determine the depth of flow and runoff velocity of the stormwater as it passes over the spreader lip and into the filter strip. A wide lip will distribute the flow over a longer level section, which reduces the potential for concentrated flow across the filter.
3. Slope – The slope of the filter strip should be as flat as possible while allowing for drainage. Saturation may occur when extremely flat slopes are used.

Level Spreader

A level spreader should be provided at the upper edge of a vegetated filter strip when the width of the contributing drainage area is greater than that of the filter (see Figure 14.06-2.) Runoff may be directed to the level spreader as sheet flow or concentrated flow. However, the design must ensure that runoff fills the spreader evenly and flows over the level lip as uniformly as possible. The level spreader should extend across the width of the filter, leaving only 10 feet open on each end.

Pervious Berm

To force ponding in a vegetated filter strip, a pervious berm may be installed. It should be constructed using a moderately permeable soil such as ASTM ML, SM, or SC. Soils meeting USDA sandy loam or loamy sand texture, with a minimum of 10 to 25% clay, may also be used. Additional loam should be used on the berm ($\pm 25\%$) to help support vegetation. An armored overflow should be provided to allow larger storms to pass without overtopping the berm. Maximum ponding depth behind a pervious berm is 1 foot.

Vegetation

A filter strip should be densely vegetated with a mix of erosion resistant plant species that effectively bind the soil. Certain plant types are more suitable than others for urban stormwater control. The selection of plants should be based on their compatibility with climate conditions, soils, and topography and their ability to tolerate urban stresses from pollutants, variable soil moisture conditions and ponding fluctuations.

A filter strip should have at least two of the following vegetation types:

- deep-rooted grasses, ground covers, or vines
- deciduous and evergreen shrubs
- under- and over-story trees

Native plant species should be used if possible. Non-native plants may require more care to adapt to local hydrology, climate, exposure, soil and other conditions. Also, some non-native plants may become invasive, ultimately choking out the native plant population. This is especially true for non-native plants used for stabilization.

Newly constructed stormwater BMPs will be fully exposed for several years before the buffer vegetation becomes adequately established. Therefore, plants which require full shade, are susceptible to winter kill or are prone to wind damage should be avoided.

Plant materials should conform to the American Standard for Nursery Stock, current issue, as published by the American Association of Nurserymen. The botanical (scientific) name of the plant species should be according to the landscape industry standard nomenclature. All plant material specified should be suited for USDA Plant Hardiness Zones 6 or 7 (see Figure 14.06- 3).

Construction Specifications

Overall, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U.S. Army Corps of Engineers, should be followed where applicable to construct a vegetated filter strip. The specifications should also satisfy all requirements of the local government.

Sequence of Construction

Vegetated filter strip construction should be coordinated with the overall project construction schedule. Rough grading of the filter strip should not be initiated until adequate erosion controls are in place.

Soil Preparation

Topsoil should be 8 inches thick, minimum. If grading is necessary, the topsoil should be removed and stockpiled. If the subsoil is either highly acidic or composed of heavy clays, ground dolomite limestone should be applied at an appropriate rate based on soil and slope conditions.

Subsoil should be tilled to a depth of at least 3 inches to adequately mix in soil additives and to permit bonding of the topsoil to the subsoil. If the existing topsoil is inadequate to support a densely vegetated filter strip, then suitable material should be imported. Proper specifications for imported topsoil should include the following:

1. The USDA textural triangle classification.
2. Requirements for organic matter content (not less than 1.5% by weight), pH (6 to 7.5), and soluble salt (not greater than 500 parts per million).
3. Placement thickness and compaction. Topsoil should be uniformly distributed and compacted, and should have a minimum compacted depth of 6 to 8 inches.

Maintenance/Inspection Guidelines

Vegetated filter strips require regular maintenance. Field studies indicate that the primary causes of failure of these BMPs is of lack of maintenance so it is important to monitor the sites for proper establishment and maintenance of healthy vegetative cover.

The following are maintenance and inspection guidelines. Specific facilities may require other measures not discussed here. It is the designer's responsibility to decide if additional measures are necessary and to take the proper course of action.

Filter strips should be inspected regularly for gully erosion, density of vegetation, damage from foot or vehicular traffic, and evidence of concentrated flows circumventing the strip. The level spreader should also be inspected to verify that it is functioning as intended.

Inspections are critical during the first few years to ensure that the strip becomes adequately established. Maintenance is especially important during this time and should include watering, fertilizing, re-seeding or planting as needed.

Once a filter strip is well established and functioning properly, periodic maintenance, such as watering, fertilizing and spot repair, may still be necessary. However, fertilization efforts should be minimized. Natural selection allows certain species (usually native plants) to thrive while others decline. Excessive fertilization and watering to maintain individual plantings may prove costly, especially in abnormally dry or hot seasons. Overseeding and replanting should be limited to those species which have exhibited the ability to thrive.

To increase the functional longevity of a vegetated filter strip, the following practices are recommended:

- Regular removal of accumulated sediment,
- periodic reestablishment of vegetation in eroded areas or areas covered by accumulated sediment,
- periodic weeding of invasive species or weeds, and
- periodic pruning of woody vegetation to stimulate growth

FIGURE 14.06-1
Vegetated Filter Strip

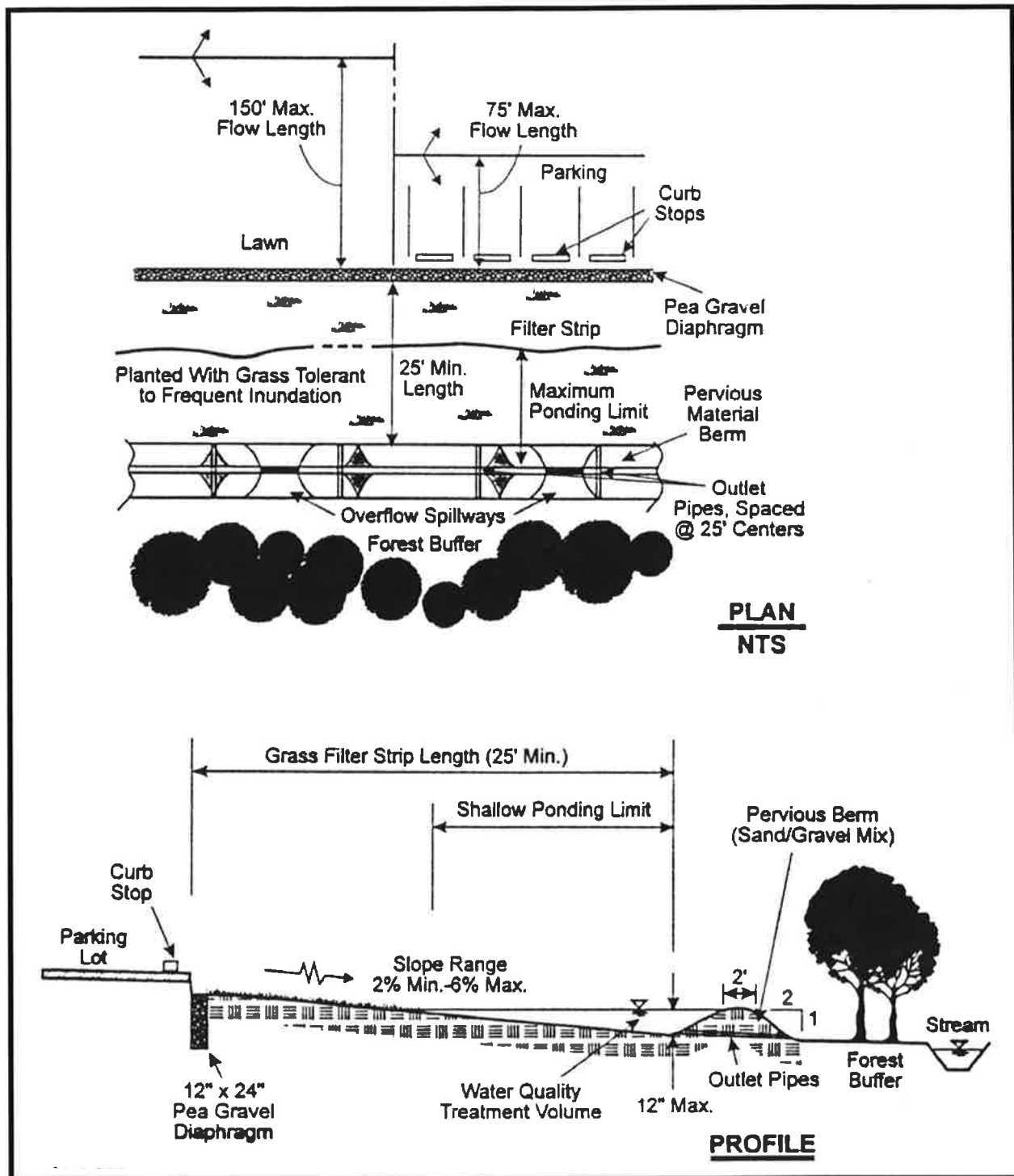
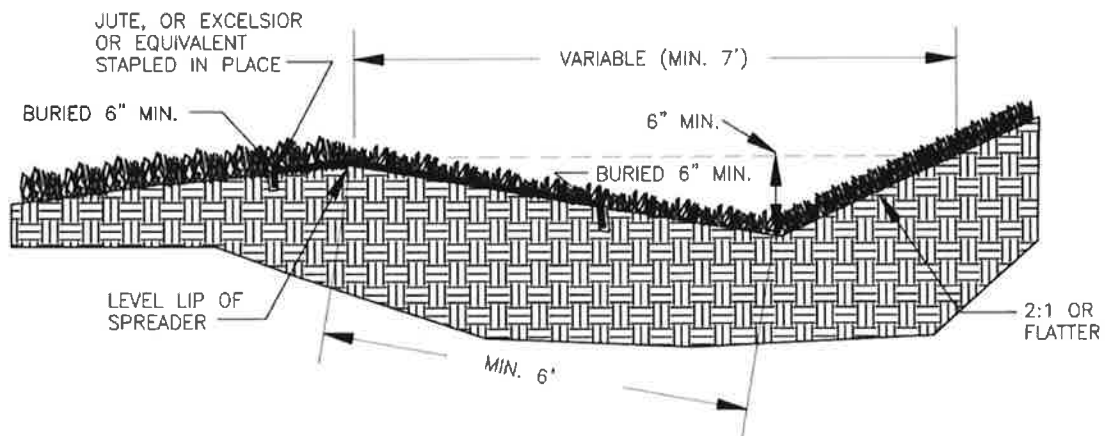


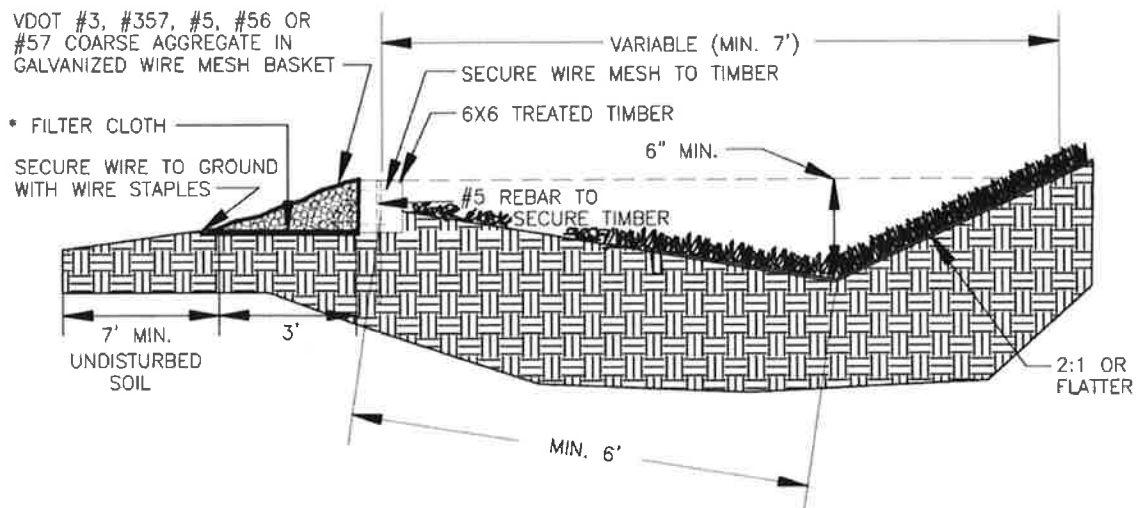
FIGURE 14.06- 2
Level Spreader

LEVEL SPREADER CROSS SECTION



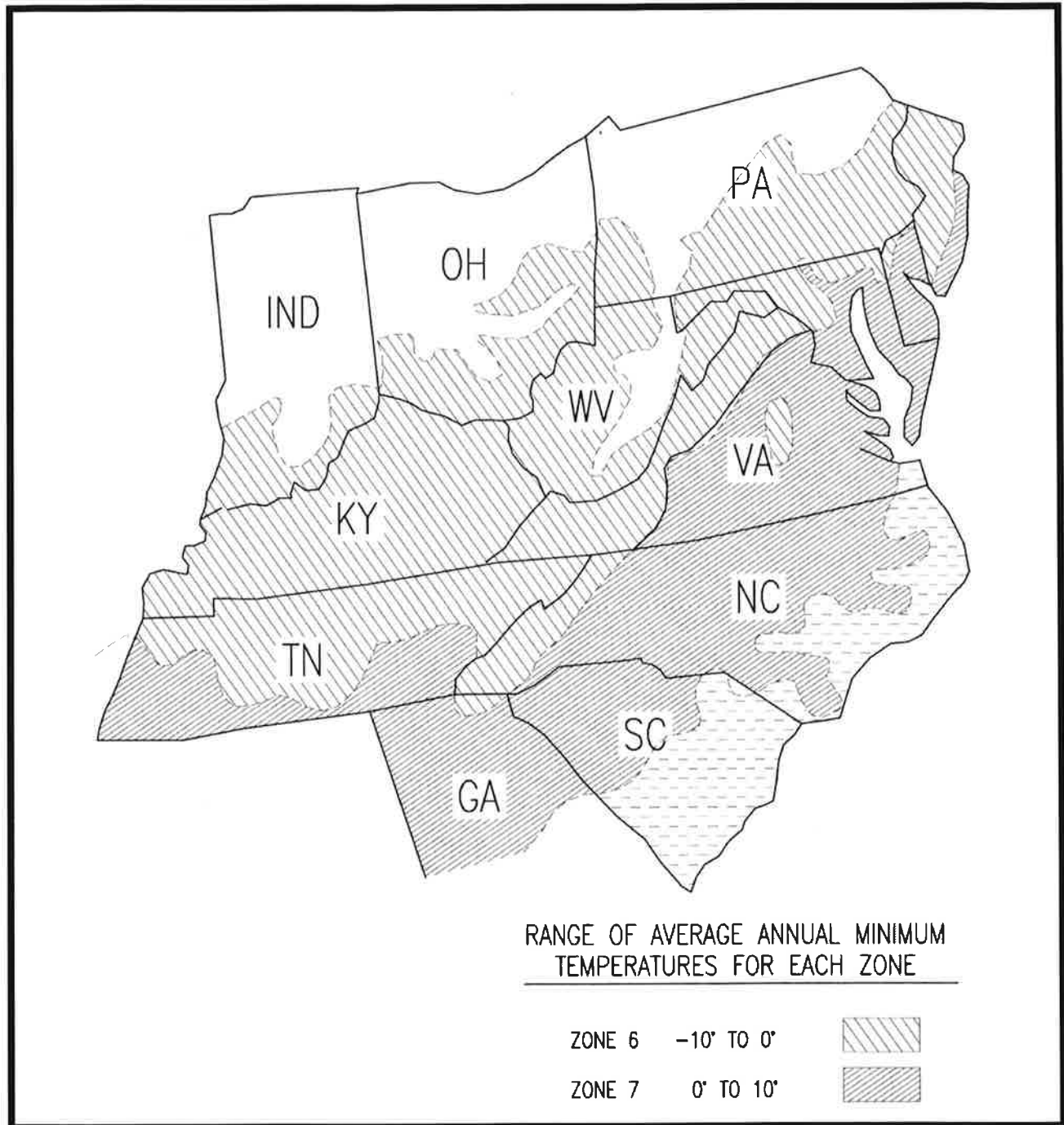
LEVEL SPREADER WITH VEGETATED LIP

CROSS SECTION



LEVEL SPREADER WITH RIGID LIP

FIGURE 14.06- 4
USDA Plant Hardiness Zones



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Vegetated Filter Strip. Note landscaped areas parallel to contours to force runoff to spread out. No evidence of channel flow short circuiting filter strip.

MINIMUM STANDARD 14.07

GRASSED SWALE



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14.07-1	Stone or Riprap Sizes for Gabion Baskets	14.07-12

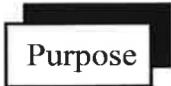
MINIMUM STANDARD 14.07

GRASSED SWALE

Definition

A grassed swale is a broad and shallow earthen channel vegetated with erosion resistant and flood-tolerant grasses. Check dams are strategically placed in the swale to encourage ponding behind them.

A water quality swale is a broad and shallow earthen channel vegetated with erosion resistant and flood tolerant grasses, and underlain by an engineered soil mixture.

Purpose

The purpose of grassed swales and water quality swales is to convey stormwater runoff at a non-erosive velocity in order to enhance its water quality through infiltration, sedimentation, and filtration. Check dams are used within the swale to slow the flow rate and create small, temporary ponding areas. A water quality swale is appropriate where greater pollutant removal efficiency is desired.

Water Quality Enhancement

Grassed swales and water quality swales remove pollution through sedimentation, infiltration, and filtration. Water quality swales are specifically engineered to filter stormwater through an underlying soil mixture while grasses swales are designed to slow the velocity of flow to encourage settling and filtering through the grass lining. Vegetation filters out the sediments and other particulate pollutants from the runoff and increases the opportunity for infiltration and adsorption of soluble pollutants. The flow rate becomes a critical design element, since runoff must pass through the vegetation slowly for pollutant removal to occur. Monitoring of grassed swales has indicated low to moderate removal of soluble pollutants (phosphorous and nitrogen) and moderate to high removal of particulate pollutants.

Flood Control

Grassed swales and water quality swales will usually provide some peak attenuation depending on the storage volume created by the check dams. However, flood control should be considered a secondary function of grassed swales since the required storage volume for flood control is usually more than they can provide.

FIGURE 14.07-1
Typical Grassed Swale Configuration

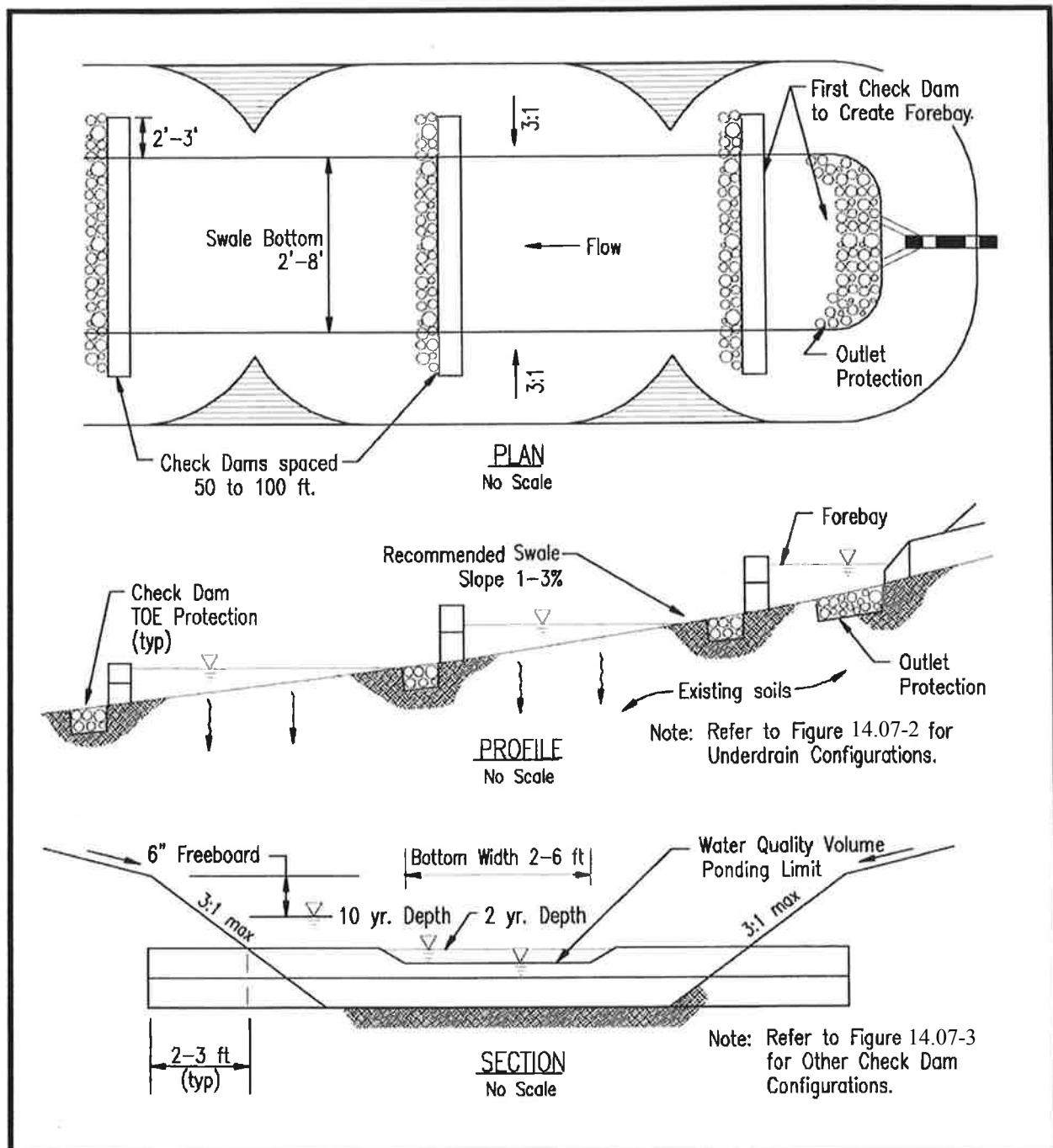
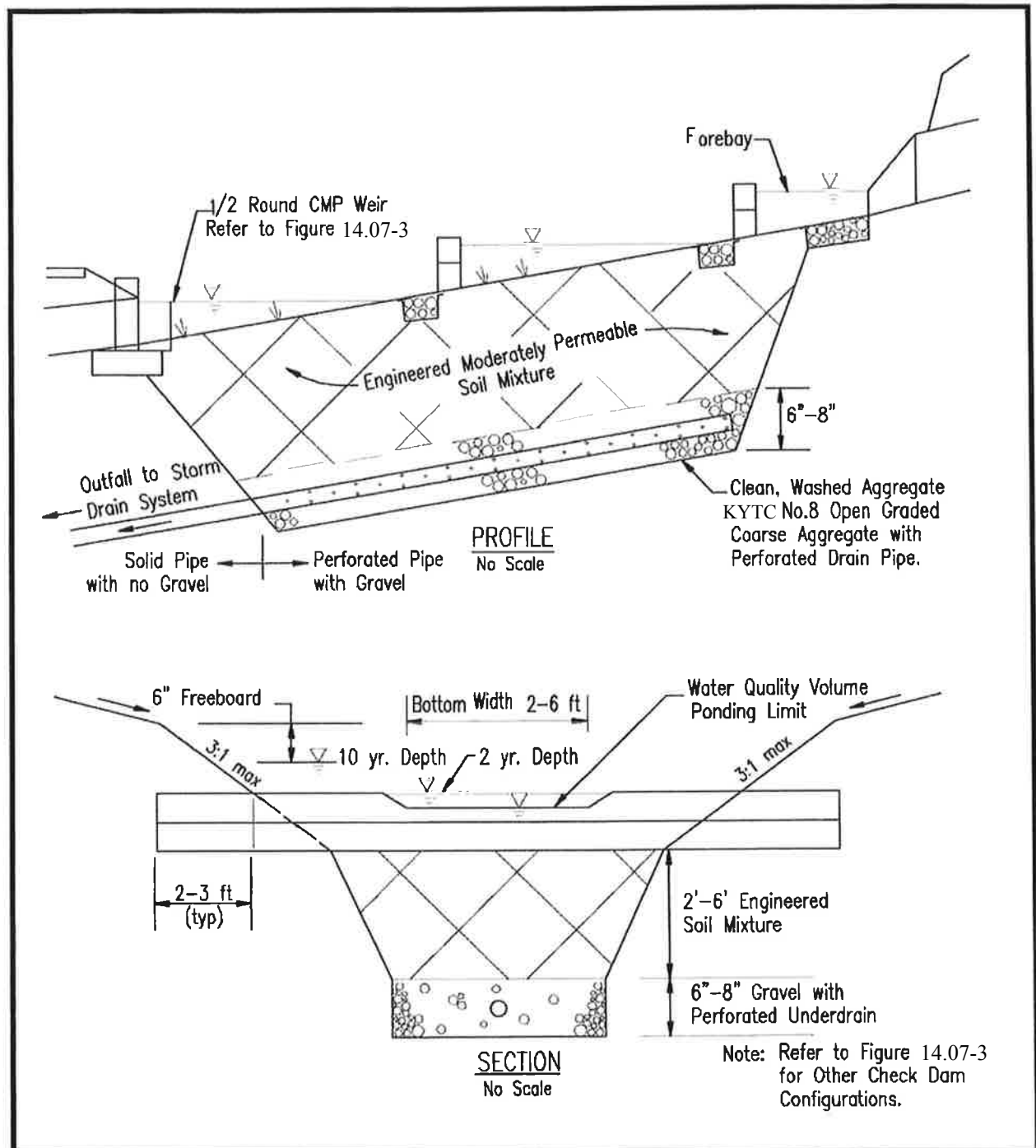


FIGURE 14.07-2
Typical Water Quality Swale Configuration



Channel Erosion Control

Grassed swales and water quality swales may also provide some benefits relative to channel erosion by reducing the peak rate of discharge from a drainage area. However, the holding capacity of a grassed swale designed for water quality purposes is limited.

Condition Where Practice Applies

Drainage Area

Grassed swales and water quality swales engineered for enhancing water quality cannot effectively convey large flows. Therefore, their contributing drainage areas must be kept small. The dimensions (length, width, and overall geometry) and slope of the swale, and its ability to convey the 10-year storm at a non-erosive velocity will set the size of the contributing drainage area.

Development Conditions

Grassed swales are commonly used instead of curb and gutter drainage systems in low- to moderate-density (16 to 21% impervious) single-family residential developments. Since grassed swales do not function well with high volumes or velocities of stormwater, they have limited application in highly urbanized or other highly impervious areas. However, swales may be appropriate for use in these areas if they are constructed in series or as pretreatment facilities for other BMPs.

Grassed swales are usually located within the right-of-way when used to receive runoff from subdivision or rural roadways. They may also be installed within drainage easements along the side or rear of residential lots. Grassed swales can be strategically located within the landscape to intercept runoff from small impervious surfaces (small parking lots, rooftops, etc.) as a component of a subdivision-wide or development-wide BMP strategy.

Water quality swales are appropriate for the same development conditions as those listed for grassed swales with the addition of higher densities of development (16 - 37% impervious) due to the increased pollutant removal capability.

Planning Considerations

Figure 14.07-1 presents a grassed swale designed to hold small pockets of water behind each check dam. The water slowly drains through small openings in the check dam and/or infiltrates into the ground. Slow channel velocities allow the vegetation to filter out sediments and other particulate pollutants from the runoff and increases the opportunity for infiltration and adsorption of soluble pollutants.

Figure 14.07-2 presents a water quality swale with an engineered soils media directly under the swale, with an underdrain. This design may be used in areas where the soils are not conducive to infiltration, or in developments where the swale is constructed beside a roadway using fill or compacted soils.

Site Conditions

The following items should be considered when selecting a grassed swale as a water quality BMP:

1. Soils – Grassed swales can be used with soils having moderate infiltration rates of 0.27 inches per hour (silt loam) or greater. Besides permeability, soils should support a good stand of vegetative cover with minimal fertilization.

Water quality swales can be used in areas of unsuitable soil conditions for infiltration since the engineered soil mixture and underdrain system is used in place of the insitu soils.

2. Topography – The topography of the site should be relatively flat so that the swale can be constructed with a slope and cross-section that maintains low velocities and creates adequate storage behind the check dams.
3. Depth to water table – A shallow or seasonally-high groundwater table will inhibit the opportunity for infiltration. Therefore, the bottom of the swale should be at least 2 feet above the water table.

Sediment Control

Grassed swales may be used for conveyance of stormwater runoff during the construction phase of development. However, the swales should be maintained as required by the local program requirements. Before final stabilization, sediment must be removed from the swales and the soil surface prepared for final stabilization. Tilling of the swale bottom may be needed to open the surface pores and re-establish the soil's permeability. Because of this likelihood of significant rehabilitation of the grassed swale after stabilization of the contributing area, it is encouraged that water quality swales be constructed only after the drainage area has been stabilized.

This section presents minimum criteria and recommendations for the design of grassed swales used to enhance water quality. It is the designer's responsibility to decide which criteria are applicable to the particular swale being designed and to decide if any additional design elements are required. The designer must also provide for the long-term functioning of the facility by choosing appropriate structural materials.

Design Criteria

The design of a water quality grassed swale includes calculations for traditional swale parameters (flow rate, maximum permissible velocities, etc.) along with storage volume calculations for the water quality volume.

Hydrology

The hydrology of a grassed swale's contributing drainage area should be developed per Chapter 8, Surface Drainage

Swale Geometry

A grassed swale should have a trapezoidal cross-section to spread flows across its flat bottom. Triangular or parabolic shaped sections will concentrate the runoff and should be avoided. The side slopes of the swale should be no steeper than 3H:1V to simplify maintenance and to help prevent erosion.

Bottom Width

The bottom width of the swale should be 2 feet minimum and 6 feet maximum in order to maintain sheet flow across the bottom and to avoid concentration of low flows. The actual design width of the swale is determined by the maximum desirable flow depth, as discussed below.

Flow Depth

The flow depth for a water quality grassed swale should be approximately the same as the height of the grass. An average grass height for most conditions is 4 inches. Therefore, the maximum flow depth for the water quality volume should be 4 inches (Center for Watershed Protection, 1996).

Flow Velocity

The maximum velocity of the water quality volume through the grassed swale should be no greater than 1.5 feet per second. The maximum design velocity of the larger storms should be kept low enough so as to avoid resuspension of deposited sediments. The 2-year storm recommended maximum design velocity is 4 feet per second and the 10-year storm recommended maximum design velocity is 7 feet per second

Longitudinal Slope

The slope of the grassed swale should be as flat as possible, while maintaining positive drainage and uniform flow. The minimum constructable slope is between 0.75 and 1.0%. The maximum slope depends upon what is needed to maintain the desired flow velocities and to provide adequate storage for the water quality volume, while avoiding excessively deep water at the downstream end.

Generally, a slope of between 1 and 3% is recommended. The slope should never exceed 5%

Swale length

Swale length is dependent on the swale's geometry and the ability to provide the required storage for the water quality volume.

Swale Capacity

The capacity of the grassed swale is a combined function of the flow volume (the water quality volume) and the physical properties of the swale such as longitudinal slope and bottom width. By using the Manning equation or channel flow nomographs, the depth of flow and velocity for any given set of values can be obtained. The Manning's 'n' value, or roughness coefficient, varies with the depth of flow and vegetative cover. An 'n' value of 0.15 is appropriate for flow depths of up to 4 inches (equal to the grass height). The n value decreases to a minimum of 0.03 for grass swales at a depth of approximately 12 inches.

A grassed swale should have the capacity to convey the peak flows from the 10-year design storm without exceeding the maximum permissible velocities. (Note that a maximum velocity is specified for the 2-year and 10-year design storms to avoid resuspension of deposited sediments and other pollutants and to prevent scour of the channel bottom and side slopes.) The swale should pass the 10-year flow over the top of the check dams with 6 inches, minimum, of freeboard. As an alternative, a bypass structure may be engineered to divert flows from the larger storm events (runoff greater than the water quality volume) around the grassed swale. However, when the additional area and associated costs for a bypass structure and conveyance system are considered, it may be more economical to simply increase the bottom width of the grassed swale. It should then be designed to carry runoff from the 10-year frequency design storm at the required permissible velocity.

The longitudinal slope and the bottom width may be adjusted to achieve the maximum allowable velocity according to the Manning equation:

$$Q = \left[\frac{1.49}{n} r^{2/3} s^{1/2} \right] A$$

Where:

- Q = peak flow rate, cfs
- n = Manning's roughness coefficient
- r = hydraulic radius, ft. = A / wp
- s = longitudinal slope of the channel
- A = cross-sectional area of the channel, ft²

The portion of the equation within the brackets represents the velocity of flow. The previous equation can be rewritten as:

$$Q = VA$$

Where: Q = peak flow rate, cfs $\frac{1.49}{n} r^{2/3} s^{1/2}$
 V = flow velocity, ft/s =
 A = cross-sectional area of the channel, ft².

Water Quality Volume

If a grassed swale is used as a conveyance channel, its purpose is to transport stormwater to the discharge point. However, the purpose of a water quality grassed swale is to slow the water as much as possible to encourage pollutant removal.

The use of check dams will create segments of the swale which will be inundated for a period of time. The required total storage volume behind the check dams is equal to the water quality volume for the contributing drainage area to that point. However, the maximum ponding depth behind the check dams should not exceed 18 inches. To ensure that this practice does not create nuisance conditions, an analysis of the subsoil should be conducted to verify its permeability.

Underlying Soil Bed - Water Quality Swales

An underlying engineered soil bed and underdrain system may be utilized in areas where the soils are not permeable and the swale would remain full of water for extended periods of time (creating nuisance conditions). This soil bed should consist of a moderately permeable soil material with a high level of organic matter: 50% sand, 20% leaf mulch, 30% top soil. The soil bed should be 30 inches deep and should be accompanied by a perforated pipe and gravel underdrain system.

In residential developments with marginal soils, it may be appropriate to provide a soil bed and underdrain system in all grassed swales to avoid possible safety and nuisance concerns.

Check Dams

The use of check dams in a grassed swale should be per the following criteria:

1. Height – A maximum height of 18 inches is recommended, and the dam height should not exceed one-half the height of the swale bank.
2. Spacing – Spacing should be such that the slope of the swale and the height of the check dams combine to provide the required water quality volume behind the dams.
3. Abutments – Check dams should be anchored into the swale wall a minimum of 2 to 3 feet on each side.

4. Toe Protection – The check dam toe should be protected with riprap placed over a suitable geotextile fabric. The size (D_{50}) of the riprap should be based on the design flow in the swale. Class A1 Riprap is recommended.
5. Overflow – A notch should be placed in the top of the check dam to allow the 2-year peak discharge to pass without coming into contact with the check dam abutments, or the abutments may be protected with a non-erodible material. Six inches of freeboard should be provided between the 10-year overflow and the top of the swale.
6. Riprap check dams – Rip rap check dams should consist of a KYTC No. 1 Open-graded Coarse Aggregate core keyed into the ground a minimum of 6 inches, with a Class A riprap shell.
7. Filter fabric – Filter fabric is required under riprap and gabion check dams.
8. Driveway culvert weirs – Where a driveway culvert is encountered, a ½ round corrugated metal pipe weir bolted to the concrete driveway headwall may be utilized as a check dam, or a timber check dam placed at least one foot upstream of the culvert opening.

Outlets

Discharges from grassed swales must be conveyed at non-erosive velocities to either a stream or a stabilized channel to prevent scour at the outlet of the swale.

Inflow Points

Swale inflow points should be protected with erosion controls as needed (e.g., riprap, flow spreaders, energy dissipators, sediment forebays, etc.).

Vegetation

A dense cover of water-tolerant, erosion-resistant grass or other vegetation must be established. Grasses used in swales should have the following characteristics:

- a deep root system to resist scouring,
- a high stem density, with well-branched top growth,
- tolerance to flooding,
- resistance to being flattened by runoff, and
- an ability to recover growth following inundation.

Recommended grasses include, but are not limited to, the following: Kentucky-31 tall fescue, reed canary grass, redtop, and rough-stalked blue grass. Note that these grasses can be mixed.

The selection of an appropriate vegetative lining for a grassed swale is based on several factors including climate, soils, and topography.

Erosion control matting should be used to stabilize the soil before seed germination. This protects the swale from erosion during the germination process. In most cases, the use of sod is warranted to provide immediate stabilization on the swale bottom and/or side slopes. .

Construction Specifications

Overall, widely accepted construction standards and specifications, such as those developed by the USDA Soil Conservation Service or the U. S. Army Corps of Engineers, should be followed where applicable. Further guidance can be found in the SCS Engineering Field Manual. Specifications for the work should conform to the methods and procedures specified for earthwork, concrete, reinforcing steel, woodwork and masonry, as they apply to the site and the purpose of the structure. The specifications should also satisfy any requirements of the local government.

Sequence of Construction

The construction of grassed swales should be coordinated with the overall project construction schedule. The swale may be excavated during the rough grading phase of the project to permit use of the excavated material as fill in earthwork areas. Otherwise, grassed swales constructed or placed into service prior to the entire contributing drainage area being stabilized is discouraged. Runoff from untreated, recently constructed areas may load the newly formed swale with a large volume of fine sediment. This could seriously impair the swale's natural infiltration ability.

The specifications for construction of a grassed swale should state the following:

- the earliest point in progress when storm drainage may be directed to the swale, and
- the means by which this delay in use will be accomplished.

Due to the wide variety of conditions encountered among projects, each project should be evaluated separately evaluated to decide how long to delay use of the swale.

Excavation

Initially, the swale should be excavated to within one foot of its final elevation. Excavation to the finished grade should be deferred until all disturbed areas in the watershed have been stabilized or protected. The final phase of excavation should remove all accumulated sediment. When final grading is completed, the swale bottom should be tilled with rotary tillers or disc harrows to provide a well-aerated, highly porous surface texture.

Vegetation

Establishing dense vegetative cover on the swale side slopes and floor is required. This cover will not only prevent erosion and sloughing, but will also provide a natural means to maintain relatively high infiltration rates.

Materials

1. Check dams – Check dams shall be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams shall be underlaid by filter fabric.
 - a. Wood - pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust.
 - b. Gabions - hexagonal triple twist mesh with PVC coated galvanized steel wire. The maximum linear dimension of the mesh opening shall not exceed 4.5 inches. The area of the mesh opening shall not exceed 10 square inches.

Stone or riprap for gabions shall be sized according to Table 14.07-1. It shall consist of field stone or rough unhewn quarry stone. The stone shall be hard and angular and of a quality that will not disintegrate with exposure to water or weathering. The specific gravity of the individual stones shall be at least 2.5.

Recycled concrete may be used if it has a density of at least 150 pounds per cubic foot and does not have any exposed steel or reinforcing bars.

- c. Riprap - all riprap shall conform with KYTC Standards for open graded course aggregate.
 - d. Concrete - All concrete shall conform with KYTC or SCS specifications.
2. Underlying soil medium – The underlying soils should consist of the following:
 - a. Soil - USDA ML, SM, or SC.
 - b. Sand - ASTM C-33 fine aggregate concrete sand; KYTC fine aggregate, grading A or B.
3. Pea Gravel – Pea gravel should consist of washed ASTM M-43; KYTC No. 8 Open-graded Course Aggregate.
4. Underdrain – An underdrain system below the swale bottom shall consist of the following:
 - a. Gravel - AASHTO #7, ASTM M-43, KYTC No. 3 Open-graded Course Aggregate.
 - b. PVC Pipe - AASHTO M-278, 4-inch rigid schedule 40, perforations of 3/8-inch diameter at 6-inch centers, 4 holes per row.
 - c. Filter fabric - shall be 4 – 6 oz nonwoven needle – punched geotextile.

TABLE 14.07 - 1
Stone or Riprap Sizes for Gabion Baskets

Basket Thickness		Stone Size (in.)
(in.)	(mm.)	
6	150	3 - 5
9	225	4 - 7
12	300	4 - 7
18	460	4 - 7
36	910	4 - 12

Maintenance and Inspection Guidelines

Maintenance of grassed swales includes upkeep of the vegetative cover and preservation of the swale's hydraulic properties. Individual land owners can usually carry out the suggested maintenance procedures for the swale or the portion of the swale on their property. To ensure continued long term maintenance, all affected landowners should be made aware of their maintenance responsibilities, and maintenance agreements should be included in land titles.

The following maintenance and inspection guidelines are not intended to be all-inclusive. Specific swales may require other measures not discussed here. It is the engineer's responsibility for determining if any additional items are necessary.

Vegetation

A dense and vigorous grass cover should be maintained in a grassed swale. This will be simplified if the proper grass type is selected in the design. Periodic mowing is required to keep the swale operating properly. Grass should never be cut to a height less than 3 inches. Ideally, a grass stand of 6 inches is most effective. Stabilization and reseeding of bare spots should be performed, as needed.

Check Dams

Properly constructed check dams should require very little maintenance since they are made of non-erodible materials. Periodic removal of sediment accumulated behind the check dams should be performed, as needed.

Debris and Litter Removal

The accumulation of debris (including trash, grass clippings, etc.) in the swale can alter the hydraulics of the design and lead to additional maintenance costs. Debris can also alter the flow path along the swale bottom causing low flows to concentrate and result in erosion of the swale bottom. As with any BMP, frequent inspections by the land owner will help prevent small problems from becoming larger.

Sediment Removal

The sediment that accumulates within the swale should be manually removed and the vegetation reestablished. If accumulated sediment has clogged the surface pores of the swale, reducing or eliminating the infiltration capacity, then the surface should be tilled and restabilized. Drilling or punching small holes into the surface layer can be used instead of tilling, if desired.

FIGURE 14.07 - 3
Typical Check Dam Configurations

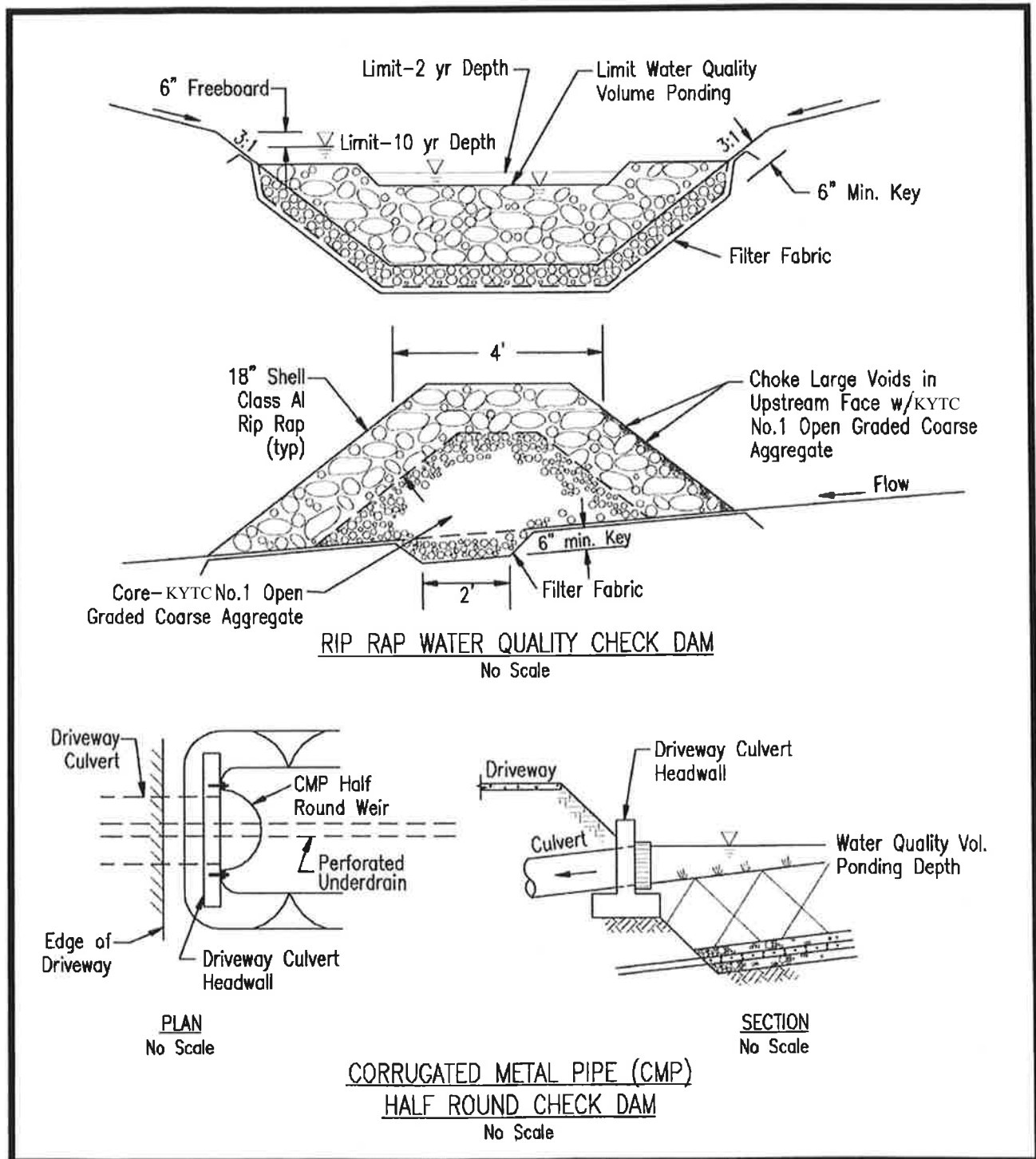
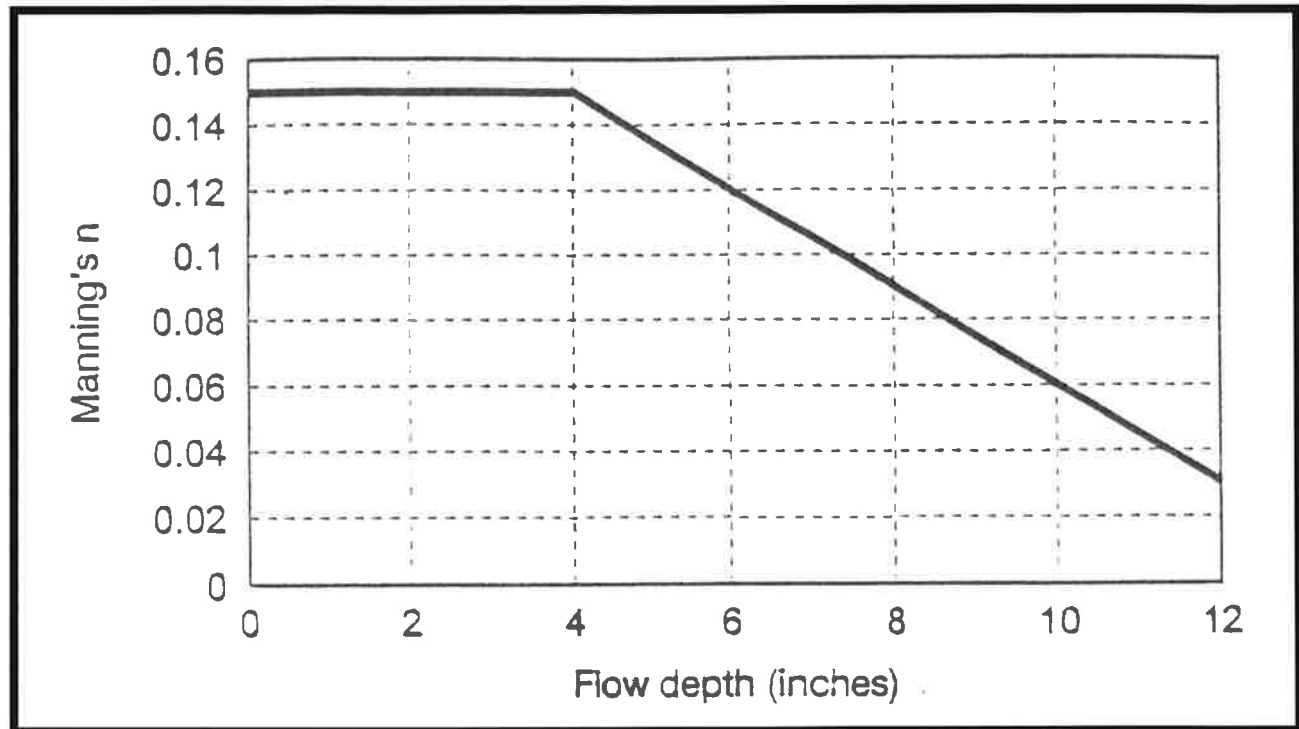


FIGURE 14.07-4
Manning's 'n' Values for Varying Depths of Flow



Design Procedures

The following design procedure represents a generic list of the steps typically required for the design of a water quality grassed swale.

1. Determine if the anticipated development conditions and drainage area are appropriate for a water quality grassed swale BMP.
2. Determine if the soils (permeability, bedrock, etc.) and topographic conditions (slopes, existing utilities, environmental restrictions) are appropriate for a grassed swale BMP.
3. Determine any additional stormwater management requirements (channel erosion, flooding) for the project.
4. Locate the grassed swale BMP(s) on the site.
5. Determine the hydrology and calculate the 2-year and 10-year peak discharges (Chapter 8) and the water quality volume for the contributing drainage area.

6. Approximate the geometry of the grassed swale and evaluate water quality parameters: water quality depth of flow (recommended maximum of 4 inches), and storage volume behind check dams (water quality volume). Adjust swale geometry and re-evaluate as needed.
7. Evaluate the grassed swale geometry for the 2-year design storm peak discharge velocity (4 feet per second), and capacity (check dam overflow), and the 10-year design storm peak discharge velocity (7 feet per second) and capacity (6 inches of freeboard). Adjust swale geometry and re-evaluate as needed.
8. Establish specifications for appropriate permanent vegetation on the bottom and side slopes of the grassed swale.
9. Establish specifications for sediment control.
10. Establish construction sequence and construction specifications.
11. Establish maintenance and inspection requirements

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Grass Swale. Note stone check dam in front of inlet creates shallow ponding area to encourage infiltration and settling.



Grass Swale through residential area. Note flat slope to encourage infiltration – ponding water gone within hours of runoff producing event.



Grass Swale with Check Dams. Note significant channel storage capacity created by check dams. Notched center allows safe overflow without scour around sides.

MINIMUM STANDARD 14.08

BIORETENTION BASIN PRACTICES



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MINIMUM STANDARD 14.08

BIORETENTION BASINS

Definition

Bioretention is an innovative BMP developed by the Prince George's County, Maryland Department of Environmental protection. The following information is drawn from their Design Manual for Use of Bioretention in Stormwater Management (P.G. County, 1993) unless otherwise noted. This technology is also referred to as "Rain Gardens."

Figure 14.08-1 illustrates the Maryland bioretention (Rain Garden) concept as adapted for use in Owensboro. There are seven major components to the bioretention area (Rain Garden): 1) the grass buffer strip; 2) the ponding area; 3) the surface mulch and planting soil; 4) the sand bed (optional); 5) the organic layer; 6) the plant material, and 7) the infiltration chambers. Each component is critical to sustaining a properly functioning BMP.

Purpose

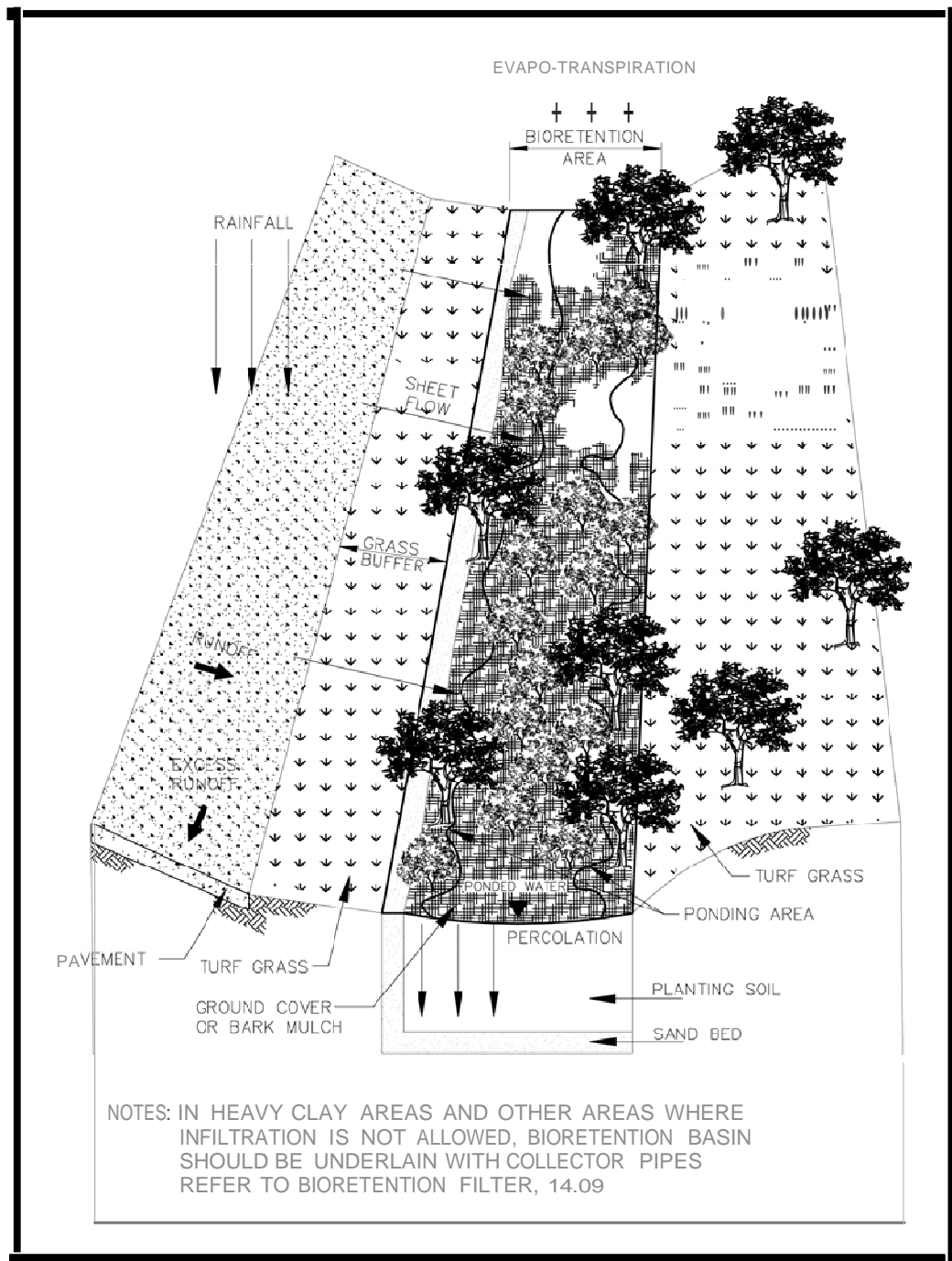
Bioretention basins are used primarily for water quality control. However, since they capture and infiltrate part of the stormwater from the drainage shed, they may provide partial or complete control of streambank erosion and partial protection from flooding (depending on the volume of water being captured and infiltrated).

Bioretention facilities (Rain Gardens) are planting areas installed in shallow basins in which the stormwater runoff is treated by filtering through the bed components, biological and biochemical reactions within the soil matrix and around the root zones of the plants, and infiltration into the underlying soil strata. Properly constructed bioretention areas replicate the ecosystem of an upland forest floor through the use of specific shrubs, trees, ground covers, mulches and deep, rich soils. Since almost all bioretention basins are intended to be visual landscape amenities as well as stormwater BMPs, aesthetic considerations may be equally as important in their use as proper engineering. Bioretention design requires participation by a person with appropriate design skills and a working knowledge of indigenous horticultural practices, preferably a Landscape Architect.

Water Quality Enhancement

Bioretention basins enhance the quality of stormwater runoff through the processes of adsorption, filtration, volatilization, ion exchange, microbial and decomposition prior to exfiltration into the surrounding soil mass. Microbial soil processes, evapotranspiration, and nutrient uptake in plants also come into play (Bitter and Bowers, 1995).

FIGURE 14.08-1
Bioretention Basin



The grass buffer strip filters particles from the runoff and reduces its velocity. The sand bed further slows the velocity of the runoff, spreads the runoff over the basin, filters part of the water, provides for positive drainage to prevent anaerobic conditions in the planting soil and enhances exfiltration from the basin. The ponding area functions as storage of runoff awaiting treatment and as a presettling basin for particulates that have not been filtered out by the grass buffer. The organic or mulch layer acts as a filter for pollutants in the runoff, protects the soil from eroding, and provides an environment for microorganisms to degrade petroleum-based solvents and other pollutants. The planting soil layer nurtures the plants with stored water and nutrients. Clay particles in the soil adsorb heavy metals, nutrients, hydrocarbons, and other pollutants. The plant species are selected based on their documented ability to cycle and assimilate nutrients, pollutants, and metals through the interactions among plants, soil, and the organic layer (ibid). By providing a variety of plants, monoculture susceptibilities to insect and disease infestation are avoided, and evapotranspiration is enhanced. The vented infiltration chambers provide unobstructed exfiltration through the open-bottomed cavities, decrease the ponding time above the basin, and aerate the filter media between storms through the open chamber cavities and vents to grade, preventing the development of anaerobic conditions. By providing a valve equipped drawdown drain to daylight, the basin can be converted into a soil media filter should exfiltration surface failures occur.

Perforated underdrain systems are recommended for facilities placed in residential areas and in all areas where the in-situ soils are questionable. Refer to 14.09A - Bioretention Filter.

The minimum width for a bioretention area is usually 10 feet, although widths as narrow as 4 feet may be used if the runoff arrives as dispersed sheet flow along the length of the facility from a properly sized vegetated strip. The minimum length should be 15 feet (for lengths greater than 20 feet, the length should be at least twice the width to allow dispersed sheet flow). As an infiltration BMP, the maximum ponding depth is restricted to six inches to restrict maximum ponding time to preclude development of anaerobic conditions in the planting soil (which will kill the plants) and to prevent the breeding of mosquitoes and other undesirable insects in the ponded water. The planting soil must have sufficient depth to provide appropriate moisture capacity, create space for the root systems, and provide resistance from windthrow (Minimum depth equal to the diameter of the largest plant root ball plus 4 inches).

Table 14.08-1 contains the target removal efficiencies once a mature plant community is created in the bioretention areas based on the volume of runoff to be captured and infiltrated.

Flood Control and Channel Erosion

The amount of flood and channel erosion control provided by bioretention basins depends on the local rainfall frequency spectrum, the amount of pre-development (or pre-redevelopment) impervious cover, the amount of post-development impervious cover, and the volume of runoff captured and infiltrated by the basin(s). The effect of the BMPs on peak flow rates from the drainage shed must be examined. As with other infiltration practices, bioretention basins tend to reverse the consequences of urban development by reducing peak flow rates and providing groundwater discharge.

TABLE 14.08-1
Pollutant Removal Efficiencies for Bioretention Basins

Conditions Where Practice Applies

Bioretention basins are suitable for use on any project where the subsoil is sufficiently permeable to provide a reasonable rate of infiltration and where the water table is sufficiently lower than the design depth of the facility to prevent pollution of the groundwater. Bioretention basins are generally suited for almost all types of development, from single-family residential to fairly high density commercial projects. They are attractive for higher density projects because of their relatively high removal efficiency. Figures 14.08-2 through 14.08-5 illustrate several applications. Bioretention basins may also be installed in off-line pockets along the drainage swales adjacent to highways or other linear projects, as illustrated in Figure 14.08-6. For large applications, several bioretention basins are preferable to a single, massive basin.

FIGURE 14.08-2
Bioretention Basin at Edge of Parking Lot With Curb

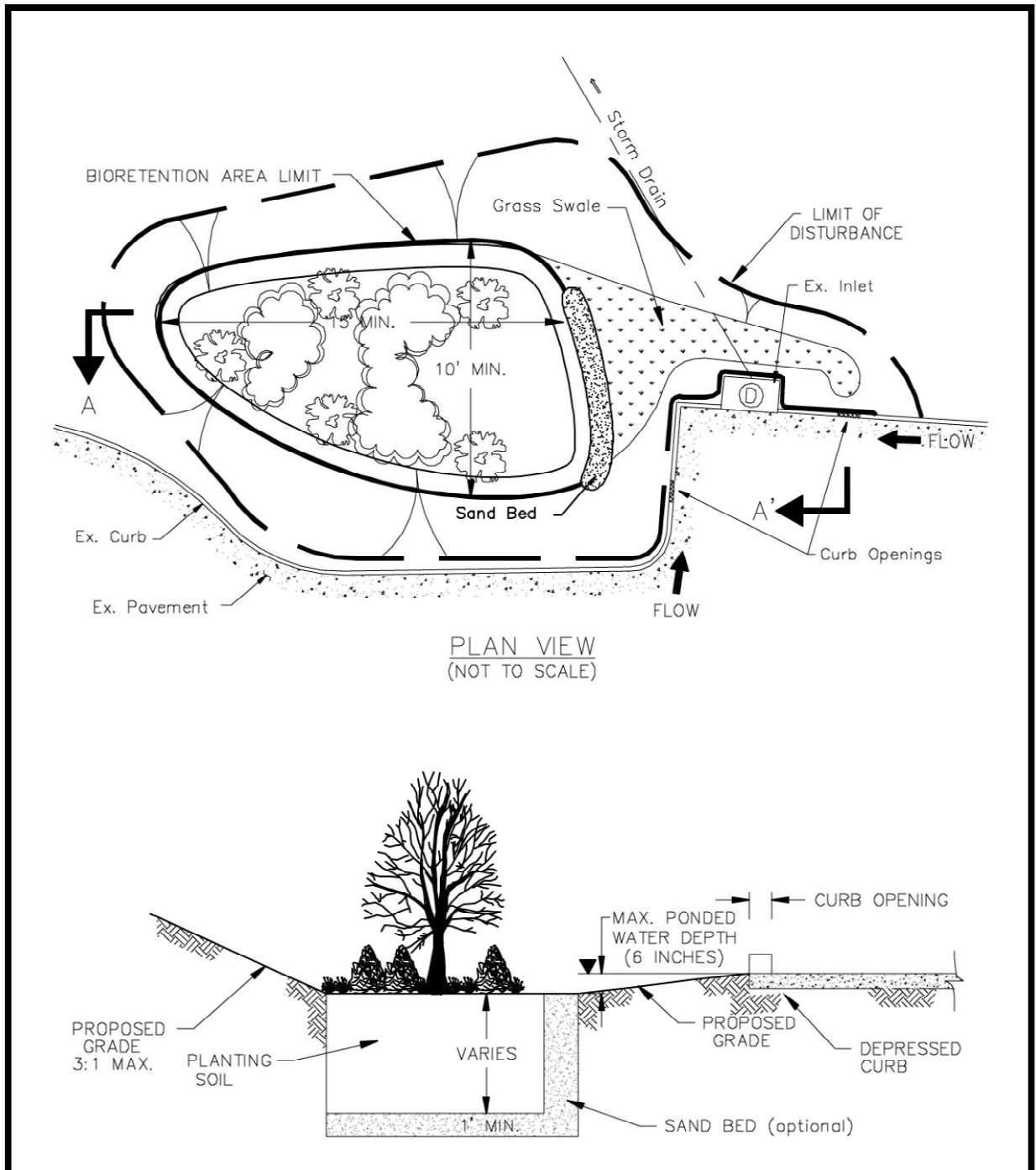


FIGURE 14.08-3
Bioretention Basin in a Planting Island in a Parking Lot

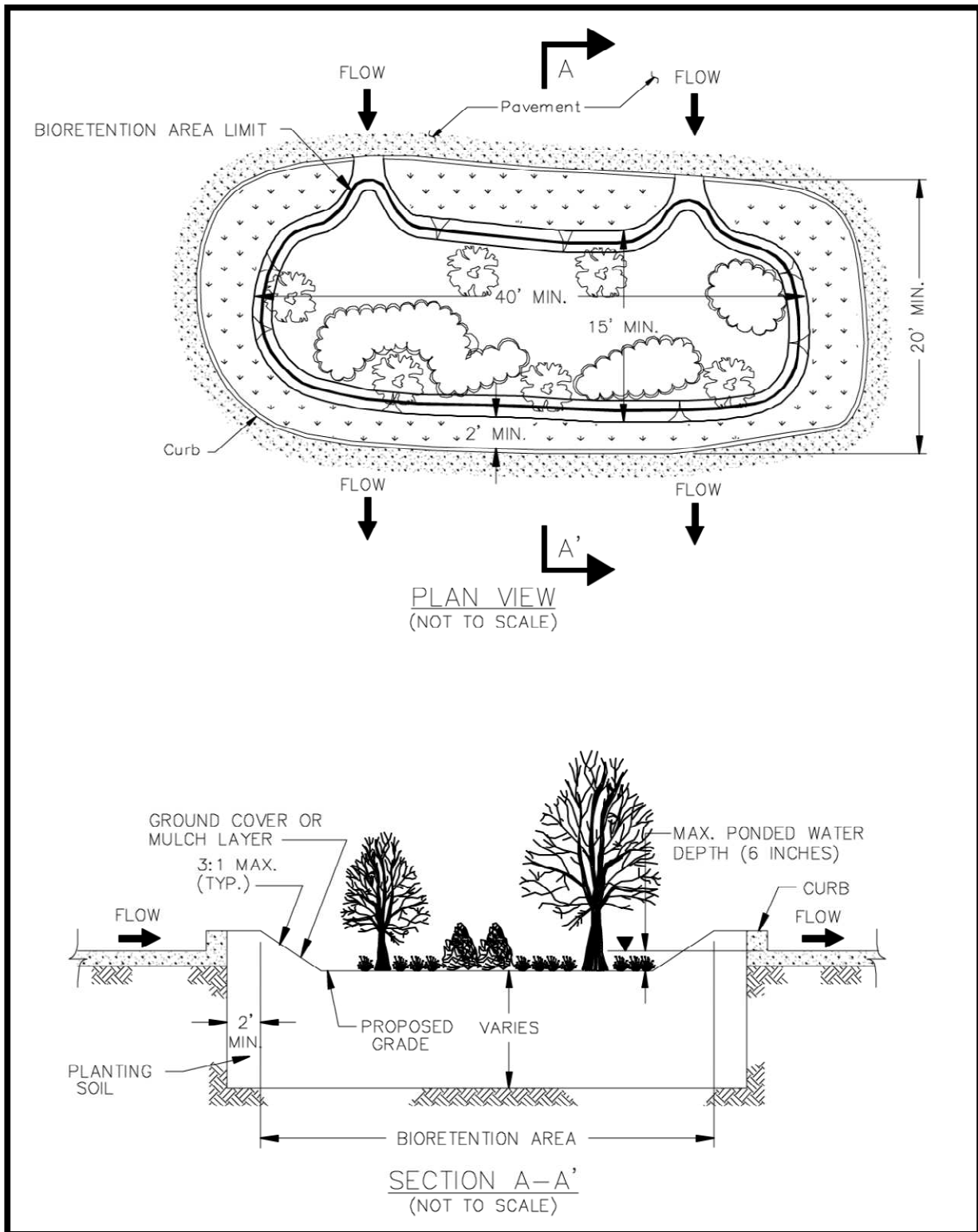


FIGURE 14.08-4
Bioretention Basin Adjacent to a Drainage Swale

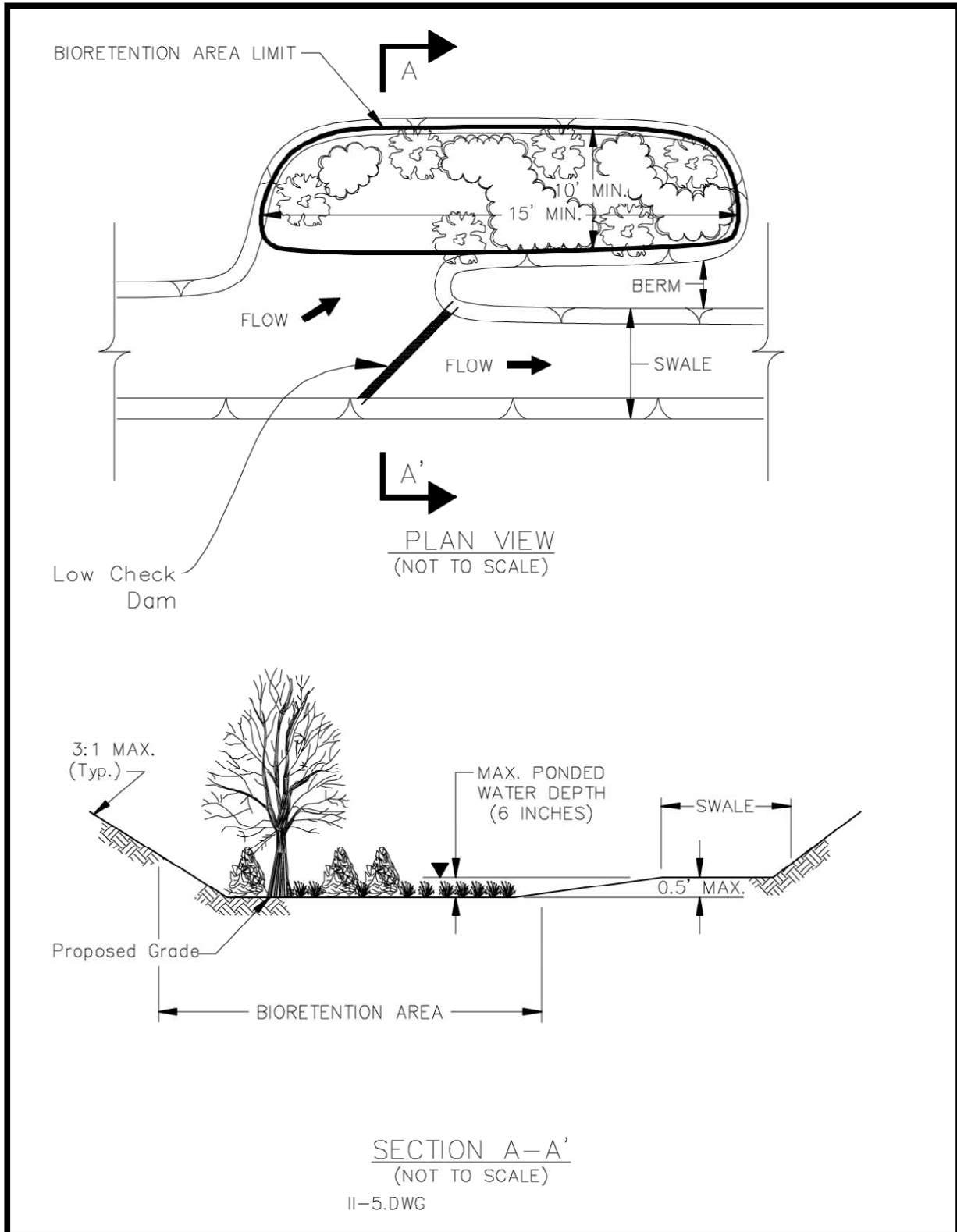
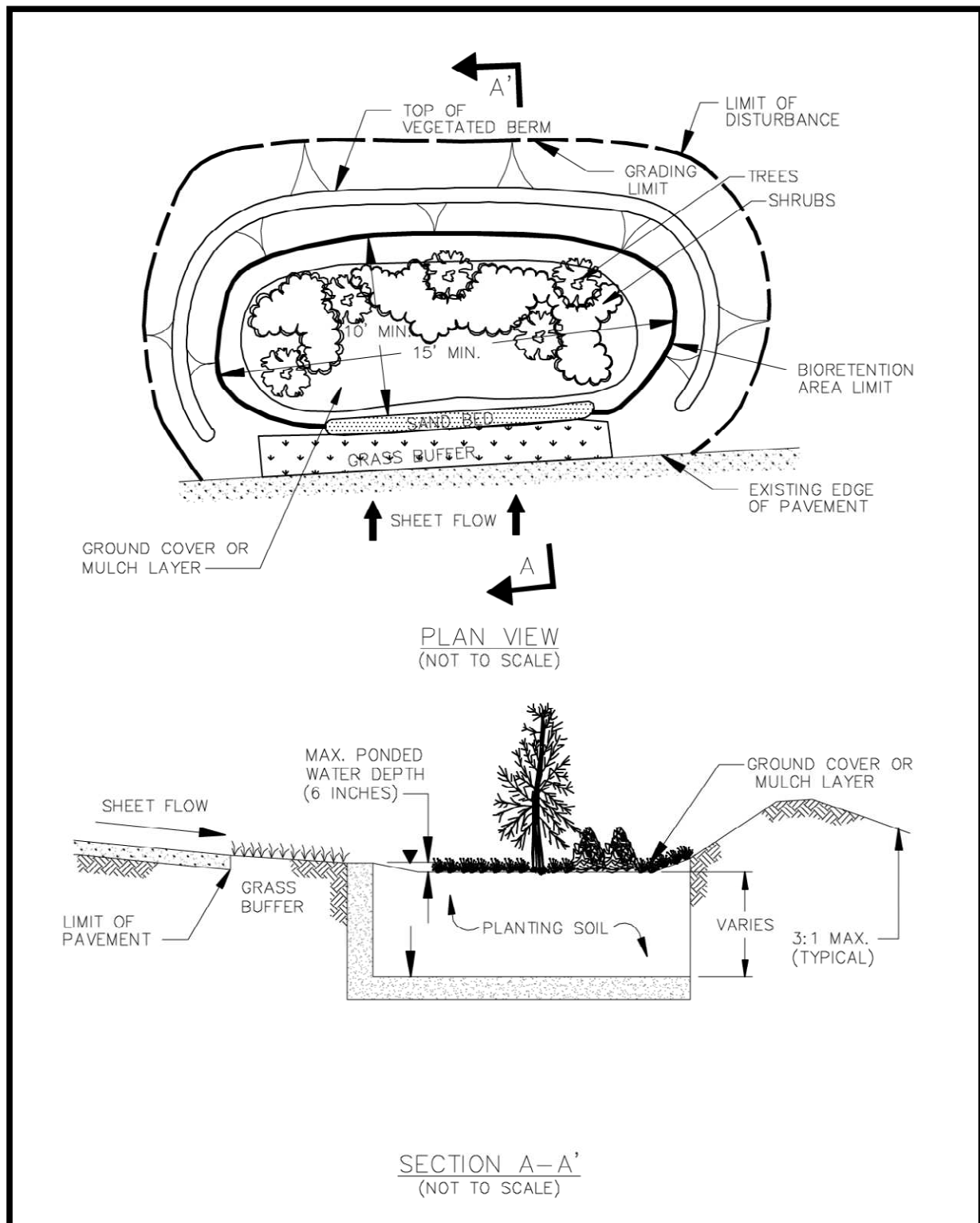


FIGURE 14.08-5
Bioretention Basin at Edge of Parking Lot Without Curbs



Planning Considerations

Site Conditions

In addition to site conditions affecting infiltration practices in general, the following apply specifically to bioretention basins. The application of individual bioretention basins will usually be limited to drainage areas from 0.25 to 1 acre. Generally, commercial or residential drainage areas exceeding 1 acre in size will discharge sheet flows greater than 5 cfs.

1. Location Guidelines

Preferable locations for bioretention basins include 1) areas upland from inlets or outfalls that receive sheet flow from graded areas, and 2) areas of the site that will be excavated or cut. When available, areas of loamy sand soils should be used since these types of soils comprise the planting soils for bioretention basins. Locating the BMP in such natural locations would eliminate the cost of importing planting soils (see soil and organic specification under Design Considerations). BMP location should be integral with preliminary planning studies.

The following areas would be undesirable for bioretention basins: 1) areas that have mature trees which would have to be removed for construction of the bioretention basin, 2) areas that have existing slopes of 20% or greater, and 3) areas above or in close proximity to an unstable soil strata such as marine clay.

2. Sizing Guidelines

For planning purposes, assume that the floor area of the bioretention basin will be a minimum of 2.5% of the impervious area draining to the basin if the first 0.64 inches of runoff is to be treated and a minimum of 4.0% of the impervious area on the drainage shed if the first 1.0 inches of runoff is to be treated. Derivation of these values is discussed below under Design Considerations. Note that small projects such as single family residences will likely default to the minimum 150 square foot area (10' X 15').

3. Aesthetic Considerations

Aesthetic considerations of the bioretention basin must be considered early in the site planning process. While topography and hydraulic considerations may dictate the general placement of such facilities, overall aesthetics of the site and the bioretention basins must be integrated into the site plan and stormwater concept plan from their inception. Both the stormwater engineer and the Landscape Architect must participate during the layout of facilities and infrastructure to be placed on the site. Bioretention design must be an integral part of the site planning process

Sediment Control

Like other infiltration practices, provisions for long-term sediment control must be incorporated into the design, as well as precautions during on-site construction activities. Careful consideration must be given in advance of construction to the effects of work sequencing, techniques, and equipment employed on the future maintenance of the practice. Serious maintenance problems can be averted, or in large part, mitigated, by the adoption of relatively simple measures during construction.

1. Construction Runoff

Bioretention basin BMPs should be constructed AFTER the site work is complete and stabilization measures have been implemented. If this is not possible, strict implementation of E&S protective measures must be installed and maintained in order to protect the bioretention facility from premature clogging and failure.

Like other infiltration BMPs, bioretention basins constructed prior to full site stabilization will become choked with sediment from upland construction operations, rendering them inoperable from the outset. Simply providing inlet protection or some other filtering mechanism during construction will not adequately control the sediment. One large storm may completely clog the bioretention basin, requiring complete reconstruction.

Experience with infiltration practices has also demonstrated that the bioretention basin site should NOT be used as the site of sedimentation basins during construction. Such use tends to clog the underlying strata and diminish their capacity to accept infiltration below that indicated in preconstruction soil studies.

Bioretention basins are landscape amenities and should be installed with other landscaping as the last stage of project construction.

A detailed sediment control design to protect the bioretention basin during its construction should be included with the facility design..

Experience with bioretention basins in Maryland has demonstrated that they must be protected until the drainage areas contributing to the practice have been adequately stabilized (P.G. Co., 1993).

The definition of the term “adequately stabilized” is critical to the success of the facility. At the conclusion of construction activity, the temporary erosion and sediment control measures are usually removed at the direction of the erosion and sediment control inspector when, at a minimum,

stabilization measures such as seed and mulch are in place. This does not mean, however, that stabilization has actually occurred. Bioretention basins must be protected until stabilization of the upland site is functioning to control the sediment load from denuded areas. Provisions to bypass the stormwater away from the bioretention basin during the stabilization period should be implemented.

2. Urban Runoff

A fully stabilized site will generate particulate pollutant load resulting from natural erosion, lawn and garden debris such as leaves, grass clippings, mulch, roadway sand, etc. Pretreatment of runoff to remove sediments prior to entering the bioretention basin is usually provided by a grass filter strip or grass channel. When runoff from sheet flow from such areas as parking lots, residential yards, etc., is involved, a grass filter strip, often enhanced with a pea gravel diaphragm, is usually employed. Table 14.08-1 provides sizing guidelines as a function of inflow approach length, land use, and slope. The minimum filter strip length (flow path) should be 10 feet.

TABLE 14.08-1
Pretreatment Filter Strip Sizing Guidance
(Source: Claytor and Schueler, 1996)

Parameter	Impervious Parking Lots				Residential Lawns				Notes
Maximum Inflow Approach Length (feet)	35		75		75		150		
Filter Strip Slope	≤ 2%	≥2%	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	
Filter Strip Minimum Length	10'	15'	20'	25'	10'	12'	15'	18'	

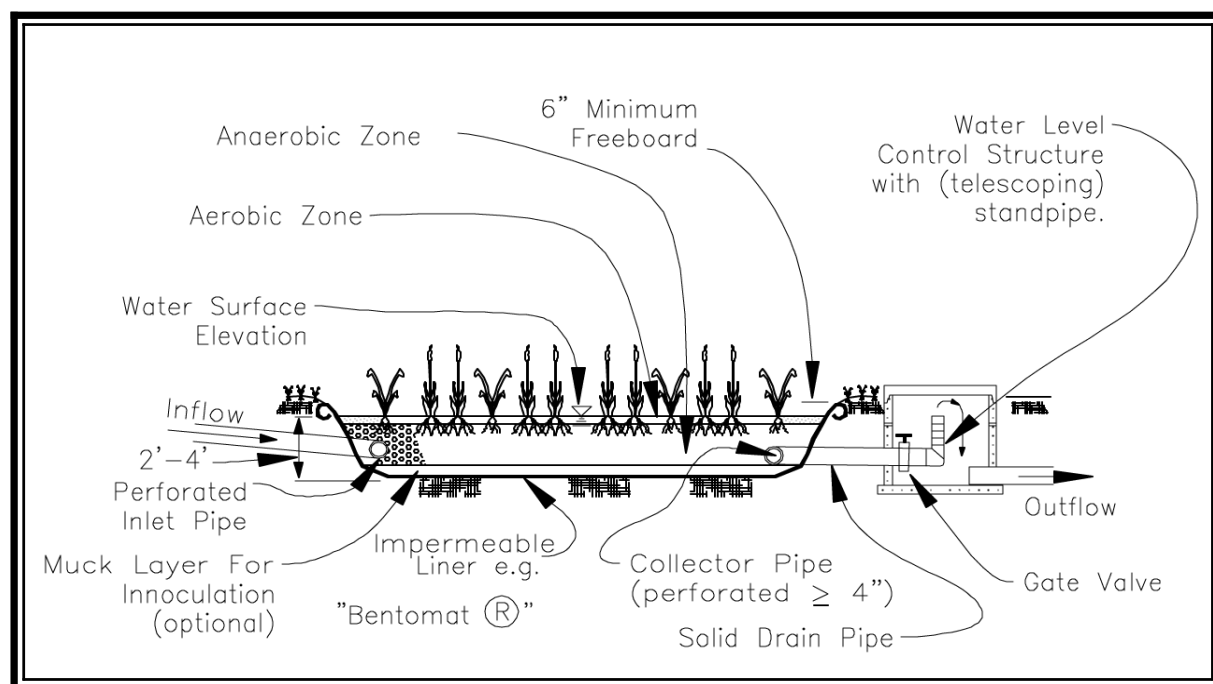
For applications where concentrated runoff enters the bioretention basin by surface flow, such as through a slotted curb opening, a grassed channel, often equipped with a pea gravel diaphragm to slow the velocity and spread out the flow entering the basin, is the usual pretreatment method. The length of the grassed channel depends on the drainage area, land use, and channel slope. Table 14.08-1 provides recommendations on sizing for grass channels leading into a bioretention basin for a one acre drainage area. The minimum grassed channel length should be 20 feet.

“Grassed filter strips, grassed channels, and side-slopes of the basin should be sodded with mature sod prior to placement of the bioretention basin into operation. Simply seeding these areas will likely result in conveyance of sediments into the basin and premature failure. Wrapping of the planting soil mixture up the side slopes beneath the sod is also recommended.”

TABLE 14.08-2
Pretreatment Grass Channel Sizing Guidance for a 1.0-Acre Drainage Area
(Source: Claytor and Schueler, 1996)

Parameter	≤ 33% Impervious		Between 34% and 66% Impervious		≥ 67% Impervious		Notes
Slope	≤2%	≥2%	≤2%	≥2%	≤2%	≥2%	Maximum slope = 4%
Grassed channel minimum length (feet)	25	40	30	45	35	50	Assumes a 2' wide bottom width

FIGURE 14.08-6
Upflow Inlet for Bioretention Basin
(Source: City of Alexandria)



When concentrated piped flow from impervious areas such as parking lots is routed to a bioretention basin, an energy absorbing and sedimentation structure in which the flow rises into the basin like a tide is usually advisable. Since sediments must usually be removed from such structures on a regular basis, they must be placed in locations where the extension booms on vacuum trucks may easily reach them. Figure 14.08-6 illustrates an upflow inlet structure for a bioretention basin. Maintenance requirements for pretreatment measures are discussed Maintenance/Inspection Guidelines.

General Design Criteria

The purpose of this section is to provide minimum criteria for the design of bioretention basin BMPs intended to comply with the Owensboro / Davies County Stormwater program's runoff quality requirements. Bioretention basins which capture and infiltrate the first 1 inch of runoff from impervious surfaces may also provide streambank erosion protection.

General

The design of bioretention basins should be in accordance with the OMPC Public Improvement Specifications as applicable as well as the additional criteria set forth below. The designer is not only responsible for selecting the appropriate components for the particular design but also for ensuring long-term operation.

Soils Investigation

As with infiltration basins (MS14.01), a minimum of one soil boring log should be required for each 5,000 square feet of bioretention basin area (plan view area) and in no case less than three soil boring logs per basin.

Topographic Conditions

Like other infiltration facilities, bioretention basins should be a minimum of 50 feet from any slope greater than 15 percent. A geotechnical report should address the impact of the basin upon the steep slope (especially in marine clay areas). Also, bioretention basins should be a minimum of 100 feet up-slope and 20 feet downslope from any buildings.

Basin Sizing Methodology

Bioretention basins are designed to exfiltrate the treatment quantity into the underlying soil strata, or into an underlying perforated underdrain system connected to a storm drain system or other outfall when the underlying soils, proximity to building foundation, or other such restrictions preclude the use of infiltration. When such an underdrain system is used, the facility is referred to as a Bioretention Filter - Minimum Standard 14.09.

Recent research at the University of Maryland has supported a reduction in overall depth of the planting soil to 2.5 feet. Generally, the soil depth can be designed to a minimum depth equal to the diameter of the largest plant root ball plus 4 inches. The recommended soil composition was revised to reduce the clay and increase the sand content (Refer to Soil Texture and Structure later in this standard). This revised soil composition also eliminated the 12" sand layer at the bottom of the facility. The researchers concluded that significant pollutant reductions are achieved in the mulch layer and the first 2 to 2.5 feet of soil.

The elevation of the overflow structure should be 0.5 feet above the mulch layer of the bioretention bed. When an underdrain system is used (Min. Std. 14.09), the overflow can be as much as 1.0 feet above the mulch layer.

The size of the bioretention facility is dictated by the amount of impervious surface in the contributing drainage area. For facilities capturing the first 0.64 inches of runoff from the impervious areas in the drainage shed, the surface area of the bioretention bed should be a minimum of 3% of the impervious area, or 1,300 square feet per impervious acre.

The minimum width and length is recommended at 10 feet and 15 feet respectively. (Widths as narrow as 4 feet may be used if the runoff arrives as dispersed sheet flow along the length of the facility from a properly sized vegetated strip).

The elevation of the overflow structure should be 0.5 feet above the mulch elevation of the bioretention bed.

Note that small projects such as single family residences may default to the minimum (10' x 15') 150 square foot area.

Runoff Pretreatment

Like other infiltration basins, bioretention basins must always be preceded by a pretreatment facility to remove grease, oil, floatable organic material, and settleable solids (see Urban Runoff section of Sediment Control under Planning Considerations above). Where space constraints allow, runoff should be filtered by a grass buffer strip and sand bed. The buffer strip and sand bed will reduce the amount of fine material entering the bioretention area and minimize the potential for clogging of the planting soil. The sand bed also increases the infiltration capacity and provides aeration for the plant roots in the bioretention area. For basins for which high sediment loadings are expected (treating largely pervious areas, etc.), the design can be modified to include a sediment forebay. Any pretreatment facility should be included in the design of the basin and should include maintenance and inspection requirements.

Drainage Considerations

The grading design must shape the site so that all runoff from impervious areas is routed through the bioretention basins. The basins must be sited so as to accept the design runoff quantity before bypassing any excess flow to the storm drainage system. Bioretention basin locations must therefore be integrated into the basic site design from its inception. Most of the Planning Considerations delineated above must come into play at this early stage in the design process. The overall site and impervious surfaces must be contoured to direct the runoff to the basins. Bioretention basins cannot usually be successfully integrated into a site design that does not take stormwater management into account from its inception. Elevations must be carefully worked out to assure that the desired amount runoff will flow into the basins and pool at no more than the maximum design depth. This requires a much higher degree of vertical control during construction that is normal with most landscaping work.

Preferably, bioretention basins should be placed “off-line,” i.e. the design should provide for runoff to be diverted into the basin until it fills with the treatment volume and then bypass the remaining flow around the BMP to the storm drainage system. The drainage system shall be designed to handle the 10-year, 24 hour storm). To prevent flood damage, however, the bioretention basin design must take into account how the runoff will be processed when larger events occur. This may require, at a minimum, that a vegetated emergency spillway be provided, and that a path for overland flow to an acceptable channel be incorporated into the design. The designer should provide for relief from the 25-year storm event.

Figure 14.08-2 illustrates an “off-line” application at the edge of a parking lot with curb and gutter. The inlet deflectors divert runoff into the bioretention basin until the basin fills and backs up. Subsequent runoff then bypasses to the adjacent, down gradient storm inlet. Figure 14.08-3 illustrates an “off-line” application in a planting island in a parking lot, while Figure 14.08-4 illustrates an “off-line” application adjacent to a drainage swale (such highway drainage). Again, runoff flows into the bioretention basin until it fills, then bypasses down the swale. Placement of a flow diversion check dam in the swale will facilitate filling the basin. In some situations, an “off-line” configuration may not be practical or economical. Figure 14.08-1 and 14.08-5 illustrate applications where sheet flow enters the bioretention basin.

Figure 14.08-7 illustrates a grading plan for a bioretention basin. The grading plan was created for a double-cell bioretention area. There is a seven-foot buffer between cells which allow for the planting of upland trees. As indicated in the grading plan, sheet and gutter flow is diverted into the bioretention areas through openings in the curb. The elevation of the invert of the bioretention area is set by the curb opening elevation. The curb opening elevation is 0.5 ft. higher than the invert of the bioretention area, so water is allowed to pond to a maximum depth of one-half foot before runoff bypasses the bioretention area and flows into the storm drain system.

Precise grading of the basin is critical to capturing the water quality volume and operation of the facility. The plan should have a contour interval of no more than one-foot, and spot elevations should be shown throughout the basin. The perimeter contour elevation should contain the design storm without over topping anywhere except at the outflow structure.

Planting Plan

Selection of plantings must include coordination with overall site planning and aesthetic considerations for designing the bioretention plant community. Tables listing suitable species of trees, shrubs, and ground cover are provided at the end of this section. This listing is not intended to be all-inclusive due to the continual introduction of new horticultural varieties and species in the nursery industry.

1. Planting Concept

The use of plantings in bioretention areas is modeled from the properties of a terrestrial forest community ecosystem. The terrestrial forest community ecosystem is an upland community dominated by trees, typically with a mature canopy, having a distinct sub-canopy of understory trees, a shrub layer, and herbaceous layer. In addition, the terrestrial forest ecosystem typically has a well-

developed soil horizon with an organic layer and a mesic moisture regime. A terrestrial forest community model for stormwater management was selected based upon a forest's documented ability to cycle and assimilate nutrients, pollutants, and metals through the interactions among plants, soil, and the organic layer. These three elements are the major elements of the bioretention concept.

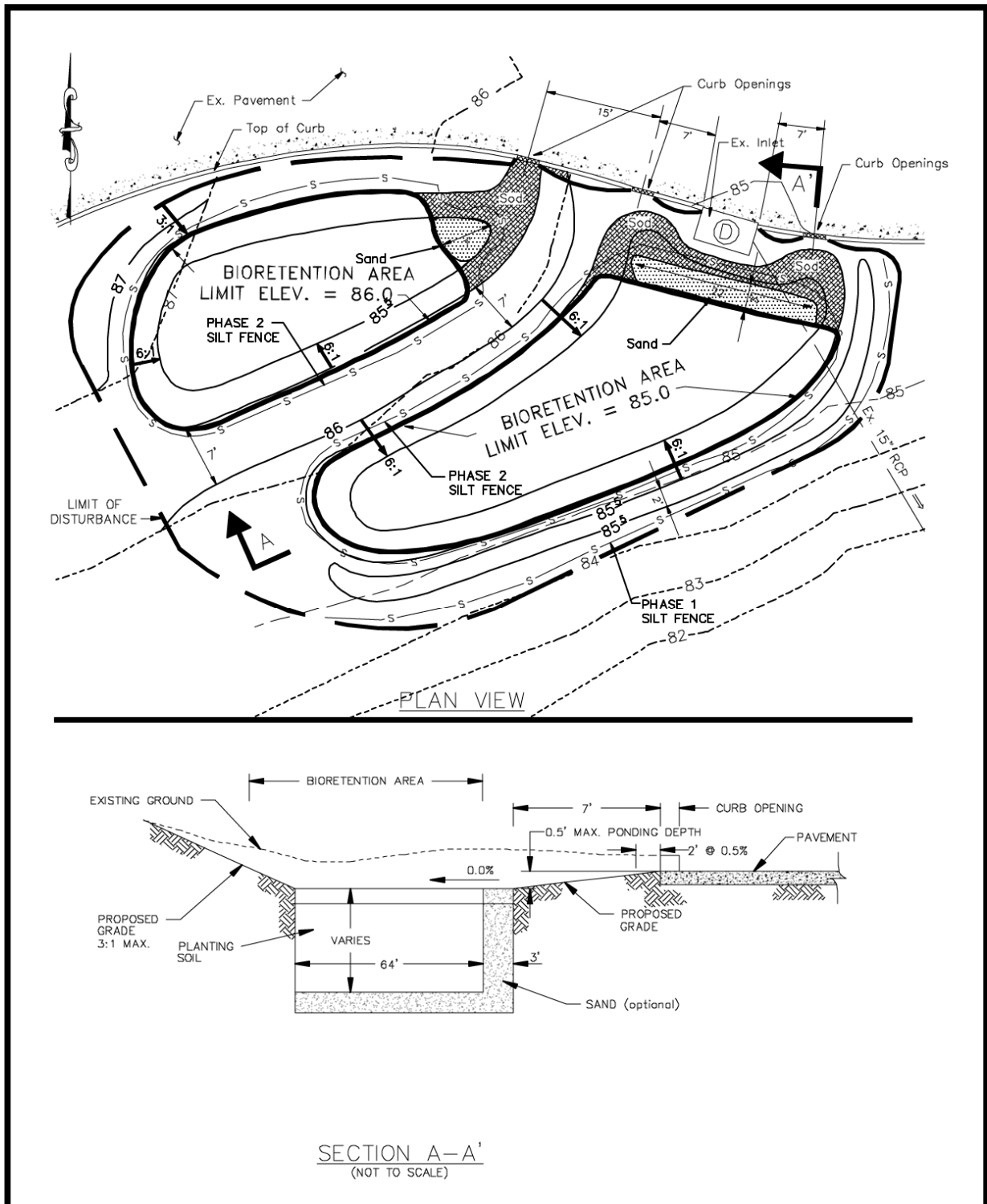
Key elements of the terrestrial forest ecosystem that have been incorporated into bioretention design include species diversity, density, and morphology, and use of native plant species. Species diversity protects the system against collapse from insect and disease infestations and other urban stresses such as temperature and exposure. Typically, indigenous plant species demonstrate a greater ability of adapting and tolerating physical, climatic, and biological stresses.

2. Plant Species Selection

Plant species appropriate for use in bioretention areas are presented in Tables 14.08-5A through 14.08-5C, provided at the end of this section. These species have been selected based on the ability to tolerate urban stresses such as pollutants, variable soil moisture and ponding fluctuations. Important design considerations such as form, character, massing, texture, culture, growth habits/rates, maintenance requirements, hardiness, size, and type of root system are also included. A key factor in designating a species as suitable is its ability to tolerate the soil moisture regime and ponding fluctuations associated with bioretention. The plant indicator status (Reed, 1988) of listed species are predominantly facultative (i.e., they are adapted to stresses associated with both wet and dry conditions); however, facultative upland and wetland species have also been included. This is important because plants in bioretention areas will be exposed to varying levels of soil moisture and ponding throughout the year, ranging from high levels in the spring to potential drought conditions in the summer.

Recent research suggests an increase in the importance of the mulch layer and groundcover plant species in pollutant removal. The plant list in this standard will be expanded to include perennial flowering plants. A robust groundcover species with a thick mulch layer is recommended.

FIGURE 14.08 – 7
Grading Plan for Bioretention Basin



Designers considering species other than ones listed in Tables 14.08-5A - 14.08-5C should consult the following reference material on plant habitat requirements, and consider site conditions to ensure that alternative plant material will survive.

American Association of Nurserymen, Latest Edition. American Standard for Nursery Stock ASNI Z60, Washington, D.C.

Dirr, Michael A., 1975. Manual of Woody Landscape Plants, Stripes Publishing Company, Champagne, Illinois.

Hightshoe, G.L., 1988. Native Trees, Shrubs, and Vines for Urban and Rural America. Van Nostrand Reinhold, New York, New York.

Reed, P.B.Jr., 1988. National List of Species That Occur in Wetlands: Northeast. United States Fish and Wildlife Service, St. Petersburg Florida.

Reasons for exclusion of certain plants from bioretention areas include inability to meet the criteria outlined in Tables 14.08-5A - 14.08-5C (pollutant and metals tolerance, soil moisture and structure, ponding fluctuations, morphology, etc.).

3. Site and Ecological Considerations

Each site is unique and may contain factors that should be considered before selecting plant species. An example Plant Material Checklist is provided in Appendix 3E. The checklist has been developed to assist the designer in identifying critical factors about a site that may affect both the plant material layout and the species selection.

Selection of plant species should also be based on site conditions and ecological factors. Site considerations include microclimate (light, temperature, wind), the importance of aesthetics, overall site development design and the extent of maintenance requirements, and proposed or existing buildings. Of particular concern is the increase in reflection of solar radiation from buildings upon bioretention areas. Aesthetics are critical in projects of high visibility. Species that require regular maintenance (shed fruit or are prone to storm damage) should be restricted to areas of limited visibility and pedestrian and vehicular traffic.

Interactions with adjacent plant communities are also critical. Nearby existing vegetated areas dominated by non-native invasive species pose a threat to adjacent bioretention areas. Proposed bioretention area species should be evaluated for compatibility with adjacent plant communities. Invasive species typically develop into monocultures by out competing other species. Mechanisms to avoid encroachment of undesirable species include increased maintenance, providing a soil breach between the invasive community for those species that spread through rhizomes, and providing annual removal of seedlings from wind borne seed dispersal. Existing disease or insect infestations associated with existing site conditions or in the general area that may effect the bioretention plantings.

4. Number of Species

A minimum of three species of trees and three species of shrubs should be selected to insure diversity. In addition to reducing the potential for monoculture mortality concerns, a diversity of trees and shrubs with differing rates of transpiration may ensure a more constant rate of evapotranspiration and nutrient and pollutant uptake throughout the growing season.

Herbaceous ground covers are important to prevent erosion of the mulch and the soil layers. Suitable herbaceous ground covers are identified in Table 14.08-5C.

5. Number and Size of Plants

The requisite number of plantings varies, and should be determined on an individual site basis. On average, 1000 trees and shrubs should be planted per acre. For example, a bioretention area measuring 15' x 40' would contain a combination of trees and shrubs totaling 14 individuals. The Prince Georges County recommended minimum and maximum number of individual plants and spacing are given in Table 14.08-3. Two to three shrubs should be specified for each tree (2:1 to 3:1 ratio of shrubs to trees).

At installation, trees should be 1.0 inches minimum in caliper, and shrubs 3 to 4 feet in height or 18 to 24 inches in spread per ASNI Z60. Ground cover may be as seed or, preferably, plugs. The relatively mature size requirements for trees and shrubs are important to ensure that the installation of plants are readily contributing to the bioretention process (i.e., evapotranspiration, pollutant uptake).

TABLE 14.08-3
Recommended Tree and Shrub Spacing

	Tree Spacing (feet)	Shrub Spacing (feet)	Total Density (stems/acre)
Maximum	19	12	400
Average	12	8	1000
Minimum	11	7	1250

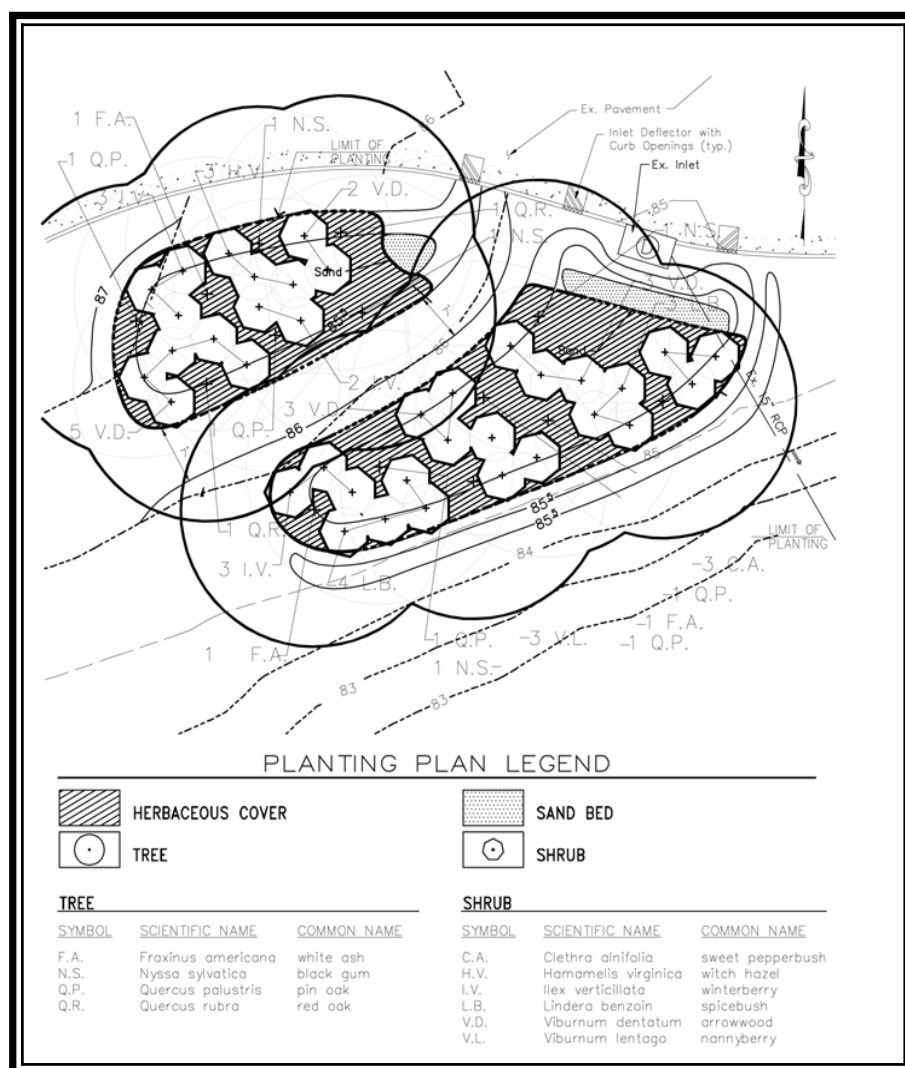
6. Plant Layout

The layout of plant material can be a flexible process; however, the designer should follow some basic guidelines. As discussed above, the designer should first review the Plant Checklist (Appendix D). The checklist table can help expose any constraints that may limit the use of a particular species and/or where a species can be installed.

There are two guidelines that should apply to all bioretention areas. First, woody plant material should not be placed within the immediate areas of where flow will be entering the bioretention area.

Besides possibly concentrating flows, trees and shrubs can be damaged as a result of the flow. Secondly, it is recommended that trees be planted primarily on the perimeter of bioretention areas, to maximize the shading and sheltering of bioretention areas to create a microclimate which will limit the extreme exposure from summer solar radiation and winter freezes and winds. An example planting plan is shown in Figure 14.08-8.

FIGURE 14.08 - 8
Sample Planting Plan



Mulch Layer Guidelines

A mulch layer serves to prevent erosion and to protect the soil from excessive drying. Soil biota existing within the organic and soil layer are important in the filtering of nutrients and pollutants and assisting in maintaining soil fertility. Bioretention areas can be designed either with or without a mulch layer. If a herbaceous layer or ground cover (70 to 80% coverage) is provided, a mulch layer is not necessary. Areas should be mulched once trees and shrubs have been planted.

Any ground cover specified as plugs may be installed once mulch has been applied.

The mulch layer recommended for bioretention may consist of either a standard landscape fine shredded hardwood mulch or shredded hardwood chips. Both types of mulch are commercially available and provide excellent protection from erosion.

Mulch shall be free of weed seeds, soil, roots, or any other substance not consisting of either bole or branch wood and bark. The mulch shall be uniformly applied approximately 2 to 3 inches in depth. Mulch applied any deeper than three inches reduces proper oxygen and carbon dioxide cycling between the soil and the atmosphere.

Grass clippings are unsuitable for mulch, primarily due to the excessive quantities of nitrogen built up in the material. Adding large sources of nitrogen would limit the capability of bioretention areas to filter the nitrogen associated with runoff.

Plant Material Guidelines

1. Plant Material Source

The plant material should conform to the current issue of the American Standard for Nursery Stock published by the American Association of Nurserymen. Plant material should be selected from certified nurseries that have been inspected by state or federal agencies. The botanical (scientific) name of the plant species should be in accordance with a standard nomenclature source such as Birr, 1975.

Some of the plant species listed in Tables 14.08-5A - 14.08-5C, Recommended Plant Species For Use in Bioretention may be unavailable from standard nursery sources. These are typically species native to Kentucky and may not be commonly used in standard practices. Designers may need to contact nurseries specializing in native plants propagation.

2. Installation

The success of bioretention areas is dependent on the proper installation specifications that are developed by the designer and subsequently followed by the contractor. The specifications include the procedures for installing the plants and the necessary steps taken before and after installation. Specifications designed for bioretention should include the following considerations:

- Sequence of Construction
- Contractors Responsibilities
- Planting Schedule and Specifications
- Maintenance
- Warranty

The sequence of construction describes site preparation activities such as grading, soil amendments, and any pre-planting structure installation. It also should address erosion and sediment control procedures. Erosion and sediment control practices should be in place until the entire bioretention area is completed. The contractors responsibilities should include all the specifications that directly effect the contractor in the performance of his or her work. The responsibilities include any

penalties for unnecessarily delayed work, requests for changes to the design or contract, and exclusions from the contract specifications such as vandalism to the site, etc.

The planting schedule and specifications include type of material to be installed (e.g., ball and burlap, bare root, or containerized material), timing of installation, and post installation procedures. Balled and burlapped and containerized trees and shrubs should be planted during the following periods: March 15 through June 30 and September 15 through November 15. Ground cover excluding grasses and legumes can follow tree and shrub planting dates. Grasses and legumes typically should be planted in the spring of the year. The planting of trees and shrubs should be performed by following the planting specifications set forth in the OMPC PI specifications that provide guidelines that ensure the proper placement and installation of plant material. Designers may choose to use other specifications or to modify the jurisdiction specifications. However, any deviations from the jurisdiction specifications need to address the following:

- transport of plant material
- preparation of the planting pit
- installation of plant material
- stabilization seeding (if applicable)
- maintenance

An example of general planting specification for trees and shrubs and ground cover is given under Construction Specifications below.

3. Warranties

Typically, a warranty is established as a part of any plant installation project. The warranty covers all components of the installation that the contractor is responsible for. The plant and mulch installation for bioretention should be performed by a professional landscape contractor. An example of standard guidelines for landscape contract work is provided below:

- The contractor shall maintain a one (1) calendar year 80% care and replacement warranty for all planting.
- The period of care and replacement shall begin after inspection and approval of the complete installation of all plants and continue for one calendar year.
- Plant replacements shall be in accordance with the maintenance schedule.

Plant Growth and Soil Fertility

A discussion of plant growth and soil fertility development over time is important to for estimating the success and lifespan of bioretention areas. The physical, chemical, and biological factors influencing plant growth and development will vary over time as well as for each bioretention area. However, there are certain plant and soil processes that will be the same for all bioretention areas.

1. Plant Growth

The role of plants in bioretention includes uptake of nutrients and pollutants and evapotranspiration of stormwater runoff. The plant material, especially ground covers, are expected to contribute to the evapotranspiration process within the first year of planting. However, trees and shrubs that have been recently planted demonstrate slower rates of growth for the first season due to the initial shock of transplanting. The relative rate of growth is expected to increase to normal rates after the second growth season.

The growth rate for plants in bioretention areas will follow a similar pattern to that of other tree and shrub plantings (reforestation projects, landscaping). For the first two years, the majority of tree and shrub growth occurs with the expansion of the plant root system. By the third or fourth year the growth of the stem and branch system dominates increasing the height and width of the plant. The comparative rate of growth between the root and stem and branch system remains relatively the same throughout the lifespan of the plant. The reproductive system (flowers, fruit) of the plants is initiated last.

The growth rates and time for ground covers to become acclimated to bioretention conditions is much faster than for trees and shrubs. The rate of growth of a typical ground cover can often exceed 100 percent in the first year. Ground covers are considered essentially mature after the first year of growth. The longevity of ground covers will be influenced by the soil fertility and chemistry as well as physical factors, such as shading and overcrowding from trees and shrubs and other ecological and physical factors.

Plants are expected to increase their contribution to the bioretention concept over time, assuming that growing conditions are suitable. The rate of plant growth is directly proportional to the environment in which the plant is established. Plants grown in optimal environments experience greater rates of growth. One of the primary factors determining this is soil fertility.

2. Soil Fertility

Initially, soil in bioretention areas will lack a mature soil profile. It is expected that over time discrete soil zones referred to as horizons will develop. The development of a soil profile and the individual horizons is determined by the influence of the surrounding environment including physical, chemical, and biological processes. Two primary processes important to horizon development is microbial action and the percolation of runoff in the soil.

Horizons expected to develop in bioretention areas include an organic layer, followed by two horizons where active leaching (eluviation) and accumulation (illuviation) of minerals and other substances occur. The time frame for the development of soil horizons will vary greatly. As an average, soil horizons may develop within three to ten years. The exception to this is the formation of the organic layer often within the first or second year (Brady, 1984).

The evaluation of soil fertility in bioretention may be more dependent on the soil interactions relative to plant growth than horizon development. The soil specified for bioretention is important in filtering pollutants and nutrients as well as supply plants with water, nutrients, and support. Unlike plants that will become increasingly beneficial over time, the soil will begin to filter the storm water runoff immediately. It is expected that the ability to filter pollutants and nutrients may

decrease over time, reducing the soil fertility accordingly. Substances from runoff such as salt and heavy metals eventually disrupt normal soil functions by lowering the cation exchange capacity (CEC). The CEC, the ability to allow for binding of particles by ion attraction, decreases to the point that the transfer of nutrients for plant uptake can not occur. However, the environmental factors influencing each bioretention area will vary enough that it is difficult to predict for the lifespan of soils. Findings from other stormwater management systems suggest an accumulation of substances eliminating soil fertility within five years. The monitoring of soil development in bioretention areas will help develop better predictions on soil fertility and development.

Construction Specifications

The construction of bioretention basins should be in accordance with the criteria set forth below. These specifications have been adapted from the Prince George's County, Maryland publication, Design Manual for Use of Bioretention in Stormwater Management.

Sequence of Construction

The sequence of various phases of basin construction must be coordinated with the overall project construction. As with other infiltration practices, rough excavation of the basin may be scheduled with the rough grading of the project to permit use of the excavated material as fill elsewhere on the site. However, the bioretention basin must not be constructed or placed in service until the entire contributing drainage area has been stabilized. Runoff from untreated, recently constructed areas within the drainage area may otherwise load the newly formed basin with a large load of fine sediment, seriously impairing the natural infiltration ability of the basin floor. For these reasons, the locations of infiltration bioretention basins must NOT be used for sediment basins for erosion and sediment protection during site construction. The sequence of construction shall be as follows:

1. Install Phase I erosion and sediment control measures for the site.
2. Grade each site to elevations shown on plan. Initially, the basin floor may be excavated to within one foot of its final elevation. Excavation to finished grade shall be deferred until all disturbed areas within the watershed have been stabilized and protected. Construct curb openings, and/or remove and replace existing concrete as specified on the plan. Curb openings shall be blocked or other measures taken to prohibit drainage from entering construction area.
3. Complete construction on the watershed and stabilize all areas draining to the Bioretention basin.
4. Remove Phase I sediment control devices at direction of designated inspector.
5. Install Phase II erosion and sediment control measures for bioretention area.

6. Remove all accumulated sediment and excavate Bioretention Area to proposed depth. Use relatively light, tracked equipment to avoid compaction of the basin floor. After final grading is completed, deeply till the basin floor with rotary tillers or disc harrows to provide a well-aerated, highly porous surface texture.
7. Install the infiltration chambers, piping, manifolds, drains, vents, and infiltration stone in accordance in with the specifications and directions of the chamber manufacturer. Install a six-inch layer of washed, 1/4-inch pea gravel above the stone. Install a 1-foot layer of ASTM C-33 concrete sand on top of the pea gravel. Lightly compact with a landscaping roller.
8. After confirmation that soil meets specs by performing the requisite gradation and chemical tests (see below), fill Bioretention Area with planting soil and sand, as shown in the plans and detailed in the specifications.
9. Install vegetation and ground cover specified in the planting plan for Bioretention Area. Install mulch layer if called for in the design.
10. Place sod, EC fabric, or non erosive lining (depending on inflow velocities) in the inlet channel and/or filter strips.
11. Upon authorization from designated inspector, remove all sediment controls and stabilize all disturbed areas. Unblock curb openings, and provide drainage to the Bioretention Areas.

Bioretention Area Soil Specifications

1. Planting Soil

The bioretention areas shall contain a planting soil mixture of 50% sand, 30% leaf compost (fully composted, NOT partially rotted leaves), and 20% topsoil. Topsoil shall be sandy loam or loamy sand of uniform composition, containing no more than 5% clay, free of stones, stumps, roots, or similar objects greater than one inch, brush, or any other material or substance which may be harmful to plant growth, or a hindrance to plant growth or maintenance.

The top soil shall be free of plants or plant parts of Bermuda grass, Quack grass, Johnson grass, Mugwort, Nutsedge, Poison Ivy, Canadian Thistle or others as specified. It shall not contain toxic substances harmful to plant growth.

The top soil shall be tested and meet the following criteria:

pH range:	5.0 - 7.0
Organic matter:	Greater than 1.5
Magnesium (Mg):	100+ Units
Phosphorus (P ₂ O ₅):	150+ Units
Potassium (K ₂ O):	120+ Units
Soluble salts:	not to exceed 900 ppm/.9 MMHOS/cm (soil) not to exceed 3,000 ppm/2.5 MMHOS/cm (organic mix)

The following testing frequencies shall apply to the above soil constituents:

pH, Organic Matter 1 test per 90 cubic yards, but no more than 1 test per Bioretention Area

Magnesium, Phosphorus, Potassium, Soluble Salts:

1 test per 500 cubic yards, but no less than 1 test per borrow source

One grain size analysis shall per performed per 90 cubic yards of planting soil, but no less than 1 test per Bioretention Area. Soil tests must be verified by a qualified professional.

2. Mulch

A mulch layer shall be provided on top of the planting soil. An acceptable mulch layer shall include shredded hardwood or shredded wood chips or other similar product.

Of the approved mulch products all must be well aged, uniform in color, and free of foreign material including plant material.

3. Sand

The sand for bioretention basins when utilized, shall be ASTM C-33 Concrete Sand and free of deleterious material.

4. Compaction

Soil shall be placed in lifts less than 18 inches and lightly compacted (minimal compactive effort) by tamping or rolled with a hand-operated landscape roller.

Bioretention Area Planting Specifications

1. Root stock of the plant material shall be kept moist during transport from the source to the job site and until planted.
2. Walls of planting pit shall be dug so that they are vertical.
3. The diameter of the planting pit must be a minimum of six inches (6") larger than the diameter of the ball of the tree.
4. The planting pit shall be deep enough to allow 1/8 of the overall dimension of the root ball to be above grade. Loose soil at the bottom of the pit shall be tamped by hand.
5. The appropriate amount of fertilizer is to be placed at the bottom of the pit (see below for fertilization rates).
6. The plant shall be removed from the container and placed in the planting pit by lifting and carrying the plant by its' ball (never lift by branches or trunk).

7. Set the plant straight and in the center of the pit so that approximately 1/8 of the diameter of the root ball is above the final grade.
8. Backfill planting pit with existing soil.
9. Make sure plant remains straight during backfilling procedure
10. Never cover the top of the ball with soil. Mound soil around the exposed ball.
11. Trees shall be braced by using 2" by 2" white oak stakes. Stakes shall be placed parallel to walkways and buildings. Stakes are to be equally spaced on the outside of the tree ball. Utilizing hose and wire the tree is braced to the stakes.
12. Because of the high levels of nutrients in stormwater runoff to be treated, bioretention basin plants should not require chemical fertilization.

Maintenance/Inspection Guidelines

The following maintenance and inspection guidelines are not intended to be all inclusive. Specific Facilities may require additional measures not discussed here.

A schedule of recommended maintenance for bioretention areas is given in Table 14.08-5. The table gives general guidance regarding methods, frequency, and time of year for maintenance.

Planting Soil

Urban plant communities tend to become very acidic due to precipitation as well as the influences of storm water runoff. For this reason, it is recommended that the application of alkaline, such as limestone, be considered once to twice a year. Testing of the pH of the organic layer and soil, should precede the limestone application to determine the amount of limestone required.

Soil testing should be conducted annually so that the accumulation of toxins and heavy metals can be detected or prevented. Over a period of time, heavy metals and other toxic substances will tend to accumulate in the soil and the plants. Data from other environs such as forest buffers and grass swales suggest accumulation of toxins and heavy metals within five years of installation. However, there is no methodology to estimate the level of toxic materials in the bioretention areas since runoff, soil, and plant characteristics will vary from site to site.

As the toxic substances accumulate, the plant biologic functions may become impaired, and the plant may experience dwarfed growth followed by mortality. The biota within the soil can also become void and the natural soil chemistry may be altered. The preventative measures would include the removal of the contaminated soil. In some cases, removal and disposal of the entire soil base as well as the plant material may be required.

Mulch

Bioretention areas should be mulched once the planting of trees and shrubs has occurred. Any ground cover specified as plugs may be installed once the area has been mulched. Ground cover established by seeding and/or consisting of grass should not be covered with mulch.

Plant Materials

An important aspect of landscape architecture is to design areas that require little maintenance. Certain plant species involve maintenance problems due to dropping of fruit or other portions of the plant. Another problem includes plants, primarily trees, that are susceptible to windthrow, which creates a potential hazard to people and property (parked cars). As a result, some plant species will be limited to use in low-traffic areas.

Ongoing monitoring and maintenance is vital to the overall success of bioretention areas. Annual maintenance will be required for plant material, mulch layer, and soil layer. A maintenance schedule should include all of the main considerations discussed below. The maintenance schedule usually includes maintenance as part of the construction phase of the project and for life of the design. An example maintenance schedule is shown in Table 14.08-4.

Maintenance requirements will vary depending on the importance of aesthetics. Soil and mulch layer maintenance will be most likely limited to correcting areas of erosion. Replacement of mulch layers may be necessary every two to three years. Mulch should be replaced in the spring. When the mulch layer is replaced, the previous layer should be removed first. Plant material upkeep will include addressing problems associated with disease or insect infestations, replacing dead plant material, and any necessary pruning.

Control of Sediments on the Drainage Shed

Care must be taken to protect the bioretention basin from excessive sediments from the drainage shed. Whenever additional land disturbing activity takes place in the area draining to the basin, effective erosion and sediment control measures must first be put in place to exclude sediments from the basin. Performance based special measures over and above those specified in the Virginia Erosion and Sediment Control Handbook, latest edition, may be required to assure that the bioretention basin is not damaged by such land disturbance. When sand or other street abrasives are used during the snow or icing conditions to provide traction on roadways or parking lots draining to bioretention basins, the pavement should be power/vacuum swept as soon as freezing weather abates to prevent damage to the basins.

TABLE 14.08 - 4
Example Maintenance Schedule for Bioretention Basin

Description	Method	Frequency	Time of the year
SOIL			
Inspect and Repair Erosion	Visual	Monthly	Monthly
ORGANIC LAYER			
Remulch any void areas	By hand	Whenever needed	Whenever needed
Remove previous mulch layer before applying new layer (optional)	By hand	Once every two to three years	Spring
Any additional mulch added (optional)	By hand	Once a year	Spring
PLANTS			
Removal and replacement of all dead and diseased vegetation considered beyond treatment	See planting specifications	Twice a year	3/15 to 4/30 and 10/1 to 11/30
Treat all diseased trees and shrubs	Mechanical or by hand	N/A	Varies, depends on insect or disease infestation
Watering of plant material shall take place at the end of each day for fourteen consecutive days after planting has been completed	By hand	Immediately after completion of project	N/A
Replace stakes after one year	By hand	Once a year	Only remove stakes In the spring
Replace any deficient stakes or wires	By hand	N/A	Whenever needed
Check for accumulated sediments	Visual	Monthly	Monthly

TABLE 14.08-5A RECOMMENDED PLANT SPECIES FOR USE IN BIORETENTION --- TREE SPECIES															
Species	Moisture Regime		Tolerance						Morphology			General Characteristics			Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects Disease	Exposure	Form	Height	Root System	Native	Non-native	Wildlife	
Acer rubrum red maple	FAC	Mesic - Hydric	4-6	H	H	H	H	Partial Sun	Single to multi-stem tree	50-70'	Shallow	Yes	-	High	-
Amelanchier canadensis shadbush	FAC	Mesic	2-4	H	M	-	H	Partial Sun	Single to multi-stem tree	35-50'	Shallow	Yes	-	High	Not recommended for full sun.
Betula nigra river birch	FACW	Mesic - Hydric	4-6	-	M	M	H	Partial Sun	Single to multi-stem tree	50-75'	Shallow	Yes	-	High	Not susceptible to bronze birch borer.
Betula populifolia gray birch	FAC	Xeric - Hydric	4-6	H	H	M	H	Partial Sun	Single to multi-stem tree	35-50'	Shallow to deep	-	Yes	High	Native to New England area.
Fraxinus americana white ash	FAC	Mesic	2-4	M	H	H	H	Sun	Large tree	50-80'	Deep	Yes	-	Low	-
Fraxinus pennsylvanica green ash	FACW	Mesic	4-6	M	H	H	H	Partial Sun	Large tree	40-65'	Shallow to deep	Yes	-	Low	-
Ginkgo biloba Maidenhair tree	FAC	Mesic	2-4	H	H	H	H	Sun	Large tree	50-80'	Shallow to deep	-	Yes	Low	Avoid female species-offensive odor from fruit.
Gleditsia triacanthos honeylocust	FAC	Mesic	2-4	H	M	-	M	Sun	Small canopied large tree	50-75'	Shallow to deep variable taproot	Yes	-	Low	Select thornless variety.
Juniperus virginiana eastern red cedar	FACU	Mesic - Xeric	2-4	H	H	-	H	Sun	Dense single stem tree	50-75'	Taproot	Yes	-	Very High	Evergreen
Koeleruteria paniculata golden-rain tree	FACU	Mesic	2-4	H	H	H	H	Sun	Round, dense shade tree	20-30'	Shallow	-	Yes	No	-
Liquidambar styraciflua sweet gum	FAC	Mesic	4-6	H	H	H	M	Sun	Large tree	50-70'	Deep taproot	Yes	-	High	Edge and perimeter; fruit is a maintenance problem.
Nyssa sylvatica black gum	FACW	Mesic - Hydric	4-6	H	H	H	H	Sun	Large tree	40-70'	Shallow to deep taproot	Yes	-	High	-

H High Tolerance
M Medium Tolerance
L Low Tolerance

FAC Facultative - Equally likely to occur in wetlands or non-wetlands.
FACU Facultative Upland - Usually occur in non-wetlands, but occasionally found in wetlands.
FACW Facultative Wetland - Usually occur in wetlands, but occasionally found in non-wetlands.

NOTE: Heights shown in table are under ideal conditions in rural settings. They do not reflect urban conditions, under which plants do not commonly survive to such maturity.

TABLE 14.08-5A RECOMMENDED PLANT SPECIES FOR USE IN BIORETENTION --- TREE SPECIES

Species	Moisture Regime		Tolerance						Morphology			General Characteristics			Comments
	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects Disease	Exposure	Form	Height	Root System	Native	Non-native	Wildlife	
Scientific Name Common Name															
Platanus acerifolia London plane-tree	FACW	Mesic	2-4	H	-	-	M	Sun	Large tree	70-80'	Shallow	-	Yes	Low	Tree roots can heave sidewalks.
Platanus occidentalis sycamore	FACW	Mesic - Hydric	4-6	M	M	M	M	Sun	Large tree	70-80'	Shallow	Yes	-	Med.	Edge and perimeter; fruit is a maintenance problem; tree is also prone to windthrow.
Populus deltoides eastern cottonwood	FAC	Xeric - Mesic	4-6	H	H	H	L	Sun	Large tree with spreading branches	75-100'	Shallow	Yes	-	High	Short lived.
Quercus bicolor swamp white oak	FACW	Mesic to wet Mesic	4-6	H	-	H	H	Sun to partial sun	Large tree	75-100'	Shallow	Yes	-	High	One of the faster growing oaks.
Quercus coccinea scarlet oak	FAC	Mesic	1-2	H	M	M	M	Sun	Large tree	50-75'	Shallow to deep	Yes	-	High	-
Quercus macrocarpa bur oak	FAC	Mesic to wet Mesic	2-4	H	H	H	M	Sun	Large spreading tree	75-100'	Taproot	-	Yes	High	Native to midwest.
Quercus palustris pin oak	FACW	Mesic - Hydric	4-6	H	H	H	M	Sun	Large tree	60-80'	Shallow to deep taproot	Yes	-	High	-
Quercus phellos willow oak	FACW	Mesic to wet Mesic	4-6	H	-	-	H	Sun	Large tree	55-75'	Shallow	Yes	-	High	Fast growing oak.
Quercus rubra red oak	FAC	Mesic	2-4	M	H	M	M	Sun to partial sun	Large spreading tree	60-80'	Deep taproot	Yes	-	High	-

H High Tolerance
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L Low Tolerance

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FACW Facultative Wetland - Usually occur in wetlands, but occasionally found in non-wetlands.

NOTE: Heights shown in table are under ideal conditions in rural settings. They do not reflect urban conditions, under which plants do not commonly survive to such maturity.

TABLE 14.08-5A RECOMMENDED PLANT SPECIES FOR USE IN BIORETENTION --- TREE SPECIES															
Species	Moisture Regime		Tolerance						Morphology			General Characteristics			Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects Disease	Exposure	Form	Height	Root System	Native	Non-native	Wildlife	
Robinia pseudo-acacia black locust	FAC	Mesic - Xeric	2-4	H	H	H	M	Sun	Typically tall and slender	30-50'	Shallow	Yes	-	Low	Edge and perimeter; fruit is a maintenance problem; tree is also prone to windthrow.
Taxodium distichum bald cypress	FACW	Mesic - Hydric	4-6	-	-	M	H	Sun to partial sun	Typically single stem tree	75- 100'	Shallow	Yes	-	Low	Not well documented for planting in urban areas.
Zelkova serrata Japanese zelkova	FACU	Mesic	1-2	M	M	-	H	Sun	Dense shade tree	60-70'	Shallow	-	Yes	Low	Branches can split easily in storms.

H High Tolerance
M Medium Tolerance
L Low Tolerance

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FACW Facultative Wetland - Usually occur in wetlands, but occasionally found in non-wetlands.

NOTE: Heights shown in table are under ideal conditions in rural settings. They do not reflect urban conditions, under which plants do not commonly survive to such maturity.

TABLE 14.08-5B RECOMMENDED PLANT SPECIES FOR USE IN BIORETENTION --- SHRUB SPECIES															
Species	Moisture Regime		Tolerance						Morphology			General Characteristics			Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/Grease	Metals	Insects Disease	Exposure	Form	Height	Root System	Native	Non-native	Wildlife	
Berberis koreana barberry	FAC	Mesic	2-4	H	H	H	M	Sun to partial sun	Oval shrub	4-6'	Shallow	-	Yes	Low	-
Berberis thunbergii Japanese barberry	FAC	Mesic	2-4	H	H	H	M	Sun	Rounded, broad dense shrub	5-7'	Shallow	-	Yes	Med.	-
Clethra alnifolia sweet pepperbush	FAC	Mesic to wet Mesic	2-4	H	-	-	H	Sun to partial sun	Ovoid shrub	6-12'	Shallow	Yes	-	Med.	Coastal plain species
Cornus Stolonifera red osier dogwood	FACW	Mesic - Hydric	2-4	H	H	H	M	Sun or shade	Arching, spreading shrub	8-10'	Shallow	Yes	-	High	Needs more consistent moisture levels.
Euonymus europaeus spindle-tree	FAC	Mesic	1-2	M	M	M	M	Sun to partial sun	Upright dense oval shrub	10-12'	Shallow	-	Yes	No	-
Hamamelis virginiana witch-hazel	FAC	Mesic	2-4	M	M	M	M	Sun or shade	Vase-like compact shrub	4-6'	Shallow	Yes	-	Low	-
Hypericum densiflorum common St. John's wort	FAC	Mesic	2-4	H	M	M	H	Sun	Ovoid shrub	3-6'	Shallow	Yes	-	Med.	-
Ilex glabra inkberry	FACW	Mesic to wet Mesic	2-4	H	H	-	H	Sun to partial sun	Upright dense shrub	6-12'	Shallow	Yes	-	High	Coastal plain species
Ilex verticillata winterberry	FACW	Mesic to wet Mesic	2-4	L	M	-	H	Sun to partial sun	Spreading shrub	6-12'	Shallow	Yes	-	High	-
Juniperus communis "compressa" common juniper	FAC	Dry Mesic - Mesic	1-2	M	H	H	M - H	Sun	Mounded shrub	3-6'	Deep taproot	-	Yes	High	Evergreen

H High Tolerance
M Medium Tolerance
L Low Tolerance

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TABLE 14.08-5B RECOMMENDED PLANT SPECIES FOR USE IN BIORETENTION --- SHRUB SPECIES															
Species	Moisture Regime		Tolerance						Morphology			General Characteristics			Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects Disease	Exposure	Form	Height	Root System	Native	Non-native	Wildlife	
<i>Juniperus horizontalis</i> "Bar Harbor" creeping juniper	FAC	Dry Mesic - Mesic	1-2	M	H	H	M - H	Sun	Matted shrub	0-3'	Deep taproot	-	Yes	High	Evergreen
<i>Lindera benzoin</i> spicebush	FACW	Mesic to wet Mesic	2-4	H	-	-	H	Sun	Upright shrub	6-12'	Deep	Yes	-	High	-
<i>Myrica pennsylvanica</i> bayberry	FAC	Mesic	2-4	H	M	M	H	Sun to partial sun	Rounded, compacted shrub	6-8'	Shallow	Yes	-	High	Coastal plain species
<i>Physocarpus opulifolius</i> ninebark	FAC	Dry Mesic to wet Mesic	2-4	M	-	-	H	Sun	Upright shrub	6-12'	Shallow	Yes	-	Med.	May be difficult to locate.
<i>Viburnum cassinoides</i> northern wild raisin	FACW	Mesic	2-4	H	H	H	H	Sun to partial sun	Rounded, compacted shrub	6-8'	Shallow	Yes	-	High	-
<i>Viburnum dentatum</i> arrow-wood	FAC	Mesic	2-4	H	H	H	H	Sun to partial sun	Upright, multi-stemmed shrub	8-10'	Shallow	Yes	-	High	-
<i>Viburnum lentago</i> nannyberry	FAC	Mesic	2-4	H	H	H	H	Sun to partial sun	Upright, multi-stemmed shrub	8-10'	Shallow	Yes	-	High	-

H High Tolerance
M Medium Tolerance
L Low Tolerance

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FACW Facultative Wetland - Usually occur in wetlands, but occasionally found in non-wetlands.

TABLE 14.08-5C RECOMMENDED PLANT SPECIES FOR USE IN BIORETENTION --- HERBACEOUS SPECIES*															
Species	Moisture Regime		Tolerance						Morphology			General Characteristics			Comments
Scientific Name Common Name	Indicator Status	Habitat	Ponding (days)	Salt	Oil/ Grease	Metals	Insects Disease	Exposure	Form	Height	Root System	Native	Non-native	Wildlife	
Agrostis alba redtop	FAC	Mesic - Xeric	1-2	H	-	H	H	Shade	Grass	2-3'	Fibrous Shallow	Yes	-	High	-
Andropogon gerardi bluejoint	FAC	Dry Mesic - Mesic	1-2	-	-	-	-	Sun	Grass	2-3'	Fibrous Shallow	Yes	-	High	-
Deschampsia caespitosa tufted hairgrass	FACW	Mesic to wet Mesic	2-4	H	-	H	H	Sun	Grass	2-3'	Fibrous Shallow	Yes	-	High	May become invasive.
Lotus Corniculatus birdsfoot-trefoil	FAC	Mesic - Xeric	1-2	H	L	H	H	Sun	Grass	2-3'	Fibrous Shallow	Yes	-	High	Member of the legume family.
Panicum virgatum switch grass	FAC to FACU	Mesic	2-4	H	-	-	H	Sun or Shade	Grass	4-5'	Fibrous Shallow	Yes	-	High	Can spread fast and reach height of 6'.

H High Tolerance
M Medium Tolerance
L Low Tolerance

FAC Facultative - Equally likely to occur in wetlands or non-wetlands.
FACU Facultative Upland - Usually occur in non-wetlands, but occasionally found in wetlands.
FACW Facultative Wetland - Usually occur in wetlands, but occasionally found in non-wetlands.

*NOTE: This list is representative of grasses with known success in these type applications. There are other suitable native wildflower species and other grasses that may be used as well. A proposed planting plan and list of species must be provided with development plans for review and approval.



Bioretention Filter in multi-family residential setting.



Bioretention Basins in office setting parking lot.

MINIMUM STANDARD 14.09

BIORETENTION FILTERS



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MINIMUM STANDARD 14.09

BIORETENTION FILTERS

Definition

Bioretention basins that rely on infiltration (MINIMUM STANDARD 14.08: BIORETENTION BASINS) may not be feasible in many ultra-urban settings because of the proximity of building foundations or because soils are not conducive to exfiltration from the basin. Bioretention Filters were developed for use in such circumstances.

Bioretention soil media filters are essentially bioretention basins with the infiltration chamber gallery equipped with a permanent and continuous connection to the storm sewer system. The bioretention basin shown in Figure 14.09-1 illustrates a bioretention basin equipped to function as a filter.

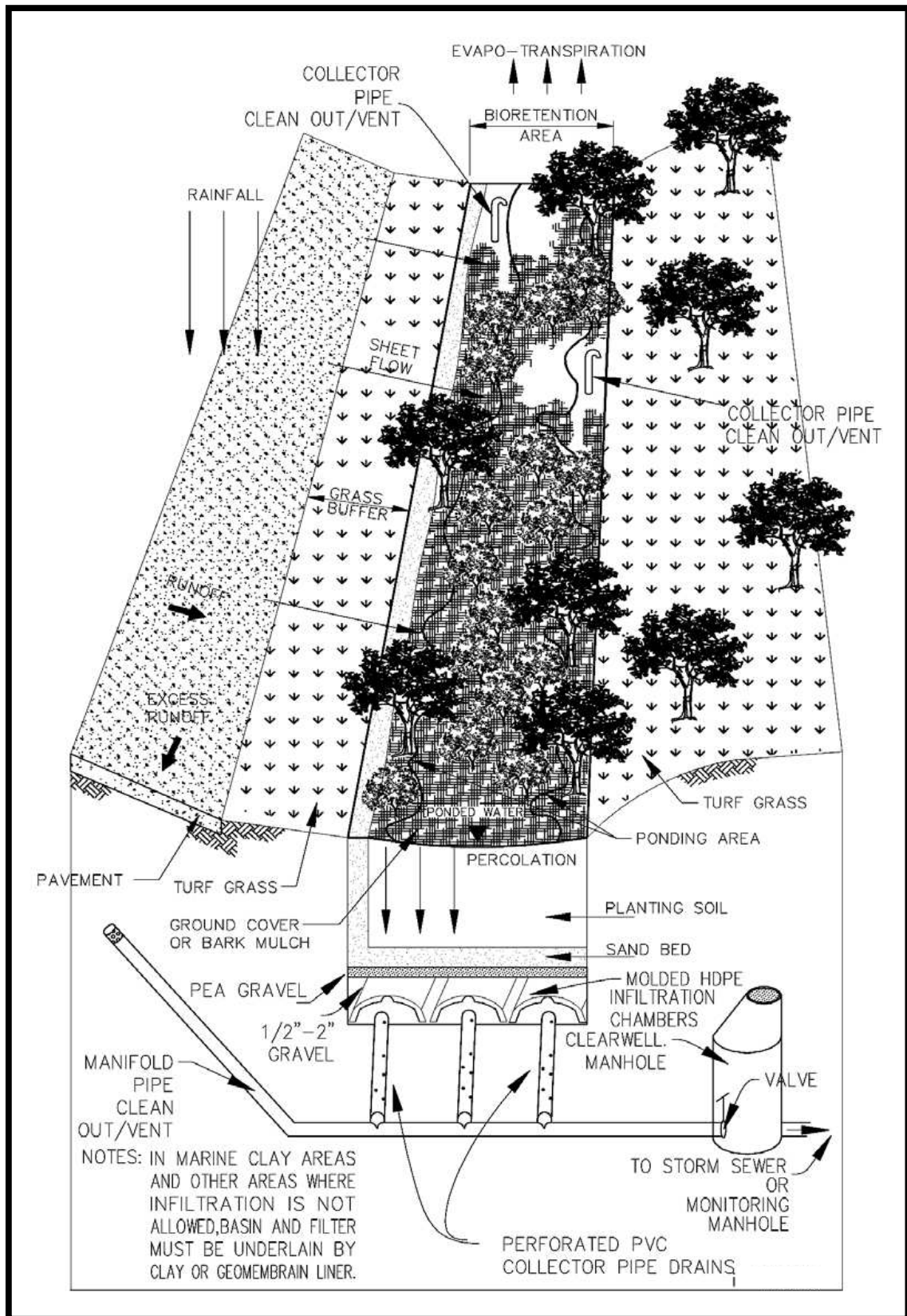
When used in areas underlain by marine clays or in proximity to building foundations, the entire basin must be provided with a dense clay or geomembrane liner. When the filter concept must be used simply because of low percolation rates of the soil, the liner may be omitted. The vertical sand column is also optional on a bioretention filter.

Purpose

Water Quality Enhancement

Like bioretention basins, bioretention filters are used primarily for water quality control. Bioretention filters enhance the quality of stormwater runoff through the processes of adsorption, filtration, volatilization, ion exchange, microbial and decomposition prior to collection of the treated effluent in the collector pipe system. Microbial soil processes, evapotranspiration, and nutrient uptake in plants also come into play (Bitter and Bowers, 1995). The manner in which these processes work is discussed under MINIMUM STANDARD 14.08, BIORETENTION BASINS. The minimum widths and lengths for bioretention basins (10' and 15', respectively) also apply to bioretention filters. However, since runoff will be treated faster in a bioretention filter, it may be pooled to a maximum depth of 1 foot above the basin floor rather than the 0.5 feet allowed in a bioretention basin.

FIGURE 14.09A-1
Bioretention Filter



Flood Control and Channel Erosion Control

The amount of flood and channel erosion control protection provided by bioretention basins depends on the local rainfall frequency spectrum, the amount of pre-development (or pre-redevelopment) impervious cover, the amount of post-development impervious cover, and the volume of runoff captured and infiltrated by the basin(s). The effect of the BMPs on peak flow rates from the drainage shed must be examined. As with other infiltration practices, bioretention basins tend to reverse the consequences of urban development by reducing peak flow rates and providing groundwater discharge.

Conditions Where Practice Applies

Bioretention Filters are generally suited for almost all types of development, from single-family residential to fairly high density commercial projects. They are attractive for higher density projects because of their relatively high removal efficiency. The critical prerequisite is the existence of a deep enough storm sewer to accept drainage from the collector pipe system by gravity flow. All of the applications shown in Figures 14.08-2 through 14.08-6 under MS 14.08 may be built as bioretention filters. As with bioretention basins, for large applications, several connected bioretention filters are preferable to a single, massive filter.

Planning Considerations

Site Conditions

Except for those dealing with proper soils to accept infiltration and sizing of the filters, all of the Site Conditions considerations for bioretention basins contained in MINIMUM STANDARD 14.08 BIORETENTION BASINS also apply to bioretention filters. The same drainage area range applies, as do the same Location Considerations. In addition to site conditions, the following apply specifically to bioretention filters.

1. Sizing Guidelines

For planning purposes, assume that the floor area of a bioretention filter will be 3% of the impervious area draining to the filter if 0.64 inches of runoff are to be treated.

2. Aesthetic Considerations

All of the discussion of aesthetics under MINIMUM STANDARD 14.08: BIORETENTION BASINS apply equally to bioretention filters. Overall aesthetics of the bioretention filters must be integrated into the site plan and stormwater concept plan from their inception. Biomorphic shapes which follow the ground contours should be used rather than angular shapes. The bioretention filter should be essentially almost invisible upon completion, blending in with the other landscaping of the site. Both the stormwater engineer and the landscaping planner must participate in the layout of the facilities and infrastructure to be placed on the site.

Sediment Control

All of the Sediment Control considerations for bioretention basins under MS 14.08: Bioretention Basins also apply to bioretention filters.

Like bioretention basins, bioretention filters should be constructed only AFTER the site work is complete and stabilization measures have been implemented. Experience with bioretention basins and soil media filters has demonstrated that bioretention filters must be protected from all sediment loads.

Bioretention filters must retain sediment control protection until stabilization of the upland site is functional to control the sediment load from denuded areas. Provisions to bypass the stormwater away from the bioretention filter during the stabilization period must be implemented.

General Design Criteria

The purpose of this section is to provide minimum criteria for the design of bioretention filter BMPs intended to comply with the Owensboro/Daviess County Stormwater Management program's runoff quality requirements. Bioretention filters which capture and treat the first one inch of runoff from impervious surfaces may also provide streambank erosion protection.

General

The design of bioretention filters should be in accordance with the OMPC PI Specifications as well as the additional criteria set forth below. The designer is not only responsible for selecting the appropriate components for the particular design but also for ensuring long-term operation.

Integration of the bioretention filters into the general landscaping scheme of the project must be coordinated with the landscaping professional at the inception of the design process. Use of such techniques as biomorphic shapes to present a pleasing aesthetic appearance is of equal importance with hydrological and hydraulic functioning of the basins. Properly designed bioretention filters should not be readily identifiable as stormwater BMPs by the lay observer.

Basin Sizing Methodology

Bioretention filters are designed to filter the treatment volume into the underlying gravel bed and collector pipe system. Bioretention filters are sized using the same sizing methodology as that of bioretention basins.

The elevation of the overflow structure should be 1.0 feet above the elevation of the bioretention bed.

If the filter soil remains constantly wet, anaerobic conditions will develop, which will kill the plants and cause iron phosphates which have been previously captured to break down and escape into the effluent.

Continuous or frequent flows (such as basement sump pump discharges, cooling water, condensate water, artesian wells, etc.) and flows containing swimming pool and sauna chemicals must be EXCLUDED from routing through bioretention or bioretention filter BMPs since such flows will cause the BMP to MALFUNCTION!

The Planting Plan, Planting Soil Guidelines, Mulch Layer Guidelines, Plant Material Guidelines, Plant Growth and Soil Fertility criteria of MINIMUM STANDARD 14.08: BIORETENTION BASINS, also apply to bioretention filters.

Basin Liners

Impermeable liners may be either clay, concrete or geomembrane. If geomembrane is used, suitable geotextile fabric shall be placed below and on the top of the membrane for puncture protection. Clay liners shall meet the specifications in Table 14.09-1.

The clay liner shall have a minimum thickness of 12 inches.

If a geomembrane liner is used it shall have a minimum thickness of 30 mils and be ultraviolet resistant.

The geotextile fabric (for protection of geomembrane) shall meet the specifications in Table 14.09-2.

TABLE 14.09 - 1
Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	Cm/Sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423 & D-424	%	Not less than 15
Liquid Limits of Clay	ASTM D-2216	%	Not less than 30
Clay Compaction	ASTM-2216	%	95% of Standard Proctor Density
Clay Particles Passing	ASTM D-422	%	Not less than 30

TABLE 14.09 - 2
Geotextile Specification for Basin Liner
“Sandwich”

Property	Test Method	Unit	Specification
Unit Weight		Oz./Sq.Yd.	8 (minimum)
Filtration Rate		In./Sec.	0.08 (minimum)
Puncture Strength	ASTM D-751 (Modified)	Lb.	125 (minimum)
Mullen Burst Strength	ASTM D-751	Psi.	400 (minimum)
Tensile Strength	ASTM D-1682	Lb.	300
Equiv. Opening Size	U.S. Standard Sieve	No.	80 (minimum)

Equivalent methods for protection of the geomembrane liner will be considered on a case by case basis. Equivalency will be judged on the basis of ability to protect the geomembrane from puncture, tearing and abrasion.

When molded chambers are incorporated into the design, a minimum of four inches of gravel or crushed stone should be added beneath the molded chambers or other conveyance system to allow settling of filter fines into the voids. As with bioretention basins, filter strips, grassed channels, and side slopes should be sodded with mature sod, and planting soil should be wrapped up the side slopes under the sod.

All other factors dealing with bioretention filters are identical to those for bioretention basins in general, M.S.14.08



Bioretention Filter in ultra-urban setting. Note curb cut, gravel energy dissipater, and clean out/observation wells.



Bioretention Filter located in required parking lot green space.



Bioretention Filter in multi-family residential setting.

MINIMUM STANDARD 14.10

VEGETATED ROOF



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MINIMUM STANDARD 14.10

VEGETATED ROOF

DESCRIPTION

Vegetated roofs (also known as *green roofs*, *living roofs* or *ecorooofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Vegetated roofs capture and temporarily store stormwater runoff in the growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites.

There are two different types of vegetated roof systems: *intensive* vegetated roofs and *extensive* vegetated roofs. Intensive systems have a deeper growing media layer that ranges from 6 inches to 4 feet thick, which is planted with a wider variety of plants, including trees. By contrast, extensive systems typically have much shallower growing media (2 to 6 inches), which is planted with carefully selected drought tolerant vegetation. Extensive vegetated roofs are much lighter and less expensive than intensive vegetated roofs and are recommended for use on most development and redevelopment sites.

NOTE: This specification is intended for situations where the primary design objective of the vegetated roof is stormwater management and, unless specified otherwise, addresses extensive roof systems.

Designers may wish to pursue other design objectives for vegetated roofs, such as energy efficiency, green building or LEED points, architectural considerations, visual amenities and landscaping features, which are often maximized with intensive vegetated roof systems. However, these design objectives are beyond the scope of this specification.

Vegetated roofs typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Extensive vegetated roofs are designed to have minimal maintenance requirements. Plant species are selected so that the roof does not need supplemental irrigation or fertilization after vegetation is initially established.

PERFORMANCE

The overall stormwater functions of vegetated roofs are summarized in **Table 14.10-1**.

Table 14.10-1:
Summary of Stormwater Functions Provided by Vegetated Roofs ¹

Stormwater Function	Level 1 Design	Level 2 Design
Annual Runoff Volume Reduction (RR)	45%	60%
Channel Protection & Flood Mitigation ²	Use the following Curve Numbers (CN) for Design Storm events: 1-year storm = 64; 2-year storm = 66; 10-year storm = 72; and the 100 year storm = 75	
¹ Sources: CWP and CSN (2008) and CWP (2007).		
² See Miller (2008), NVRC (2007) and MDE (2008)		

DESIGN TABLE

The major design goal for Vegetated Roofs is to maximize nutrient removal and runoff volume reduction. To this end, designers may choose the baseline design (Level 1) or choose an enhanced (Level 2) design that maximizes nutrient and runoff reduction. In general, most intensive vegetated roof designs will automatically qualify as being Level 2. **Table 14.10-2** (next page) lists the design criteria for Level 1 and 2 designs.

Table 14.10-2. Green Roof Design Guidance

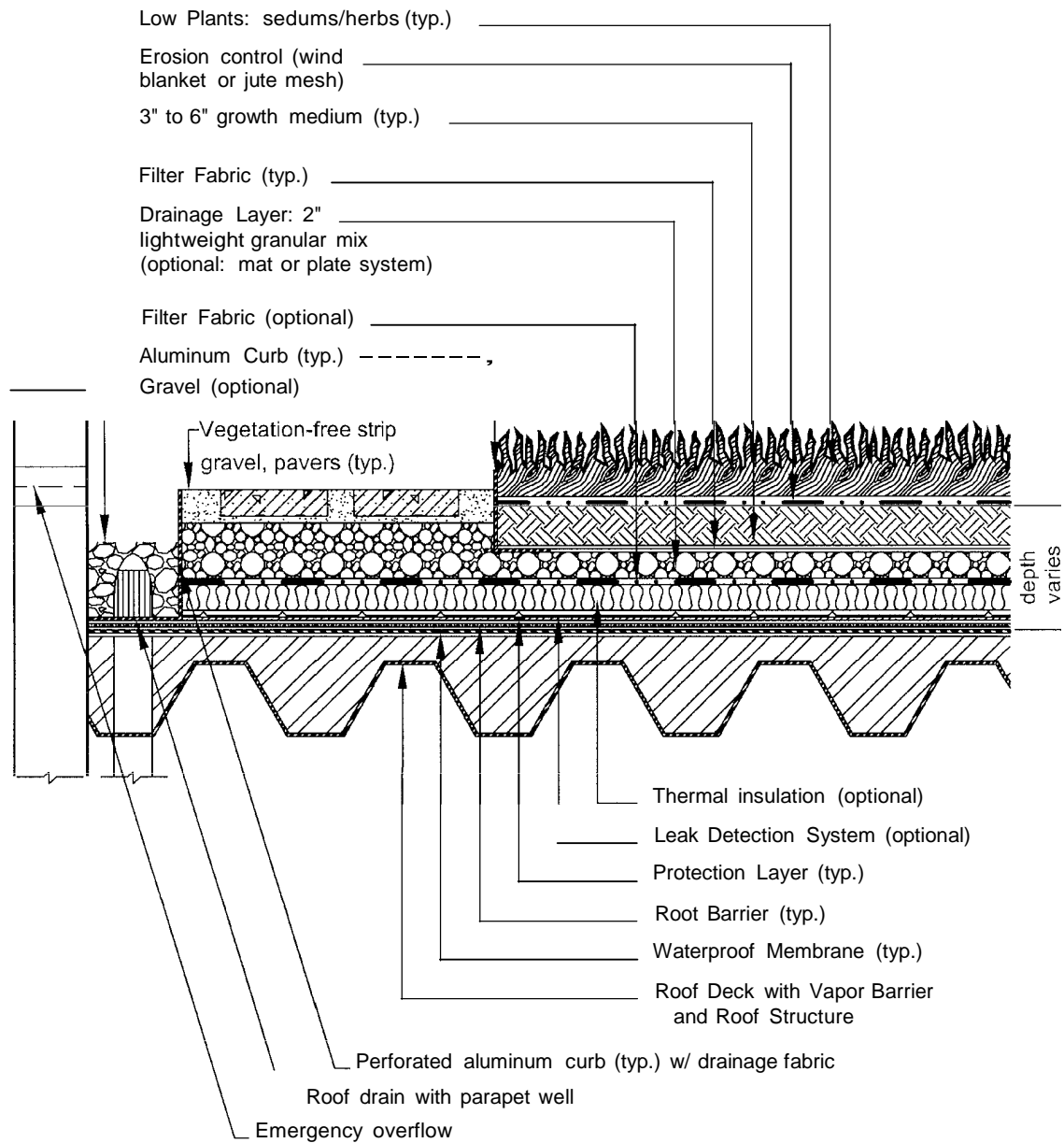
Level 1 Design (RR:45; TP:0; TN:0)	Level 2 Design (RR: 60; TP:0; TN:0)
$T_v = 1.0 (R_v)^1 (A)/12$	$T_v = 1.1 (R_v)^1 (A)/12$
Depth of media up to 4 inches	Media depth 4 to 8 inches
Drainage mats	2-inch stone drainage layer
No more than 20% organic matter in media	No more than 10% organic matter in media
All Designs: Must be in conformance to ASTM (2005) International Green (Vegetated) Roof Stds.	
¹ R _v represents the runoff coefficient for a conventional roof, which will usually be 0.95. The runoff reduction rate applied to the vegetated roof is for "capturing" the Treatment Volume (T _v) compared to what a conventional roof would produce as runoff.	

TYPICAL DETAILS

Figure 14.10-1
Photos of Vegetated Roof Cross-Sections (source: B. Hunt, NCSU)

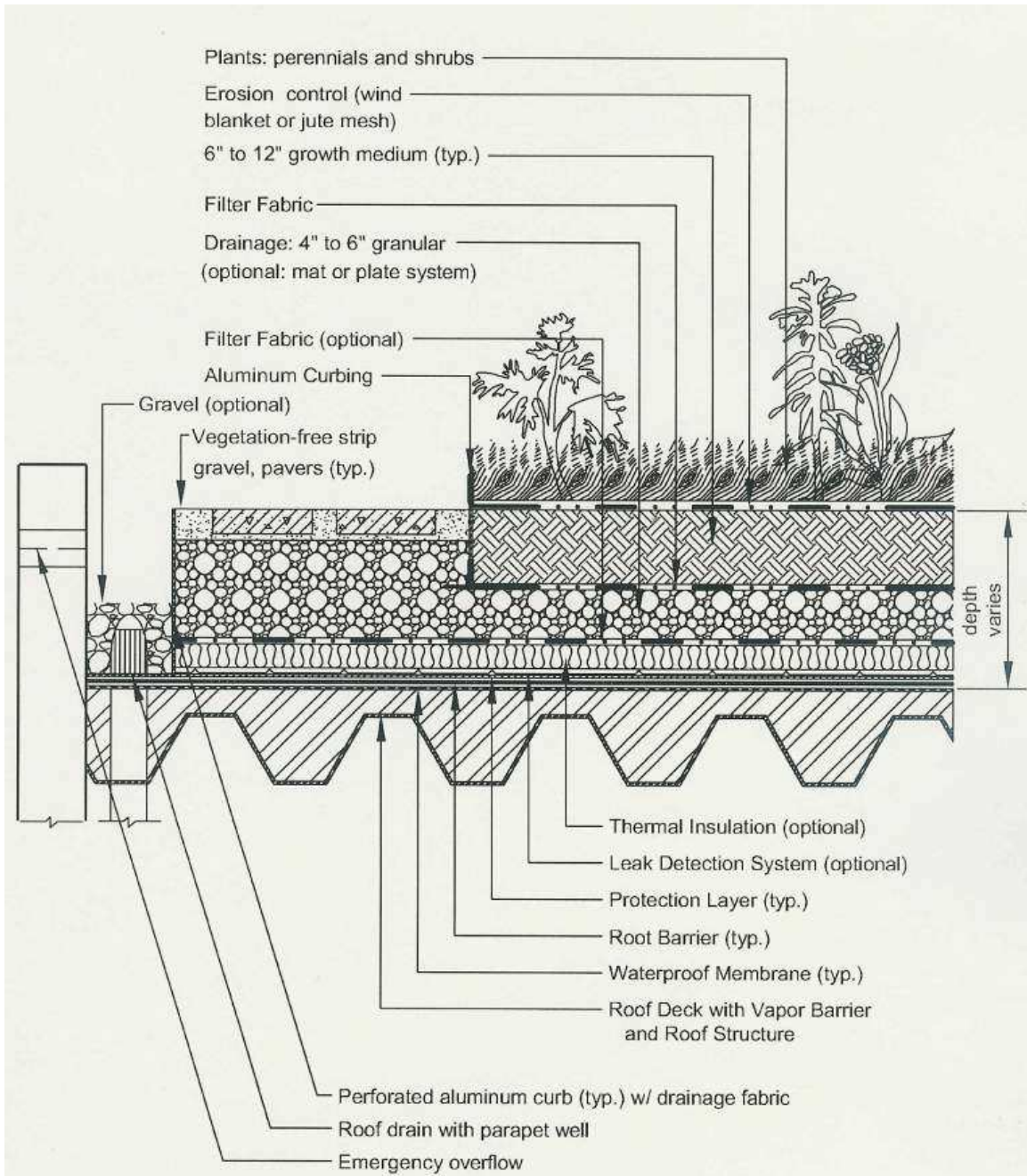


Figure 14.10-2
 Typical Section –Extensive Vegetated Roof
 (Source: Northern VA Regional Commission)



CROSS SECTION VIEW (NTS)

Figure 14.10-3
 Typical Section- Intensive Vegetated Roof
 (Source: NorthernVA Regional Commission)



CROSS SECTION (NTS)

**PHYSICAL FEASIBILITY &
DESIGN APPLICATIONS****Typical applications**

Vegetated roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings. They are particularly well suited for use on ultra-urban development and redevelopment sites. Vegetated roofs can be used on a variety of rooftops, including the following:

- Non-residential buildings (e.g. commercial, industrial, institutional and transportation uses)
- Multi-family residential buildings (e.g. condominiums or apartments)
- Mixed-use buildings

Local regulations may also permit the use of vegetated roofs on single family residential roofs.

Common Site Constraints

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

Roof Pitch. Treatment volume (Tv) is maximized on relatively flat roofs (a pitch of 1 to 2%). Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media. Vegetated roofs can be installed on rooftops with slopes up to 25% if baffles, grids, or strips are used to prevent slippage of the media. The effective treatment volume (Tv), however, diminishes on rooftops with steep pitches (Van Woert et al, 2005).

Roof Access. Adequate access to the roof must be available to deliver construction materials and perform routine maintenance. Roof access can be achieved either by an interior stairway through a penthouse or by an alternating tread device with a roof hatch or trap door not less than 16 square feet in area and with a minimum dimension of 24 inches (NVRC, 2007). Designers should also consider how they will get construction materials up to the roof (e.g., by elevator or crane), and how construction materials will be stockpiled in the confined space.

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

Setbacks. Vegetated roofs should not be located near rooftop electrical and HVAC systems. A 2-foot wide vegetation-free zone is recommended along the perimeter of the roof, with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak. The 2-foot setback may

be relaxed to 1 foot for very small vegetated roof applications.

Retrofitting Green Roofs: Key feasibility factors to consider when evaluating a retrofit include the area, age and accessibility of the existing roof, and the capability of the building's owners to maintain it. Options for green roof retrofits are described in Profile Sheet RR-3 of Schueler et al (2007). The structural capacity of the existing rooftop can be a major constraint to a green roof retrofits.

Local Building Codes. Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the vegetated roof design should comply with the Kentucky Building Code with respect to roof drains and emergency overflow devices.

Construction Cost. When viewed strictly as stormwater treatment systems, vegetated roofs can cost between \$12 and \$25 per square foot, ranking them among the most costly stormwater practices available (Moran et al, 2004, Schueler et al 2007). These cost analyses, however, do not include life cycle cost savings relating to increased energy efficiency, higher rents due to green building scores, and increased roof longevity. These benefits over the life cycle of a vegetated roof may make it a more attractive investment. In addition, several communities may offer subsidies or financial incentives for installing vegetated roofs.

Risks of Leaky Roofs. Although well designed and installed green roofs have less problems with roof leaks than traditional roofs, there is a perception among property managers, insurers and product fabricators that this emerging technology could have a greater risk of problems. For an excellent discussion on how to properly manage risk in vegetated roof installations, see Chapter 9 in Weiler and Scholz-Barth (2009).

DESIGN CRITERIA

Overall Sizing

Vegetated roof areas should be sized to capture a portion of the Treatment Volume (T_v). The required size of a vegetated roof will depend on several factors, including the porosity and hydraulic conductivity of the growing media and the underlying drainage materials. Site designers and planners should consult with vegetated roof manufacturers and material suppliers for specific sizing guidelines. As a general sizing rule, the following equation can be used to determine the water quality treatment storage volume retained by a vegetated roof:

$$T_v = (RA * D * P)/12$$

Where, T_v = storage volume (cu. ft.)
 RA = vegetated roof area (sq. ft.)
 D = media depth (in.)
 P = media porosity (usually 0.3, but consult manufacturer specifications)

The resulting T_v can then be compared to the required T_v for the entire rooftop area (including all non-vegetated areas) to determine if it meets or exceeds the required T_v for Level 1 or Level 2 design, as shown in **Table 14.10-2** above.

Guidance for selecting the appropriate post development CN for the vegetated roof for four different design storms is also provided in **Table 14.10-2**; in general, lower curve numbers are associated with more frequent design storms. In most cases, the maximum design storm is the 10-year event.

Structural Capacity of the Roof

Vegetated roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer should consult with a licensed structural engineer or architect to ensure that the building will be able to support the additional live and dead structural load and determine the maximum depth of the vegetated roof system and any needed structural reinforcement.

In most cases, fully-saturated extensive vegetated roofs have loads of about 15 to 25 lbs./sq. ft., which is fairly similar to traditional new rooftops (12 to 15 lbs./sq. ft.) that have a waterproofing layer anchored with stone ballast. For an excellent discussion of vegetated roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*.

Functional Elements of a Vegetated Roof System

A vegetated roof is composed of up to eight different systems or layers, from bottom to top, that are combined together to protect the roof and maintain a vigorous cover. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary vegetated roofing systems, whereas in other cases, the designer or architect must assemble their own system, in which case they are advised to consult Weiler and Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004).

1. **Deck Layer.** The roof deck layer is the foundation of a vegetated roof. It and may be composed of concrete, wood, metal, plastic, gypsum or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the vegetated roof system. In general, concrete decks are preferred for vegetated roofs, although other materials can be used as long as the appropriate system components are matched to them.
2. **Waterproofing Layer.** All vegetated roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply, and liquid-applied methods (see Weiler and Scholz-Barth, 2009 and Snodgrass and Snodgrass, 2006). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the vegetated roof system.
3. **Insulation Layer.** Many vegetated rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building and/or protects the roof deck (particularly for metal roofs). According to Snodgrass and Snodgrass (2006), the trend is to install insulation on the outside

of the building, in part to avoid mildew problems.

4. **Root Barrier.** The next layer of a vegetated roof system is a root barrier that protects the waterproofing membrane from root penetration. A wide range of root barrier options are described in Weiler and Scholz-Barth (2009). Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals that could leach into stormwater runoff should be avoided.
5. **Drainage Layer and Drainage System.** A drainage layer is then placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The drainage layer should consist of synthetic or inorganic materials (e.g. gravel, recycled polyethylene, etc.) that are capable of retaining water and providing efficient drainage. A wide range of prefabricated water cups or plastic modules can be used, as well as a traditional system of protected roof drains, conductors and roof leader. The required depth of the drainage layer is governed by both the required stormwater storage capacity and the structural capacity of the rooftop. ASTM E2396 and E2398 can be used to evaluate alternative material specifications.
6. **Root-Permeable Filter Fabric.** A semi-permeable polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it.
7. **Growing Media.** The next layer in an extensive vegetated roof is the growing media, which is typically 4 to 8 inches deep. The depth and composition of the media is described in the Filter Media Composition section in this Chapter.
8. **Plant Cover.** The top layer of a vegetated roof consists of non-native, slow-growing, shallow-rooted, perennial, succulent plants that can withstand harsh conditions at the roof surface. Guidance on selecting the appropriate vegetated roof plants for hardiness zones in the Chesapeake Bay watershed can be found in Snodgrass and Snodgrass (2006). A mix of base ground covers (usually *Sedum* species) and accent plants can be used to enhance the visual amenity value of a green roof.

Filter Media Composition

The recommended growing media for extensive vegetated roofs is composed of approximately 80% to 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials. The remaining media should contain no more than 20% organic matter, normally well-aged compost (see Stormwater Design Specification No. 4). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media should have a maximum water retention capacity of around 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

The composition of growing media for intensive vegetated roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the vegetated roof planting plan, the growing media must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees.

Conveyance and Overflow

The drainage layer below the growth media should be designed to convey the 10-year storm without backing water up to into the growing media. The drainage layer should convey flow to an outlet or overflow system such as a traditional rooftop drainage system with inlets set slightly above the elevation of the vegetated roof surface. Roof drains immediately adjacent to the growing media should be boxed and protected by flashing extending at least 3 inches above the growing media to prevent clogging.

Vegetation and Surface Cover

A planting plan must be prepared for a vegetated roof by a landscape architect, botanist or other professional experienced with vegetated roofs, and it must be reviewed and approved by the local development review authority.

Plant selection for vegetated rooftops is an integral design consideration, which is governed by local climate and design objectives. The primary ground cover for most vegetated roof installations is a hardy, low-growing succulent, such as *Sedum*, *Delosperma*, *Talinum*, *Semperivum* or *Hieracium* that is matched to the local climate conditions and can tolerate the difficult growing conditions found on building rooftops (Snodgrass and Snodgrass, 2006). Daviess County lies within USDA Plant Hardiness Zone 6 (AHS, 2003).

A list of some common vegetated roof plant species that work well in the Daviess County watershed can be found in **Table 14.10-3** below. Designers may also want to directly contact the short list of local nurseries for vegetated roof plant recommendations and availability (see **Table 14.10-3**).

- Plant choices can be much more diverse for deeper intensive vegetated roof systems. Herbs, forbs, grasses, shrubs and even trees can be used, but designers should understand they have higher watering, weeding and landscape maintenance requirements.
- The species and layout of the planting plan should reflect the location of building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and able to withstand heat, cold and high winds.

Table 14.10-3
Ground Covers for Vegetated Roofs in Daviess County

Plant Hardiness Zone 7	Plant Hardiness Zone 6
<i>Delosperma 'Tiffendell Magenta'</i>	<i>Delosperma cooperi</i>
<i>Hieracium lanatum</i>	<i>Delosperma ecklonis var. latifolia</i>
<i>Sedum lineare 'Variegatum'</i>	<i>Hieracium villosum</i>
<i>Sedum makinoi</i>	<i>Orostachys boehmeri</i>
<i>Sedum tetractinum</i>	<i>Sedum hispanicum</i>
<i>Sedum stoloniferum</i>	<i>Sedum pluricaule var. ezawe</i>
	<i>Sedum urvillei</i>
Note: Landscape architects should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for definitive list of green roof plants, including accent plants.	

- Designers should also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The planting plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on vegetated roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most vegetated roof plant species will *not* be native to Kentucky (which is contrast to *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of vegetated roof plant nurseries in the region, designers should order plants 6 to 12 months prior to the expected planting date. It is also advisable to have plant materials contract-grown.
- When appropriate species are selected, most vegetated roofs in the Bay watershed will not require supplemental irrigation, except for temporary irrigation during dry months as the vegetated roof is established. The planting window extends from the spring to early fall, although it is important to allow plants to root thoroughly before the first killing frost.
- Plants can be established using cuttings, plugs, mats, and, more rarely, seeding or containers. Several vendors also sell mats, rolls, or proprietary vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006).
- The goal for vegetated roof systems designed for stormwater management is to establish a full and vigorous cover of low-maintenance vegetation that is self-sustaining and requires minimal mowing, trimming and weeding.
- The vegetated roof design should include non-vegetated walkways (e.g., permeable paver blocks) to allow for easy access to the roof for weeding and making spot repairs.

Material Specifications

Standards specifications for North American vegetated roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The American Society for Testing and Materials (ASTM) has recently issued several overarching vegetated roof standards, which are described and referenced in **Table 14.10-4** below.

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

Table 14.10-4.
Extensive Vegetated Roof Material Specifications

Material	Specification
Roof	Structural Capacity should conform to ASTM E-2397-05, <i>Practice for Determination of Live Loads and Dead Loads Associated with Green (Vegetated) Roof Systems</i> . In addition, use standard test methods ASTM E2398-05 for <i>Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems</i> , and ASTM E 2399-05 for <i>Maximum Media Density for Dead Load Analysis</i> .
Waterproof Membrane	See Chapter 6 of Weiler and Scholz-Barth (2009) for waterproofing options that are designed to convey water horizontally across the roof surface to drains or gutter. This layer may sometimes act as a root barrier.
Root Barrier	Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	1 to 2 inch layer of clean, washed granular material, such as ASTM D 448 size No. 8 stone. Roof drains and emergency overflow should be designed in accordance with VUSBC.
Filter Fabric	Needled, non-woven, polypropylene geotextile. Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent.
Growth Media	80% lightweight inorganic materials and 20% organic matter (e.g. well-aged compost). Media should have a maximum water retention capacity of around 30%. Media should provide sufficient nutrients and water holding capacity to support the proposed plant materials. Determine acceptable saturated water permeability using ASTM E2396-05.
Plant Materials	Sedum, herbaceous plants, and perennial grasses that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. See ASTM E2400-06, <i>Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems</i> .

REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

Cold Climate and Winter Performance

Several design adaptations may be needed for vegetated roofs. The most important is to match the plant species to the appropriate plant hardiness zone. In areas with colder climates, vegetated roofs should be designed so the growing media is not subject to freeze-thaw, and provide greater structural capacity to account for winter snow loads.

Acid Rain

Much of Kentucky experiences acid rain, with rainfall pH ranging from 3.9 to 4.1. Research has shown that vegetated roof growing media can neutralize acid rain (Berhage et al, 2007), but it is not clear whether acid rain will impair plant growth or leach minerals from the growing media.

CONSTRUCTION

Construction Sequence

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

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing method, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic. Foot traffic and equipment traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting, and then planted with the ground cover and other plant materials, per the planting plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the vegetated roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).
- Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

Construction Inspection

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

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

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight;

- During placement of the drainage layer and drainage system;
- During placement of the growing media, to confirm that it meets the specifications and is applied to the correct depth;
- Upon installation of plants, to ensure they conform to the planting plan;
- Before issuing use and occupancy approvals; and
- At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

MAINTENANCE

Maintenance Inspections and Ongoing Operations

A vegetated roof should be inspected twice a year during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see **Table 14.10-5** below). In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas (refer to ASTM E2400). Many practitioners also recommend an annual application of slow release fertilizer in the first five years after the vegetated roof is installed.

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides should be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plant communities.

Written documentation between the local inspection authority and the property owner or manager should be required, in order to ensure adequate notification or authorization for access to conduct inspections.

Table 14.10-5
Typical Maintenance Activities Associated with Green Roofs

Activity	Schedule
<ul style="list-style-type: none"> • Water to promote plant growth and survival. • Inspect the vegetated roof and replace any dead or dying vegetation. 	As Needed (Following Construction)
<ul style="list-style-type: none"> • Inspect the waterproof membrane for leaking or cracks. • Annual fertilization (first five years). • Weeding to remove invasive plants. • Inspect roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Inspect the green roof for dead, dying, or invasive vegetation. Plant replacement vegetation as needed. 	Semi-Annually

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MINIMUM STANDARD 14.11

MANUFACTURED BMP SYSTEMS



MINIMUM STANDARD 14.11

MANUFACTURED BMP SYSTEMS

The Manufactured BMP Systems mentioned in this standard are meant only to provide and frame of reference. OMPC acknowledges that there may be additional Manufactured BMP Systems available at this time that are not presented in this handbook. Presentation of the following products does not preclude the use of other available systems, nor does it constitute endorsement of any one system.

Definition

A Manufactured BMP system is a structural measure which is specifically designed and sized by the manufacturer to intercept stormwater runoff and prevent the transfer of pollutants downstream.

Purpose

Manufactured BMP systems are used solely for water quality enhancement in urban and ultra-urban areas where surface BMPs are not feasible. These are flow-through structures in that the design rate of flow into the structure is regulated by the inflow pipe or structure hydraulics as opposed to traditional BMPs designed to store the entire water quality volume. When the maximum design inflow is exceeded, the excess flow bypasses the structure or flows through the structure and bypasses the treatment with minimal turbulence and resuspension of previously trapped pollutants. Structures that rely on the inflow pipe to regulate the rate of flow into the treatment chamber typically cause stormwater to back up into the upstream conveyance system or associated storage facility. Depending on the type of structure and the configuration of the conveyance system, this excess flow will either bypass the treatment chamber or be attenuated and allowed to flow through the treatment chamber at the regulated rate.

Pollutant removal efficiencies presented in this standard are based upon currently available studies. Removal efficiencies are very variable, however, and highly dependant on storm size, influent pollutant concentrations, and rainfall intensity. Several monitoring studies are ongoing and many products may be modified to improve pollutant removal performance. Therefore, the removal efficiencies presented may be subject to change. As more of these products are built and additional monitoring studies track their performance over a wide range of rainfall events, the anticipated performance of these systems as water quality BMPs will become better established.

The discussion of each of the manufactured BMP systems presented in this standard includes the target pollutants for which the BMP was designed. Many of these systems were developed to remove a specific range of particulate pollutants, or total suspended solids (TSS), from stormwater runoff. Others, such as the filtering structures discussed below, were developed to capture a broad range of pollutants. The use of phosphorus as the target or “keystone” pollutant is recommended when using the performance-based water quality criteria to select a BMP. However, for stormwater “hot-spots”, or areas from which a high concentration of urban pollutants can be expected, the primary pollutant of concern may be hydrocarbons (oil and grease), metals, or other compounds besides nutrients. Manufactured BMPs generally provide effective spill containment for material handling and transfer areas such as automobile fuel and service areas, and other urban hot-spots. Careful analysis of the proposed development project and intended uses help in selecting and appropriate BMP.

The manufactured BMP systems which have been evaluated at this time can be categorized as either:

- Hydrodynamic Structures - (Stormceptor, Vortechs Stormwater Treatment System, Downstream defender, Suntree Separation System)
- Filtering Structures - (StormFilter, StormTreat System)

Hydrodynamic Structures

Hydrodynamic structures are those which rely on settling or separation of pollutants from the runoff. The hydrodynamic structures can be generally categorized as Chambered Separation Structures or Swirl Concentration Structures.

Chambered Separation Structures rely on settling of particles and, to a lesser degree, centrifugal forces to remove pollutants from stormwater. These structures contain an upper bypass chamber and a lower storage/separation chamber. Flow enters the structure in the upper bypass chamber and is channeled through a downpipe into the lower storage/separation, or treatment, chamber. The downpipe is configured such that when the rate of inflow into the structure exceeds its operating capacity, the flow simply “jumps” over the downpipe, bypassing the lower treatment chamber.

The outlet configuration of the downpipe forces the water to enter the lower treatment chamber in one direction, which encourages circular flow. This circular flow, as well as gravitational settling, traps the sediments and other particulate pollutants (as well as any pollutants which adsorb to the particulates) at the bottom of the chamber. The water leaves the treatment chamber through a return or riser pipe. The return or riser pipe extends below the water surface within the lower treatment chamber in order to prevent trapped floatables from exiting the structure. The hydraulic gradient of the structure prevents the inflow and the discharge from creating turbulent conditions within the lower treatment chamber. This feature helps prevent the resuspension of previously trapped particulate pollutants during high flow, or “bypass”, storm events.

Swirl Separation Structures are characterized by an internal component that creates a swirling motion. This is typically accomplished by a tangential inflow location within a cylindrical chamber. The “swirl” technology is similar, if not identical to, the technology used in treating combined sewer overflows. The solids settle to the bottom and are trapped by the swirling flow path. Additional compartments or chambers act to trap oil and other floatables.

There is no bypass for larger flows prior to the treatment or swirl chamber. The larger flows simply pass through the structure untreated. However, due to the swirling motion within the structure, larger flows do not resuspend previously trapped particulates.

Filtering Structures

Filtering structures are characterized by a sedimentation chamber and a filtering chamber. The manufactured systems presented in this standard, the StormFilter and the StormTreat System, use very different configurations and filtering media. Both contain a primary settling chamber to remove heavy solids, floatables, oil, etc. The StormTreat System then directs the water through a series of screens and geotextile filters and into a containerized wetland system with soil and aquatic plants. The StormFilter, on the other hand, uses any one or combination of filter media cartridges. The filter media selected is typically based on the target pollutants to be removed or the desired efficiency. The number of cartridges is dependent on the project size, desired removal efficiency, and peak flow rates.

Conditions Where Practice Applies

Drainage Area

The sizing criteria for each manufactured BMP system should be obtained from the manufacturer to insure that the latest design and sizing criteria is used. In general, the flow-through configuration and treatment limitations will force drainage areas to remain relatively small.

Development Conditions

Manufactured BMP systems are ideal for use in ultra-urban areas since they are space efficient. Most of these systems can be placed under parking lots, or simply installed as a manhole junction box or inlet structure. Since other BMPs, such as sand filters and bioretention structures, are also suited for urban development, the designer must consider the type of pollutant load anticipated from the site, as well as other site factors, such as maintenance, aesthetics, etc., and select an appropriate BMP. In general, hydrodynamic and gross pollutant separate are recommended for the following:

- Pretreatment for other BMPs;
- Retrofit of existing development or Redevelopment; and
- Ultra-urban development areas.

Filtering structures are generally recommended for use in applications similar to Sand Filters and Bioretention Filters (Minimum Standard 14.09).

In all cases, Manufactured BMP systems must be designed in accordance with the manufacturers specifications.

Planning Considerations

The most significant feature of manufactured BMP systems is their small size and the ability to use them as retrofits underneath improved areas. (It should be noted that other BMPs, such as sand filters, can also be placed under improved areas.) The fact these BMPs are underground requires the designer to locate an acceptable outfall or improved drainage system for discharging runoff. The vertical elevation of the inflow and outflow pipe connections may be critical to the choice, or design, of the BMP.

Overflow

All of the manufactured BMP systems presented in this standard are flow-through structures that can be located on storm drainage systems that drain improved areas. Most manufactured systems, however, are designed to treat the first flush, or the water quality volume, of runoff. Therefore, an overflow, or bypass, is needed to divert flow that exceeds the design rate, or a storage facility is needed to store the appropriate volume of runoff for treatment. The discussion of each manufactured system will include the overflow or bypass provisions provided, or required.

Design Criteria

The design criteria for manufactured BMP systems should be obtained from the manufacturer. All designs should be reviewed by the manufacturer to insure that the system is appropriately designed and sized.

Maintenance and Inspections

All manufactured BMP systems require regular inspection and maintenance to maximize their effectiveness. The specific maintenance requirements and schedule should be prepared by the manufacturer and signed by the owner/operator. It should be noted that the frequency of maintenance is not only dependent on the type of manufactured system chosen, but also the pollutant load from the contributing drainage area. The frequency of maintenance required may vary from after any major storm, to once a month, to up to twice a year.

A maintenance log should be required to keep track of routine inspections and maintenance. A maintenance log can also help facility owners establish the effectiveness of certain “housekeeping” practices, such as street sweeping. Failure to maintain any stormwater BMP may result in reduced efficiency, resuspension or mixing of previously trapped pollutants, or clogging of the system.

Many suppliers of manufactured BMP systems recommend service contracts to ensure that maintenance occurs on a regular basis. Lack of maintenance is widely acknowledged to be the most prevalent cause of failure of both structural and non-structural BMPs.

Another consideration with manufactured BMP systems is the possible contamination and toxicity of trapped sediments, especially in areas considered to be stormwater hot-spots. Care must be taken in the disposal of sediment that may contain accumulations of heavy metals. Sediment testing is recommended prior to sediment removal to assure proper disposal. Experience in other jurisdictions has indicated a reluctance to on the part of waste water utility operators to accept the pump-out material from these structures. Landowners are encouraged to research the disposal options as part of the planning process prior to selecting the BMP.



Manufactured BMP Systems. Manufactured systems can be selected to address specific pollutant sources. This trench drain surrounds fuel handling area of a service station to direct any spills or other identified petroleum based contaminants to a manufactured system designed specifically for fuel or hydrocarbon containment. Note: fuel area is under cover which serves to limit the design flow entering the system.